MODERNIST CUISINE

3 · Animals and Plants

Black beans

Borage flower

MODERNIST CUISINE

The Art and Science of Cooking

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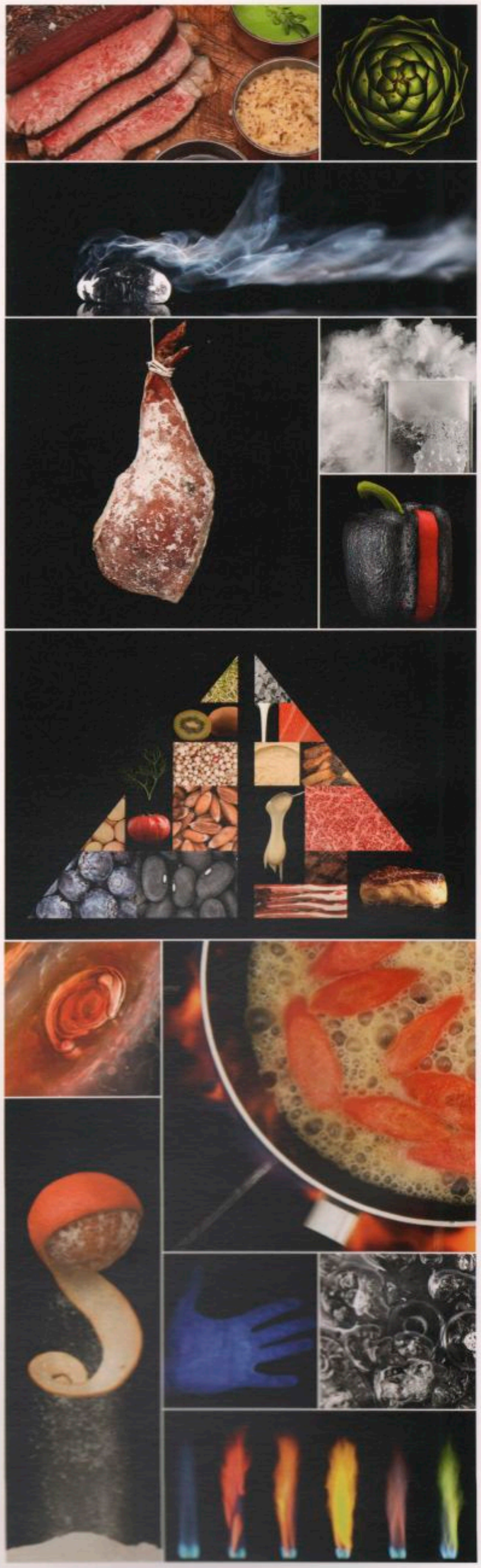
Volume 3
Animals and Plants

The Cooking Lab

VOLUME 1: HISTORY AND FUNDAMENTALS



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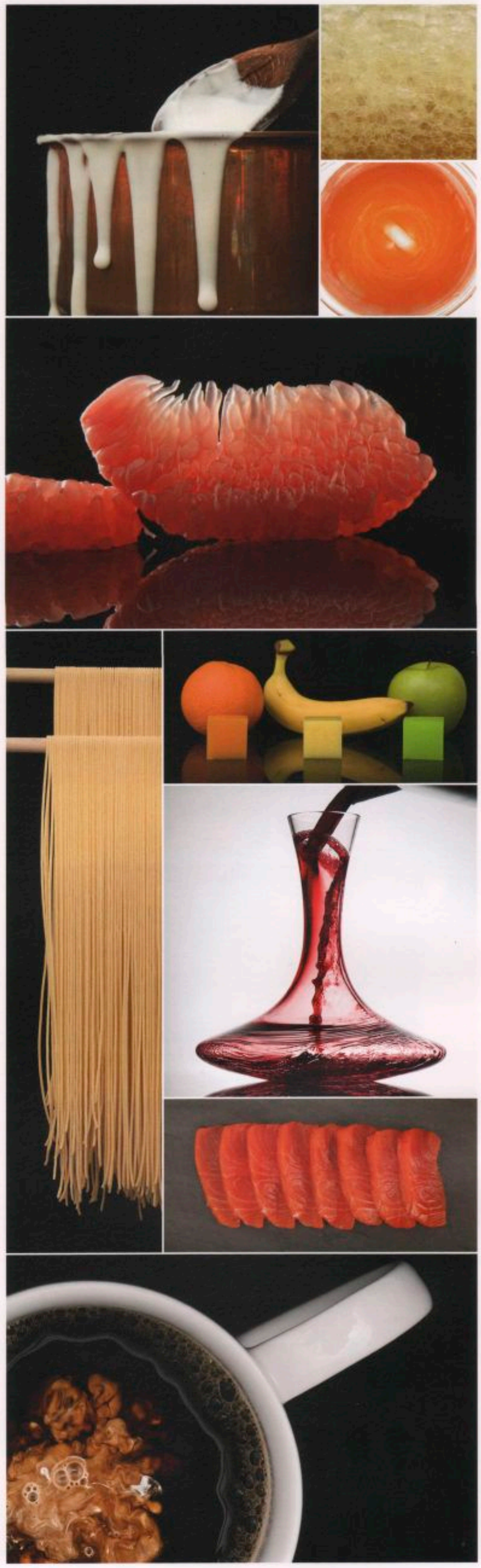

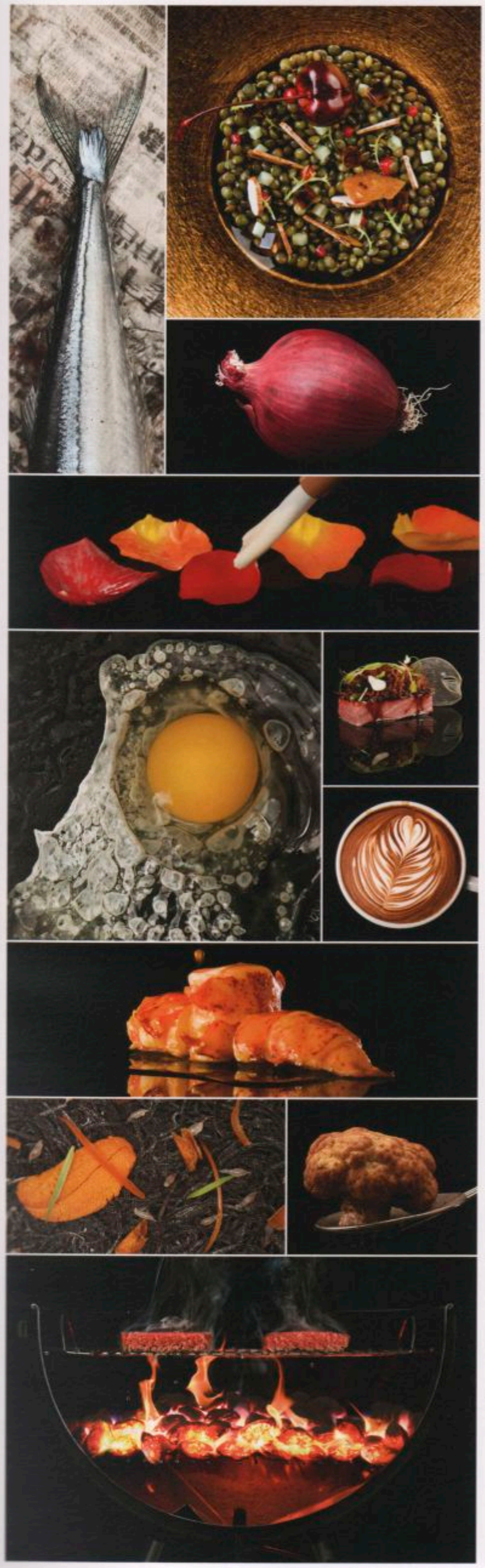

11 MEAT AND SEAFOOD

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MEAT AND SEAFOOD

Before it is meat, it is muscle. In the living animal, muscles convert chemical energy into mechanical activities such as running, swimming, or flying. In the kitchen, these activities have come to an end, but their influence lives on in surprising ways. A chef's primary goal when cooking meat or seafood is to maximize juiciness, flavor, and tenderness. But what is juiciness, and what are the factors that determine it? What exactly is meant by flavor, and where does it come from? As we will see, many common misconceptions based on an incomplete understanding of the unique biochemical nature of meat and seafood can lead cooks astray—or at least prevent them from making the most of a cut or fillet. Maximizing tenderness may seem a more obvious goal than agreeing upon the best strategy for enhancing flavor, but it is no less prone to misunderstanding and mythological explanations.

Meat was first moving machinery made of various protein structures, including fibers and connective tissue; water filled with life-sustaining molecules; and fat and fat-like molecules. All of these play critical roles in the cooking and dining experience, but not always according to conventional wisdom. Fat, for example, does not greatly affect tenderness, whereas collagen and the coarseness of muscle fibers do. How the animal has been treated in life, even well before slaughter, is another crucial factor that affects meat quality.

Cooks who understand the fundamental nature of muscle, how it is transformed into meat, and what happens as the temperature increases will be able to select the best strategies for preparing meat and to avoid common mistakes. Their technique will improve, further empowering them to experiment and innovate.

To attain the best from meat and seafood, it is worth taking the time to gain a better appreciation of the complex but fascinating structure of living muscle tissue, its variations across species, and how it becomes meat. Muscles, after all, didn't evolve in order to provide us with steaks; they exist so that living creatures can move through their environments. The relatively uncomplicated musculature of fish, for example, is adapted to the fairly simple kinetics of moving in water. Land animals, in contrast, deal with a more complex array of forces and require a highly variable, sophisticated muscular structure. Another example of how muscle function determines the nature of meat is evident in the difference between dark and light meat—a difference based largely on whether the animal tends to run (or swim or fly) through life as a marathoner or as a sprinter.

In this chapter, we explore these and other characteristics of muscle and meat based on our belief that they can provide the cook with powerful intellectual utensils for better selection and preparation in the kitchen. Following our discussion of the basic science of muscle, its conversion to meat, and the many delicious transformations made possible through proper application of heat over time, we describe several specific techniques and alternative approaches to working with meat and seafood.

This young lioness in Botswana is eating a wildebeest, or gnu. Unlike other predators, who eat their meat raw in the wild, humans have developed cooking to make animal flesh far more nutritious and easier to digest.

HOW MUSCLE WORKS

You can eat meat without understanding muscles. You can even cook it without that understanding. But we think you'll do a better job with some insight on how muscles are built and how they work.

Spend a little time in a butcher's shop, looking closely at the wares, and you'll quickly discover that a cut of meat, like a piece of wood, has a distinct grain to it. If you know what to look for, a glance at the grain of the meat can tell you a lot about how tender or tough the cut is likely to be and how best to cook it. But to develop a discerning eye, you need to understand how a muscle is organized and how it works.

Meat has a grain because it consists largely of muscle cells, also called **muscle fibers**, that are organized into groups of thread-like bundles, all of them pointing in the same direction (see How a Muscle Contracts, page 8). Those thin bundles are, in turn, grouped into slightly larger bundles, and sets of these larger bundles are found within even bigger bundles. Muscles have many levels of this bundling of bundles within the highest-level bundle, which is the whole muscle itself.

The structures that give meat grain are called **fascicles**. Theses are mid-level organizers, being neither the biggest bundles of muscle fibers nor the smallest. A particular type of connective tissue, composed mostly of **collagen**, does the job of bundling the fibers together at all levels of organization. Many characteristics of meat arise from the complex arrangement of fiber bundles and collagen sheathing.

Bundling also goes on in muscle tissue at the molecular level. Within each muscle fiber are bundles of filament-like **myofibrils**, which are made from long chains of identical **protein** links. These links are the basic contractile units of muscle, known as **sarcomeres**. There are many different kinds of proteins within a sarcomere, but just two—**myosin** and **actin**—serve to actively contract and relax the muscle.

They do that with some interesting mechanics. Six cable-like actin molecules surround each end of the rod-like myosin molecule and only partially overlap with it when the muscle is relaxed. When a muscle is chemically triggered to contract, the myosin molecule ratchets the opposing sets of actin molecules together until they nearly meet, contracting the sarcomere. Within a single muscle, tens of millions of sarcomeres can be activated in this way, shortening hundreds of thousands of muscle cells, which are mechanically connected through their various levels of collagen sheathing.

The sheaths containing individual muscle fibers are called the **endomysium** (Greek for "inner muscle"). Contractions at this level cause the fascicles—each surrounded by a collagen sheath of its own, known as the **perimysium** ("surrounding muscle")—to contract as well.

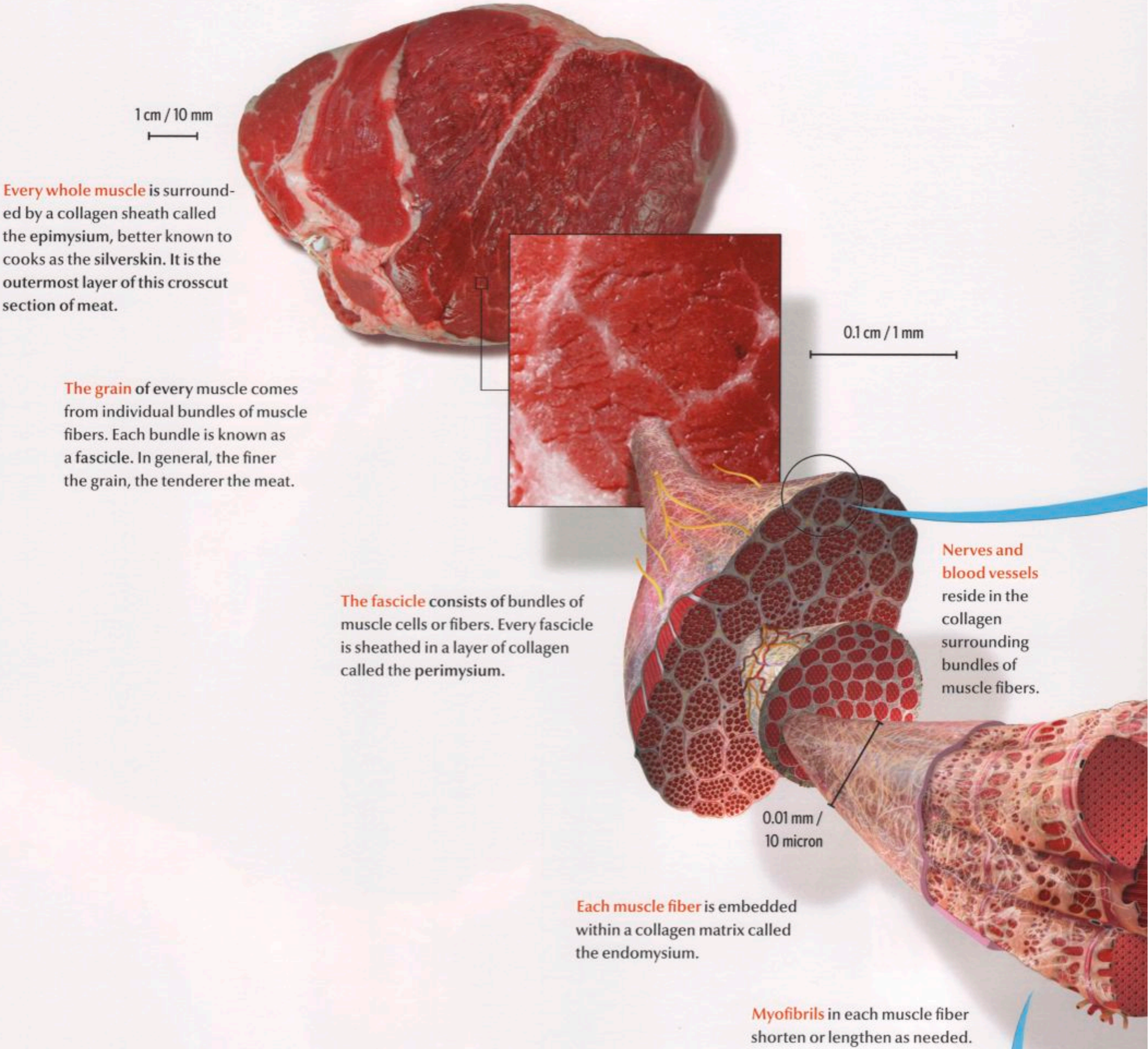
The entire muscle is sheathed in its own collagen membrane, called the **epimysium** ("outer muscle"), which, through the tendons, anchors the muscle to the bone. These collagen sheaths are needed for the muscle to work. All cuts of meat, tender or tough, thus contain a certain amount of collagen. There are differences, however, between the collagen found in tender and tough cuts of meat (see The Role of Collagen in Cooking, page 80). These differences arise from the job a muscle performs in life.

As important as collagen are the fascicles, whose structure in tender cuts of meat is not the same as it is in tough cuts. You can actually feel the difference when you rub the meat with the ball of your thumb: a tender cut feels fine-grained and smooth, whereas a tougher cut is noticeably coarse.

Those textures reflect the fact that, on average, the fascicles in tender meat are narrower than those in tough meat. This difference, which reflects differing demands put on each muscle in life, persists all the way down to the microscopic level of a contracting sarcomere.

Coarse-grained meat with thick muscle fibers is harder to bite through than fine-grained meat with thin muscle fibers; at the most basic level, this variation in fiber thickness is the biological origin of toughness. So when you're finished studying muscle physiology at the butcher's, you might want to pick up one of those finer-grained steaks for dinner.

The powerful leg muscles of a rabbit have evolved to fulfill the animal's need for strength and stamina in life. Understanding the biological differences among muscles gives a cook insight into how best to prepare them as food.



HOW A MUSCLE CONTRACTS

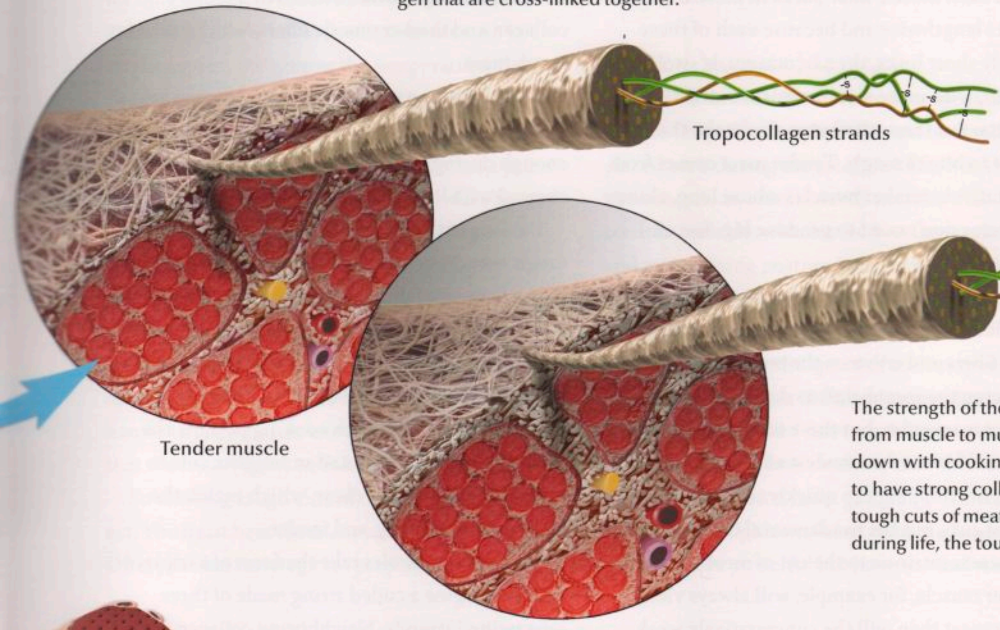
When a muscle receives the chemical signal to contract, countless protein chains within it shorten their constituent links. Within a single muscle, tens of millions of protein chains can change in this way, shortening hundreds of thousands of cells. The forces from these contracting cells cause the larger bundles containing them to contract as well. The force from each bundle's contraction is in turn communicated to the next-higher level of bundling.

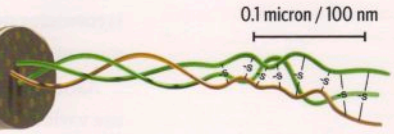
The end result is a contraction of a collagen sheath that surrounds the entire muscle and is anchored (through the tendons) to the bone. This complex structure allows muscles to transfer the force of contracting proteins to where they do the work of moving an animal's joints.

Muscles with long, skinny sarcomeres are easier to bite through than those with short, fat sarcomeres (inset), and the meat from these muscles is thus more tender. Although you cannot see microscopic sarcomeres, the coarseness of the meat grain indicates whether the muscle contains fine and easily broken sarcomeres or thick and tough ones.

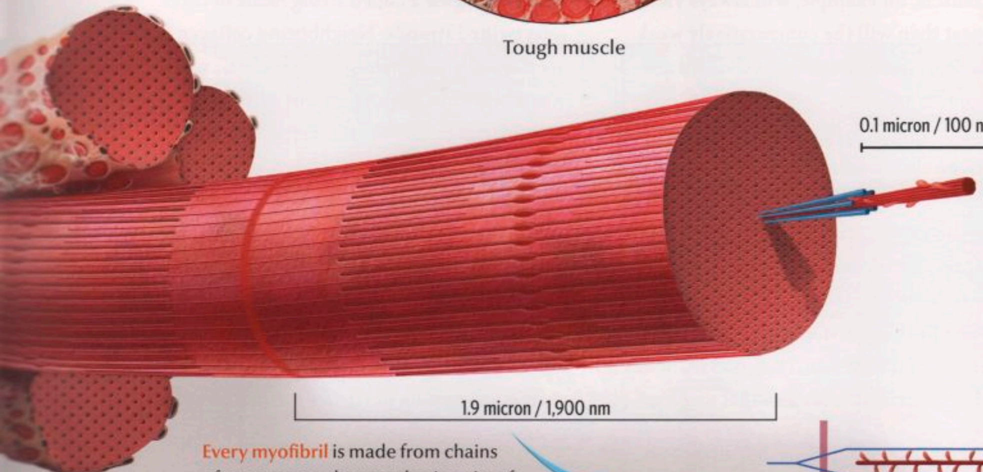
Each collagen fiber contains many fibrils, which in turn consist of strands of two different kinds of tropocollagen that are cross-linked together.

The chemical cross-links between the helical strands of tropocollagen prevent collagen from unraveling and dissolving when cooked. These bonds make muscles stronger but also make meat tougher. Long, slow cooking in the presence of water turns the collagen into gelatin, tenderizing the meat.



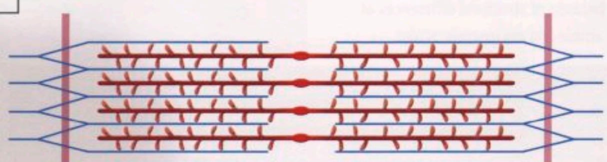


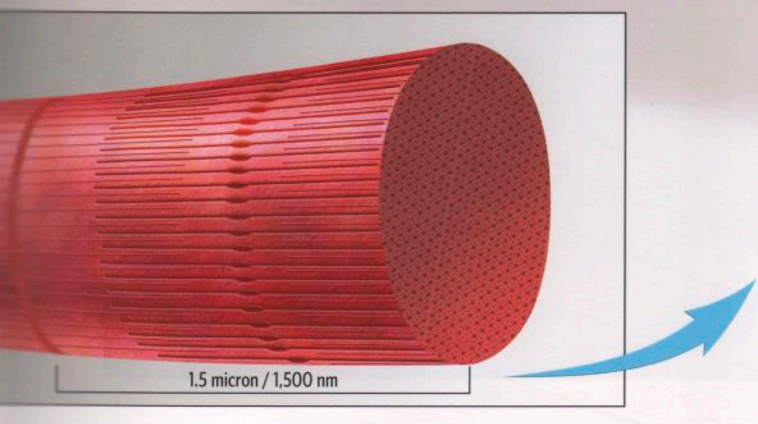
The strength of the collagen sheaths around fascicles varies from muscle to muscle. Strong collagen is difficult to break down with cooking. Large, hard-working muscles will tend to have strong collagen and more of it, which makes for tough cuts of meat. In general, the more a muscle is worked during life, the tougher it will be when cooked.

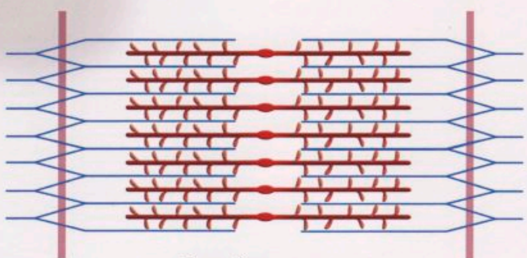


Sarcomeres contain myofilaments containing proteins known as actin (blue) and myosin (red), which cause muscle contraction when the actin filaments pull toward the center of the myosin filaments. Thick sarcomeres are more powerful because they contain more of these contractile proteins, but they're also more difficult to bite through.

Every myofibril is made from chains of sarcomeres, the most basic units of muscle contraction and relaxation.


Long, skinny sarcomere




Short, fat sarcomere

What Controls Tenderness?

Tough meat comes from the most powerful muscles of an animal. These muscles are strong because each muscle fiber packs in more contracting links lengthwise and because each of these relatively short links, the sarcomeres, is swollen in diameter, with more sets of myosin and actin filaments. But these attributes also make the meat difficult to bite through. Tender meat comes from comparatively weaker muscles whose long, skinny sarcomeres don't need to produce big, forceful movements.

As we discuss later in this chapter, a cook can use various techniques and tools to break down muscle fibers and enhance the tenderness of tough cuts. Aging the meat helps, as does soaking it in brines or marinades, but these techniques work slowly and have only a modest effect. Pounding, cutting, or chopping can quickly tenderize the toughest cuts, but the fundamental tenderness or toughness is intrinsic to the cut of meat. A strong shoulder muscle, for example, will always yield tougher meat than will the comparatively weak tenderloin. Put simply, anatomy is the ultimate arbiter of tenderness.

Mechanical meat tenderization, including pounding and Jaccard tenderizing, works by physically disrupting the structure of muscle so that it is easier to bite through.

The other major factor that comes into play here is the collagen surrounding the various bundles of muscle fibers. Tenderness varies with the strength and, to a lesser extent, the thickness of this collagen. Sex, age, breed, and the animal's nutritional history all influence the strength of its collagen to some degree. But the most important determinant is the function of the muscle it is found in. Small muscles that exert little force and that undergo only mild distortion have weak collagen and thinner muscle fibers, which together provide tender meat. Large muscles that exert great force and that undergo severe distortion have strong collagen and thicker muscle fibers, which make for tough meat.

For an illustration of how collagen changes as it cooks, see page 80.

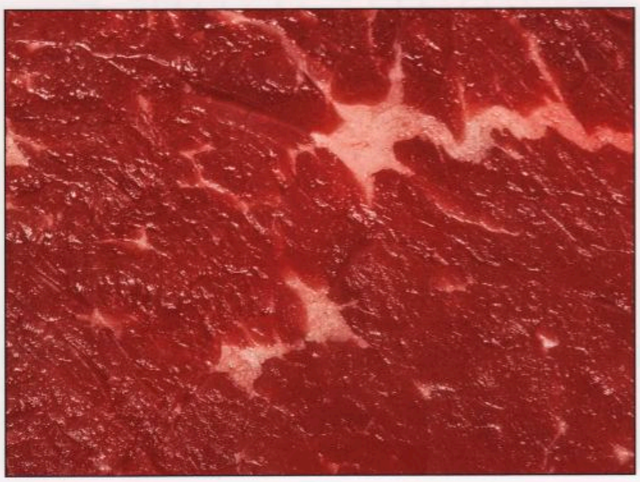
When working with tender cuts, you can safely ignore the collagen, which will come apart readily enough during cooking, allowing the meat to be chewed with little effort.

Dealing with collagen is central to cooking tough cuts. Tough cuts of meat like oxtail or veal shank have much higher fractions of collagen than do tender cuts like tenderloin. But that is not the only difference. The type of collagen in tough cuts is also more resistant to breaking down into gelatin. Dissolving it with cooking permits the thicker muscle fibers found in tougher cuts to separate easily as you chew, which makes the meat seem soft, flaky, and tender.

Collagen molecules take the form of a triple helix—imagine a coiled string made of three intertwined strands. Neighboring collagen fibers are normally woven into a tight, elastic mesh, but when heated in the presence of moisture, collagen helices tend to shrink and then unwind and fragment, loosening that mesh considerably. Finally, some of the fragments dissolve into the juices. The result is that the formerly strong network of collagen molecules becomes deliciously soft gelatin.

That transformation is not always easy to achieve, though. As animals age, the collagen in their hardworking muscles develops chemical

Fine-grained meats (left) are more tender than coarse-grained cuts (right) in large part because of structural differences at both visible and microscopic scales.



cross-links and grows stronger. To make meat cut from those muscles more tender, you must cook the meat at temperatures that are sufficiently high for long enough to break some of the collagen's cross-links and unravel these molecules. As you might expect, the greater the temperature, the faster and more completely the tough collagen fibrils come apart.

But this kind of quick tenderization has a price: a high cooking temperature causes juices to begin leaking from the meat. At even higher temperatures, the woven mesh of collagen shrinks to a greater extent before it dissolves. That shrinkage forcefully squeezes the leaking juices out of the meat and, at the same time, makes it more dense. The meat then becomes harder to chew unless enough collagen dissolves that the meat begins to flake apart.

So cooking tough cuts of meat is a balancing act. You must heat them enough but not too much. Often, the best strategy for preparing meat with strong cross-linked collagen is to cook it slowly at the lowest practical temperature (see Cooking Meat and Seafood, page 70).

Speed Versus Stamina

Every muscle in an animal's body is specialized to handle the particular physiological demands placed on it during the creature's life. For swift movements, an animal needs muscles that can contract quickly, whereas for breathing, chewing, and maintaining posture (such as standing or holding wings outstretched), it uses slowly contracting muscles.

Muscles vary in the speed of their responses because they contain different proportions of two basic kinds of fibers: "fast-twitch" ones, which bring about rapid contractions, and "slow-twitch" ones, which shorten more gradually. The former are markedly lighter-colored than the latter. They are also more powerful but have less endurance.

Another important way to minimize the amount of tough collagen is beyond a cook's control; it's in the hands of the rancher. Feeding an animal a high-calorie diet appears to accelerate the normally slow replacement of mature, strong collagen with new, weak collagen. Making such a change to the animal's diet just prior to slaughter thus produces more tender meat.

A fascicle of pork leg meat, cut crosswise and magnified by an electron microscope, reveals the muscle fibers (red) it contains and the collagen mesh (white) that holds the bundle together. A similar image of a tender muscle would reveal less surrounding collagen and thinner muscle fibers in the fascicle. A small blood vessel (purple) is also embedded in the collagen.

An iron-containing protein known as **cytochrome** (from the Greek words for "cell color") is found in dark, endurance-supporting muscle fibers. This protein is specialized for burning fat as fuel for slow and steady endurance. Because fat provides a steady supply of fuel for dark muscle fibers, there is always more fat in dark meat than light meat—one reason that many people find it more flavorful.

Because all muscles need a balance of speed and endurance, they always contain a blend of light and dark fibers. The ratio of light to dark will, however, depend on the kind of animal and on the function of the muscle from which the meat comes.

You can see the differences most starkly in the meat of chickens and turkeys, which spend very little time in the air. Their breast muscles, which they use for flapping their wings, are dominated by light fast-twitch fibers. These can produce only short bursts of activity—just long enough for a quick escape. Their legs muscles, on the other hand, need more stamina. So they contain a large number of dark slow-twitch fibers, which are capable of greater endurance.

Even within dark leg meat, there are differences from muscle to muscle. You can observe this easily with pork: a cross-section of a pork leg (see photo at right) reveals that the big outer muscles are paler than the deeper ones surrounding the bone. The light outer muscles have mostly quick-contracting fibers, which move the leg, whereas the darker muscles provide the endurance to keep the pig standing.

Fast-twitch and slow-twitch muscle fibers are found in every kind of animal: man or beast, fish or fowl. With white meats, such as veal, pork, chicken, or turkey, it's easy to distinguish between light and dark meat. These differences also exist in beef, lamb, and venison, but you cannot easily perceive them against the red background color of the meat.

What Gives Meat Its Color?

So what causes some meat to appear red and some to look white? Contrary to what many people think, the difference in color has nothing to do with blood. There's not much blood in a muscle to begin with, and in any case, at slaughter, all of the animal's blood is drained.

The blood vessels that serve muscles are found only in the connective tissue that surrounds each muscle fiber. So blood cannot directly supply oxygen within a muscle fiber. Instead, a protein called **myoglobin** serves that purpose. Like the **hemoglobin** found in blood, the myoglobin found in muscle cells readily combines with oxygen, allowing this protein to transfer oxygen from the

A cross-section of lamb shows the rich red color of the meat, which makes it difficult to distinguish muscles built for endurance from those geared for brief yet powerful bursts of activity. But both kinds of muscle are present in red meat, accounting in part for the difference between tender and tough cuts.

A pork leg has darker, red-hued muscles close to the bone that have greater stamina to keep the animal standing, whereas the pale muscles nearer to the surface are geared to respond to the shorter bursts of energy needed to walk and run.

blood to hardworking cells. Myoglobin can also store oxygen within these cells. Additionally, myoglobin functions as a pigment in meat. Depending on whether or not myoglobin is paired with an oxygen molecule, its color can vary from red (oxygenated) to purple (deoxygenated).

Animals with sedentary lives tend not to need a lot of endurance, so their muscles contain comparatively low levels of myoglobin-rich fibers. As a result, the meat from these species is pale, and the differences between light and dark meat can easily be seen. As the need for endurance increases, dark slow-twitch muscle fibers take on a red-to-purple hue from the increasing levels of myoglobin necessary to sustain effort. In extreme cases, some species of animals need so much endurance that *all* of their muscles contain lots of myoglobin-rich muscle fibers; those species produce red meat.

Slow-twitch muscle fibers provide **aerobic** endurance and thus contain relatively large quantities of myoglobin to keep up with the demand for energy-sustaining oxygen. This makes them dark, with a purple-to-red hue. Higher concentrations of myoglobin make the color of dark fiber more vibrant. Fast-twitch muscle fibers do their brief bursts of work without oxygen (that is, **anaerobically**), at least over the short term, and tend to be pale in color from a lack of oxygen-supplying myoglobin.

Cattle, sheep, elk, and other grazing animals evolved the ability to roam long distances, as did migratory birds such as ducks and wild geese, which are capable of long-endurance flight. To meet such taxing demands, the muscles of these animals contain deep-red muscle fibers—and a lot of them. In such hardy animals, even the

The "best end" of pork, taken between ribs 5 and 10, contains a dark, crescent-shaped muscle, nestled against the loin at the lower left below, that is particularly tender and juicy. This is an example of dark muscle fibers in what is considered a white meat. Although it's more difficult to see in cuts of red meat such as a beef rib roast, the same muscle exists in a similar location and is also exceptionally good.

fast-twitch fibers are imbued with the red hue of myoglobin. Unlike the pale-colored fast-twitch muscle fibers that predominate in less athletic animals, these animals rely on a third kind of muscle fiber for powerful bursts of work. Known as an **intermediate fiber,** it is a fast-twitch fiber that contains myoglobin, which shades it red and lets it fall back on aerobic metabolism for greater stamina. Thus, in animals that yield red meat, it becomes difficult to distinguish among the fast, slow, and intermediate fibers because they are all colored by myoglobin.

Although you may not always be able to see the difference between light and dark muscle fibers, you can often taste the difference. In muscles with weak collagen that contributes little to the background toughness—so generally not leg, thigh, or shoulder cuts—the darker meat will be noticeably tenderer and more flavorful.

This difference in tenderness arises because the dark muscle fibers tend to be much thinner than the light fibers and, therefore, easier to bite through—provided that the surrounding collagen is relatively weak. And because darker muscles are adapted to consume fat to fuel metabolism, these cuts of meat are imbued with marbling that packs a lot of flavor.

As an example, consider pork: nominally a "white" meat, a dark and reddish, crescent-shaped muscle is easy to see in what many chefs recognize as the best end of the loin (see photo at left). This muscle is known as the *spinalis dorsi,* but it is so small that it is not usually offered as a separate cut of meat. It is especially tender, juicy, and flavorful. You can find this muscle between the chine bone and ribs on one side and the loin on the other. Roughly, it spans the length between ribs 5 and 10. Although it can't easily be seen, a corresponding muscle exists in a beef rib roast and in the same region of other mammals.

A beef rib eye provides another example of how delicious the darker regions in tender cuts of meat can be. The rib eye is not one muscle but three: the loin (the eye), the deckle (the cap), and the relatively unknown and difficult-to-spot *spinalis dorsi.* Many cooks know that the deckle is extra juicy and tender.

This muscle is actually part of the deep pectoral muscle that is constantly exercised in life by breathing. Because this muscle does not make large, forceful movements in life, it contains relatively weak collagen. On the other hand, constant breathing requires the stamina of dark, aerobic muscle fibers. Taken together, these factors make for a very tender, finely grained muscle. Unfortunately, because it sits on the outside of the roast, it is often overcooked when using traditional cooking methods. Cooking the meat sous vide avoids this, or you can remove this muscle and cook it separately, as you would a tender fillet.

The Skinny on Fat

If meat were composed merely of muscle fibers and their collagen sheaths, it would not taste nearly as good as it does. Fortunately, meat also contains fat, embedded in the connective tissue. The fat weakens the mesh of collagen holding muscle fibers together and thus makes meat more tender.

This effect is real, but it is less important than many people believe: most studies of meat have shown that fat content—even the extreme marbling of Wagyu beef—can explain only about 20% of the variation in tenderness. (The remaining 80% hinges on other factors affecting the size and strength of muscle fibers and connective tissue.) Fat does, however, contribute to the gustatory experience in other important ways.

The red droplets you often see pooling on the surface of cooked meat aren't blood. These are meat juices that are stained red with water-soluble myoglobin. In well-cooked meat, the juices aren't red because cooking temperatures above 60 °C / 140 °F begin to break the myoglobin down, causing it to start to fade to pink. By 76 °C / 169 °F, nearly all the myoglobin is broken down, and the droplets run clear (in white meats) and gray (in red meats).

Seal meat has so much myoglobin in every muscle fiber that it is very dark—almost black. All that myoglobin offers a distinct performance advantage: it stores enough oxygen to enable seals to hold their breath on dives lasting 30 minutes or more!

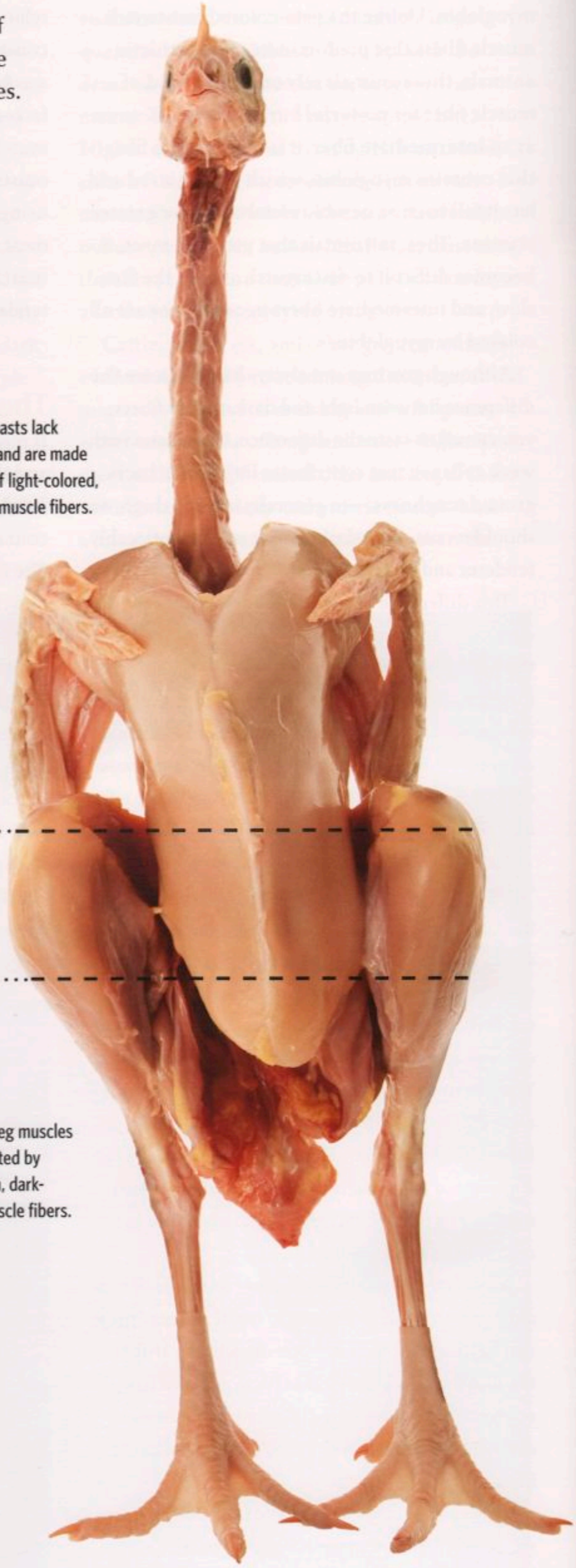
RED VERSUS WHITE

Why is chicken meat "white" while duck meat is red? Why are the breasts of either bird different than their legs? The answer to both questions is that the muscles—and the fibers that make them—have evolved to play different roles.

Chicken breasts (shown in cross-section above) are built predominately of light muscle fibers geared for short, intense bursts of activity, such as briefly taking flight to escape a hungry fox. This meat is lean because light fibers cannot burn fat. And, because a chicken is not a frequent flier, the connective tissue is relatively weak. That is why chicken breasts are suitable for quick cooking, but also why it is easy to overcook them.

A chicken's legs and thighs (shown in cross-section below) need stamina to stand, walk, and run. So they contain mostly dark endurance fibers that burn fat for fuel (hence this meat contains more flavorful fat), and they are strengthened by abundant collagen. Leg meat thus needs prolonged, moist cooking to become tender and succulent.

Chicken breasts lack myoglobin and are made up mainly of light-colored, fast-twitch muscle fibers.



Thigh and leg muscles are dominated by slow-twitch, dark-colored muscle fibers.

Animals that yield red meat, such as ducks, are endurance athletes. Both their light and dark muscle fibers are shaded red by an abundant supply of the oxygen-carrying pigment myoglobin, which provides greater stamina. Differences do exist between leaner breast meat and dark leg meat enriched with fat for fuel, but the red hue of all the meat makes seeing those differences difficult. When cooked and eaten, however, there is no question about which is which: as a rule, the fat in dark meat will make it richer and more flavorful.

Duck breasts are made up mainly of intermediate fibers, which contain enough myoglobin to make the meat red.

Duck breasts (shown in cross-section below) are a relatively lean meat. These muscles work harder during long migratory flights than those same muscles in relatively sedentary chickens do. As a result, collagen in the meat is both stronger and more abundant. This makes a duck breast chewier than a chicken breast when just cooked through. Sous vide cooking, with a short holding step, can significantly improve the tenderness of the meat.

Thigh and leg muscles are dark meat.

A duck's legs and thighs (shown in cross-section below) have a hard life. To withstand the strains of waddling and swimming, the muscles contain a lot of tough collagen. A thick covering of fat develops to insulate them from cold water. A hefty amount of energy-supplying fat also builds up among their dark red muscle fibers. This is why duck leg is particularly rich and flavorful.

Animal fat stores energy quite densely—about 37 joules per gram, which is comparable to the energy density of gasoline and diesel fuel at 46 J/g. Proteins and carbohydrates pack in much less energy at about 17 J/g.

When you bite into a cut of meat, you immediately rupture the muscle tissue, flooding your mouth with juice and fat. More marbling produces more fat, helping to enhance the first impression of how juicy a piece of meat is.

As you keep chewing, the initial burst of juiciness is swallowed. The sense you get of sustained juiciness—what cooks often describe as succulence—arises as the released fats mix with the moist gelatin produced from cooked collagen and keep the meat fibers lubricated.

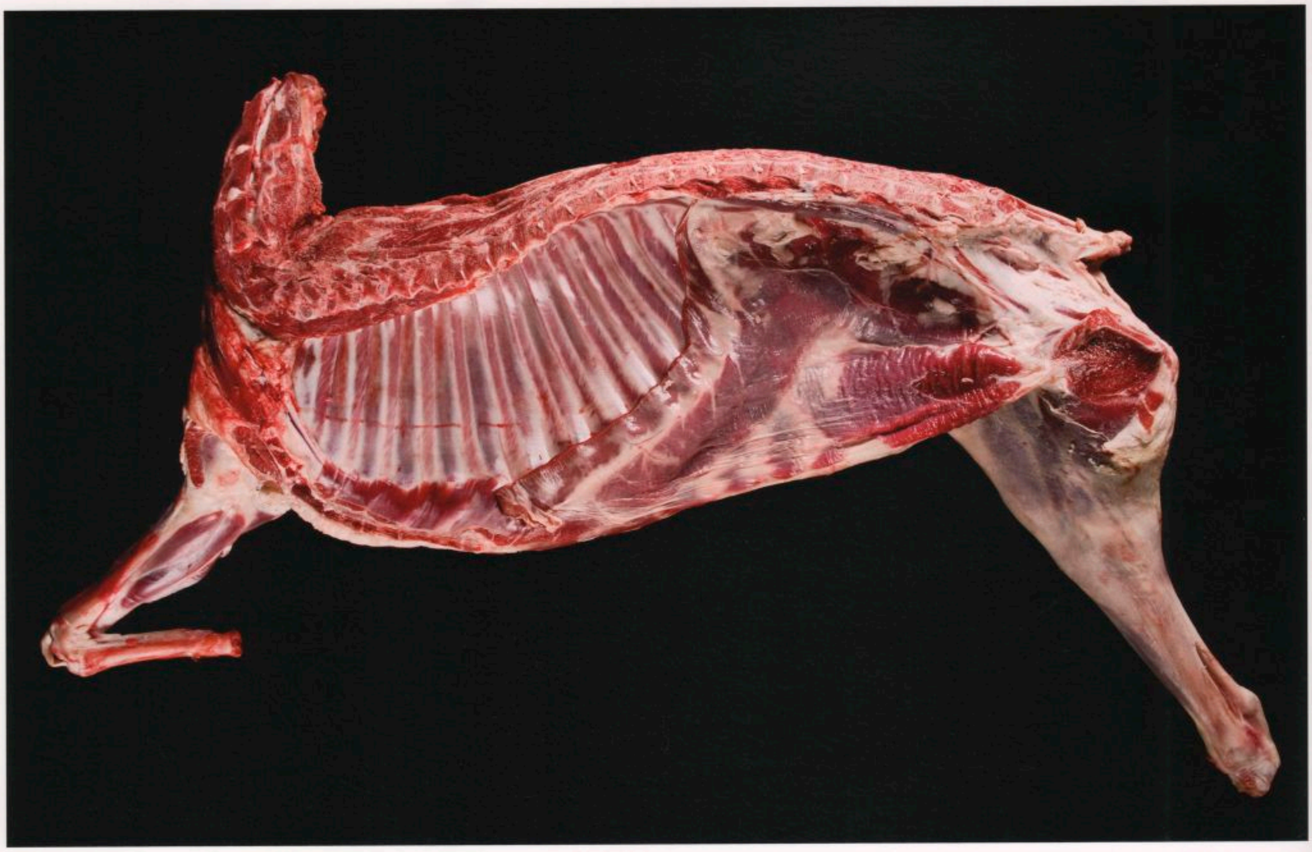
After cooking, a prime-grade steak still contains a lot of fat and some gelatin, whereas even expertly prepared veal, because it comes from such a young animal, offers little of either. As a result, a mouthful of veal may be very juicy at first, but it lacks the succulence you experience from a prime-grade steak.

The physiology of the animal is not the only factor determining succulence; the mouth of the diner plays a direct role as well. Fats, salts, and acidity in the meat all trigger the salivary glands into action, and the saliva helps keep the food succulent as it is chewed.

Fatty molecules are also enormously important sources for the aroma, and thus the flavor, of cooked meat, so it's interesting to consider why they are present in the first place. Just as animals don't grow muscles so that we can eat steaks, the fat isn't there just to please our mouths. Its function is to store energy in a very compact form for long periods of time. The price the animal pays for stashing away energy so densely is that it can recover the energy in the fat only slowly. Thus, you will not find a lot of fat in muscles that need a lot of energy in a hurry. Such muscles are dominated by lighter muscle fibers that yield pale-colored meat.

Endurance muscles need a prolonged supply of energy and a lot of dark, slow-twitch fibers that are geared to steadily burn fat. Such muscles will typically contain more fat. The slow-but-steady aerobic fibers found in such muscles can burn fat, whereas fast-contracting anaerobic fibers cannot.

The differences in cooking lamb neck, shanks, legs, and ribs can be traced to the properties of each muscle, which in turn depend on what part of the skeleton it serves, how often it has to contract, and whether it is built for constant or intermittent duty.



Japanese chefs have long sought the world's most marbled meat on both land and sea. The dense marbling of fat that is prized in Wagyu beef (top) is the result of genetics, diet, and how the cattle are raised. It commands princely sums; the example here is about $160 per pound, or €250 per kilogram, and prices sometimes soar even higher. Otoro-grade tuna (bottom), cut from the tuna's belly, also shows extreme marbling. Its cost rivals or exceeds that of Wagyu beef.

Supported by water, fish like these horse-eye jacks have no need for the complex anatomy of animals that walk on land or fly through the air. Although this makes differences from one muscle to another less extreme, it doesn't make fish any less of a challenge to cook well.

The Simplicity of Seafood

Although the muscle found in fish is decidedly less complex than that of land animals, all cooks should know a few things about its biological makeup. Perhaps the most important fact is that the collagen in fish muscle is a lot weaker than the collagen of terrestrial animals.

Fish don't need hefty collagen because they live an easier life from a mechanical perspective: they float in water, so they don't need elaborate skeletons or strong collagen in their muscles to support their weight. Hence, fish collagen doesn't contain very many stabilizing cross-links, which are what give collagen strength and slow its degradation in the muscles of land animals.

Without that resistance to degradation, the already weak collagen of a fish weakens further after its death. This is one reason why fish fillets or steaks that aren't impeccably fresh are prone to falling apart. Also, with just a bit of heating, fish collagen quickly melts, which is normally a good thing—the fork-tender character of well-cooked fish is something most people like about it. But taken too far, it becomes off-putting, a sign of poorly cooked fish.

The second, related fact of importance is that most fish are cold-blooded—some species of tuna being notable exceptions (see Why Tuna Flesh Is Red and Fatty, next page). So the proteins found in the muscles of most kinds of fish never evolved to tolerate warm, let alone hot, temperatures.

One implication of their cold-blooded origin is that the proteins in fish can become fully cooked when heated to a relatively cool temperature—a level that a person might find hot but tolerable to the touch. At slightly higher temperatures—even those that would leave most meats rare—fish proteins become entirely coagulated, leaving the cooked flesh dry and mealy.

Because fish lack elaborate skeletons, their bodies are made largely of muscle. And because most of a fish's movements are aimed at propelling it forward, nearly all of its muscles are similar in shape and size. Most fish swim lazily, except for the occasional burst of speed needed to avoid being eaten. For these infrequent but crucial moments, a fish requires a large number of powerful fast-twitch muscle fibers. This is why most fish have light-colored flesh.

The steady swimming they do the rest of the time is powered by a much smaller number of dark, high-endurance fibers running along their flanks near the midline of the backbone and just beneath the skin. (In flatfish, these high-endurance fibers are, for the most part, located on the upper side of the body.) These regions of dark, red-hued muscle fibers are sometimes called the bloodline, athough there is no blood actually present in this flesh. Confusingly, the artery and vein that run beneath the spine of a fish, and that do contain some residual blood, are also referred to as the bloodline.

You've probably often seen distinct lines zigzagging along a fish fillet. These are collagen sheaths, called **myocommata** (or **myosepta**), that divide individual muscles. They run at an angle from the backbone to the skin and are what makes swimming possible. These sheaths grow farther apart as the fish matures and each muscle gets bigger. During cooking, the large gaps between collagen sheath make the flesh of the fish fall apart more easily, sometimes so much as to be a problem.

The individual muscles within a fish, called **myotomes**, are built like the muscles in land animals, with collagen sheaths surrounding the muscle fibers from end to end. But this doesn't mean that the fibers simply run parallel to the length of the fish. That just won't work.

Instead, each individual muscle is folded into the shape of a W, with one muscle nestled into the next, which is what gives the flesh its zigzag look. Such geometry allows muscle contractions to create the undulatory motions that propel a fish forward so efficiently.

This anatomy is hard to visualize, but the cutaway images on the next page help to illustrate what is going on. Or just tease apart a fish fillet the next time you're eating one and discover for yourself how the individual muscles are arranged.

Cooked fish often comes apart in flakes. Each flake is an individual muscle, or myotome. Myotomes separate as flakes because their collagen sheaths (called myocommata) largely dissolve during cooking.

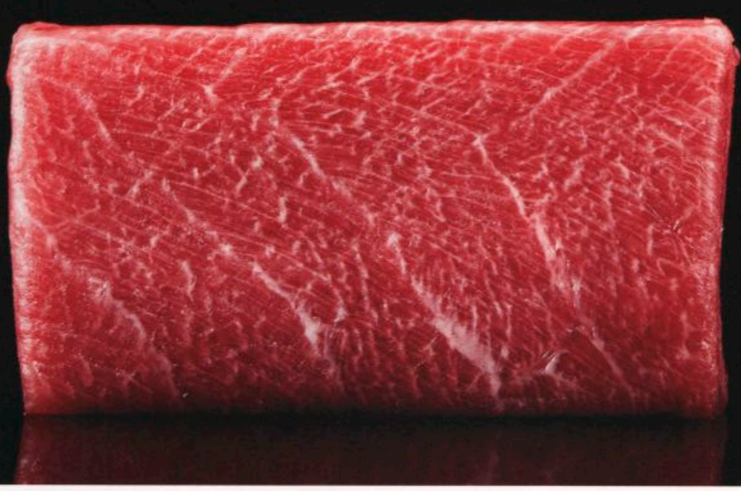
THE BIOLOGY OF

Why Tuna Flesh Is Red and Fatty

Among fish, tuna are unusual. They have deep-red flesh, often highly marbled with fat. The reason is that tuna swim long distances at high speed. So, unlike most fish, tuna muscle is made up of many aerobic muscle fibers containing large quantities of a red-pigmented protein called myoglobin, which is needed to supply these cells with oxygen.

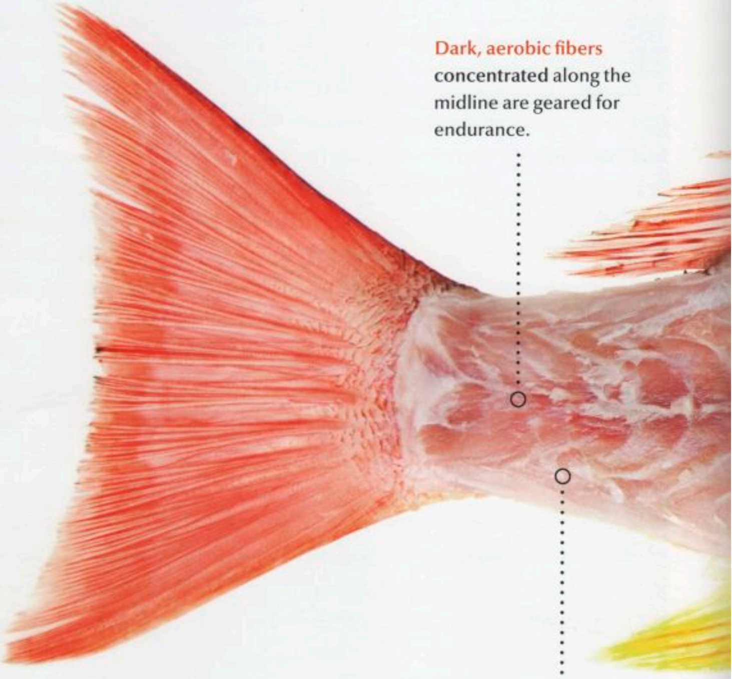
Some tuna species—including the ones commonly eaten—are also unusual in that they can raise their body temperature above that of their surroundings. This is a second reason that tuna muscle, particularly the belly flesh, is fatty. This fat provides insulation against the cold ocean.

The peculiar biology of the tuna species we eat has implications for cooking the flesh of these fish, which is best treated like tender red meat from a land-dwelling animal.



FROM THE DEEP

The streamlined body of a fish reflects the fact that most fish swim through life at a relaxed pace, punctuated by brief bursts of tremendous speed and agility. The minimalist design and two-toned appearance of a fish's muscles gives testament to this existence. A handful of deeply colored endurance fibers provides the steady, rhythmic contractions that propel a fish forward the majority of the time. But every so often a fish finds itself in imminent danger, and darts from harm's way with a furious burst of speed made possible by an enormous number of powerful but quickly exhausted light muscle fibers. The implication for the cook: the texture and flavor of a piece of fish vary because the balance between light and dark muscle fibers differs, and this in turn depends upon where the piece came from within the body of the fish.



Dark, aerobic fibers concentrated along the midline are geared for endurance.

The vertical septum is the connective tissue that divides the fish into left and right halves.

Light, anaerobic muscle fibers are specialized for bursts of speed.

The neural arch is the channel that carries spinal nerves. The Japanese ike jime method of slaughter reams it out; see page 37 for the reason why.

The hemal arch, or bloodline, carries the central blood vessel of a fish. It should be cut open, drained, and cleaned to prevent tainting the flesh with an unpleasant aroma of old blood.

Endurance muscle fibers form the dark red, myoglobin-rich flesh just under the skin at the lateral line. Confusingly, this region is often called the bloodline, although that term is better used for the hemal arch. This fish shows only a hint of the dark flesh, but in some fish (such as those shown on pages 54 and 61) it is far more visible.

The belly is rich in fat but lacks dark myoglobin. This is where premium otoro meat from tuna comes from.

Pin bones are "floating bones" in fish not attached to the main skeleton and not involved in structural support. Found within the sheets of connective tissue separating blocks of muscle, their likely purpose is to stiffen those dividers and thus amplify the force of muscle-fiber contraction.


The lateral line divides a roundfish into upper and lower halves.
A single myotome, or fish muscle, will become a single flake of flesh upon cooking.
A myocomma, a sheath of connective tissue separating adjacent muscles, is where the flesh flakes apart.


The skin of a fish is quite different from that of land-dwelling animals. For more on its unique qualities—and for cooking strategies that will make it crisp—see page 116.

Eight-Armed Swimmers

Knowing how to prepare octopus, squid, or cuttlefish doesn't require that you know how marine biologists classify these bizarre sea creatures, which spew ink and move by jet propulsion. But learning a bit about their biology before trying to cook them can be useful.

Octopuses, squid, and cuttlefish are mollusks, just like clams. They are a type of mollusk known as cephalopods, an offshoot of the mollusk lineage whose members lost most or all of their shells and evolved arms or tentacles from the "foot" their ancestors used for crawling or anchoring to the seafloor. Long ago, the forebears of most cephalopods gave up shells and feet to pursue a swimming lifestyle. The exception is the chambered nautilus, which swims but retains a shell.

Along the way, they also evolved fairly complex eyes, the ability to change skin color, and impressive brains. Aquariums abound with tales of octopuses learning how to open locks, steal fish from neighboring tanks, or otherwise demonstrate a mischievous intelligence. Although some of these stories may be exaggerated, there's no doubt that octopuses are a lot smarter than your average clam.

But the mental skills of cephalopods matter little to the cook; what matters is the structure and composition of their flesh. It differs from fish in that it contains a lot of strong collagen. The arrangement of muscle fibers in cephalopods is completely unlike that found in most other animals, whose muscles tend to be oriented in a single direction—the direction of pull. The muscle fibers and collagen sheathing of cephalopods more closely resemble the layers of wood fibers in a piece of plywood, with the grain of one layer running at perpendicular angles to the grain above and below. This allows these creatures to contract or expand their muscles in just about any direction, which accounts for the contortionist talents of the octopus.

The skin of cephalopods is too tough to be broken down by cooking, so it should be cut away. And the alternating layers of muscle and collagen are almost as tough as the skin, so care must be taken in preparation.

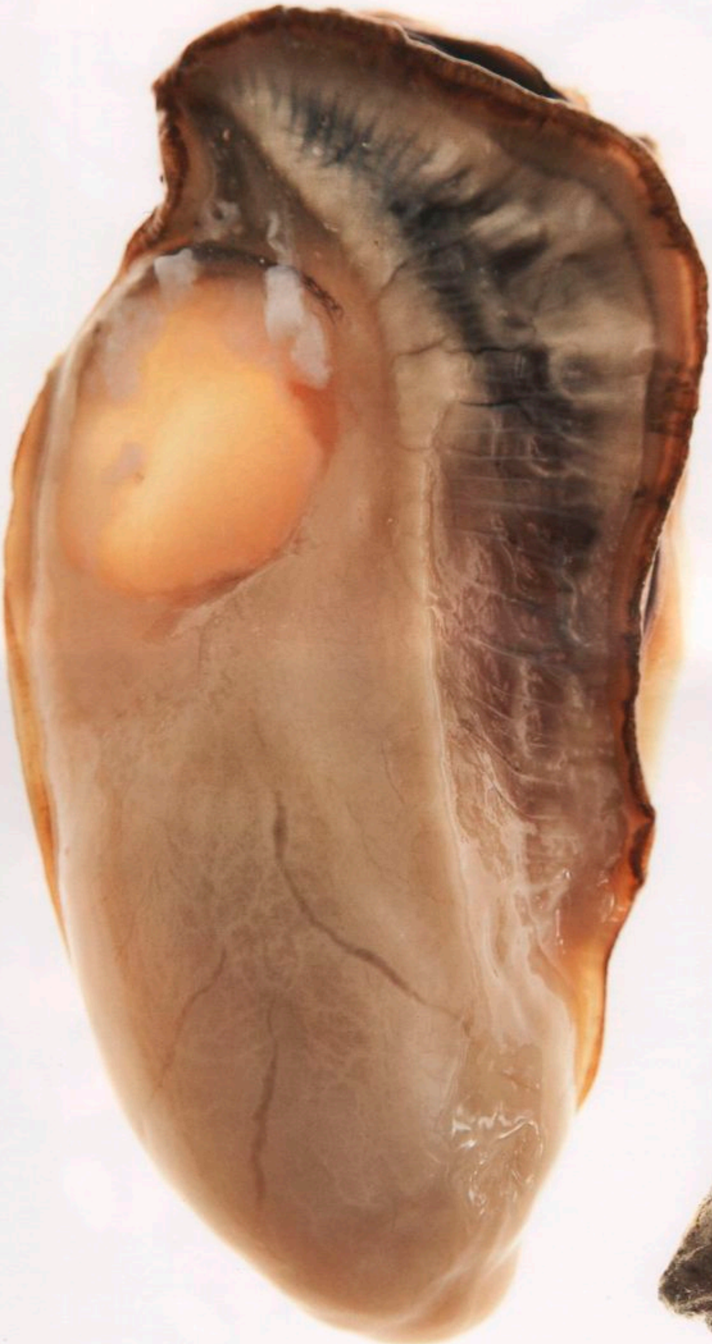
As happens with other kinds of seafood, the collagen in cephalopod muscle begins to shrink at comparatively low cooking temperatures. When it does, the crisscrossing layers of collagen in the flesh of these animals contracts every which way. Japanese cooks often circumvent this troublesome tendency by scoring the meat in several places, which causes it to open like a flower when cooked. The scoring prevents some of the contraction and also makes the meat easier to bite through, providing a pleasantly chewy—or even crunchy—meal.

At seaside restaurants in Greece, chefs pound octopus to make it more tender, and then hang it to dry a bit in the sun.

Renowned for their curiosity, cleverness, and mischievousness, octopuses are among the most intelligent of all sea creatures. But they are, in fact, related to other mollusks, including the clam, slug, and snail. An octopus's four pairs of arms evolved from the tough "foot" common to all mollusks, and its beak is a vestige of what was once a protective shell.

The arm of an octopus has remarkable flexibility. Lacking a supporting bone, the arm muscle has evolved a pattern of crisscrossed fibers surrounded by abundant collagen for strength and resilience. This makes the meat very tough. Although cooks have long disseminated many techniques for tenderizing octopus, only a few strategies truly work.

The humble oyster, anthropologists believe, was the first animal that humans actively cultivated as a food, as evidenced by prehistoric middens. Briny and sweet, the oyster is the rare example of an animal that is commonly eaten raw and intact—and frequently is even eaten alive.



Spineless Meat in a Shell

If squid, octopuses, and cuttlefish are the rocket scientists of the mollusk family, then oysters, mussels, clams, abalones, and scallops are their dim-witted relatives. Of course, shellfish lovers don't value them for their intelligence but rather their ocean-fresh flavors.

People's taste for shellfish—and perhaps even a dependence on such foodstuffs—goes way back. Archaeologists say that oysters and snails (their largely land-based cousins) were the first animals humans learned to raise. Our distant ancestors harvested oysters from tidal flats and returned the shells to the same spot so that the next crop could anchor themselves on something hard. Snail farming required only a bit more work, such as soaking a piece of wood with fermented fruit juice to attract a herd.

Depending on which type of shelled mollusk you're eating, you may consume a different part of its anatomy. Scallops, for example, normally provide only the foot, or abductor, a muscle the mollusks actually use for swimming (by opening and closing their two shells) rather than for anchoring. A scallop is mostly this single, tender muscle, which contains mostly fast-twitch fibers and hence produces white meat.

This is why scallops are best cooked by just searing the surface. That surface browns nicely because the abductor muscle contains very high levels of the mildly sweet amino acid **glycine**, which prevents the animal from being dried out by the salt in seawater, and also of **glycogen**, which provides the animal's muscle cells with easily accessible energy.

Abalones are like scallops in that you normally eat just their foot muscle and discard the entrails. Abalones are unlike scallops in that they have only a single shell and a very strong foot that lets them cling to seaweed, coral, and rocks. Because of an abundance of connective tissue present in the foot, abalones are best sliced very thinly and eaten raw or rare. With minimal cooking, their texture becomes chewy and a bit crunchy, but at higher cooking temperatures, their collagen shrinks and makes them very tough. Only very prolonged cooking softens them enough to be enjoyable again.

Oysters and mussels are a different story. They have a foot for anchoring, but it's too small and tough to be enticing. These mollusks are worth eating for their entrails, which are slick and tender.

Clams are similar to oysters and mussels; the fundamental difference is that clams have an organ known as a siphon. A clam uses its foot to bury itself completely, extending its siphon out of the sand to obtain the water it filters for food. In general, you eat all parts of clams because they are so small. The giant geoduck clam is an exception: cooks prepare only the siphon of that species, a native of the Pacific Northwest (see page 5·197).

Despite the differences in their anatomy, all shellfish are alike in their use of certain amino acids to counteract the salinity of their seawater environment. Because the salinity of seawater varies, they may need more or less of these amino acids, and that variation partly explains the different flavors of shellfish from different waters.

Heating during cooking also affects the flavor because many of the amino acids become bound up in coagulated proteins, which prevents them from contributing to the flavor. Heating also creates potent aromatic sulfide compounds that give mollusks their distinctive cooked aroma.

In general, the saltier the water they are taken from, the more savory the shellfish. This is why oysters are often "finished" in salty tidal pools for a few weeks or months before harvesting. The malleable biochemistry of their tissues also explains why shellfish are less tasty when spawning: they use up much of their flavor-enhancing energy stores to reproduce.

Anyone who cooks or eats these shellfish should understand the possible consequences of how these mollusks forage. Because these animals filter massive amounts of water to obtain a few morsels of food, they can easily become contaminated with pollutants or infectious agents. We have estimated that a single gram of diarrhea containing norovirus, the waterborne culprit behind many foodborne outbreaks of intestinal disease, can contaminate 23 km^2 / 9 mi^2 of oyster beds (see chapter 2 on Microbiology for Cooks, page 1·102).

For this reason, it is illegal in many places to

A single oyster may filter more than 20 liters of seawater a day.

Although related to the sedentary oyster, scallops are swimmers. Each has a large and powerful abductor muscle that can rapidly open and close the shell, propelling the creature through the sea. Whereas oysters are commonly gobbled whole, of the scallop we eat only this strong but sweet-tasting muscle.

Many food safety incidents are due to eating raw shellfish, particularly oysters. Food scientists are devising ways to use ultrahigh pressure to sterilize shellfish without cooking them, but these methods have not yet been widely adopted. Until they are, there isn't much you can do to eliminate the risk; either accept it, or don't eat raw shellfish.

serve the entrails of scallops. But attempts to impose the same rule for raw oysters have been repeatedly rebuffed. Nothing in life comes without risk, and nothing tastes quite like a fresh oyster.

Good Eating in an Exoskeleton

There are some 50,000 crustacean species, but lobsters, crab, shrimps, prawns, langoustines, and freshwater crayfish are the only ones you'll normally encounter on a menu. Some writers have described these animals, rather unappetizingly, as the "insects of the sea." That's because they are arthropods and, like ants and beetles, have an external skeleton, a segmented body, and other features in common with insects.

One key difference, however, is size. Before lobsters became highly valued, and hence overfished, people living along the coast of New England regularly harvested specimens weighing 18 kg / 40 lb. That was back in the day when they were considered trash food. In the 18th century, Massachusetts had a law limiting how much lobster you could feed prisoners because too much was considered "cruel and unusual" punishment. Times do change.

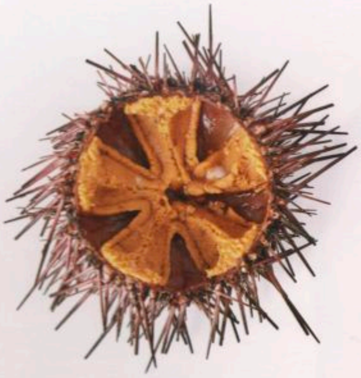
If you like lobster, don't worry about its past reputation. But be aware that all crustacean flesh contains abundant protein-splitting enzymes that can turn flesh mealy, a texture sometimes described as woolly or cotton-like, after the animal is killed. These enzymes become increasingly destructive as temperatures rise to about 55–60 °C / 130–140 °F, which is why crustaceans are usually sold either alive or boiled or steamed to a temperature hot enough to destroy the enzymes.

Inevitably, such high temperatures overcook the otherwise delicate texture of the flesh. When possible, a better alternative is to cook the flesh to much lower temperatures and then serve crustacean dishes as quickly as possible to limit the opportunity for these destructive enzymes to wreak havoc on the quality of the flesh.

Although cooking crustaceans isn't terribly complex, picking the right ones for the pot can be a challenge. You'll do better armed with the

Crabs, like all other crustaceans, have strong exoskeletons that armor their muscles from predators and, as shown here, other crabs. All crustaceans molt periodically from their shells to grow. A crustacean about to molt, or just after molting, isn't as delicious as it could be. Knowing the telltale signs is invaluable.

It took us the better part of a day to carefully dislodge this cooked lobster from its shell. Once upon a time, these ungainly sea creatures were so plentiful that the State of Massachusetts passed a law that forbade serving them to prisoners more than twice a week. Dining on lobster every day was considered to be a cruel and unusual punishment!



Sea urchins are sometimes thought to be crustaceans, but they are not. They are echinoderms, a family of animals that also includes starfish. Unlike nearly all other animals that we commonly eat, sea urchins and similar creatures are not bilaterally symmetrical, which is to say they do not have a left side and a right side. Instead, they display five-sided radial symmetry. You will find exactly five "tongues" supported by an endoskeleton when you cut open the test, or shell, of a sea urchin. The so-called tongues are actually the animal's reproductive organs.

knowledge that when crustaceans grow, they periodically shed their exoskeletons; that is, they molt. Many cooks know to avoid crustaceans that are getting ready to molt, but you may not know when to chase after those that have already molted.

Timing is important here because prior to molting, lobsters and crabs shed a large amount of muscle mass. They literally shrink inside their shells. After the exoskeleton weakens, they break out of it, living briefly without any protective covering at all. Just after molting, they pump up, adding 50%–100% to their body weight by absorbing water. You don't generally want to eat a crustacean that is about to molt or that has just molted and is taking on a lot of ballast. The exception is soft-shell crabs, which are cooked just after having molted.

Once their new shells begin to harden, crustaceans are perhaps at their best for the table. Many say that a lobster with a new exoskeleton is exceptionally sweet and firm. Likely, this is because the creature ate voraciously after molting to replenish its protein and energy stores in order to rebuild its protective armor.

How do you recognize when a crustacean is ripe for eating? Recently molted crabs and lobsters have shells with a grayish-to-green cast on their topsides and a lustrous white abdomen. That's because the pigmentation of the shell comes from the animals' diet, and they haven't yet eaten enough to color their shells more richly.

Later on, when crustaceans are at their prime for eating, their topsides will be deeply colored, and their bellies will take on a stained or dirty look. Also, their shells will have become very hard. These crustaceans will feel heavy for their size because they are filled with dense muscle tissue, not tissue that is bloated with absorbed water. Crustaceans that are about to molt feel the lightest because their shells are partly empty.

Sometimes you will see a pinkish tinge, commonly referred to as rust, on the bottoms of crabs, which can indicate that they are getting close to molting. Before they do, they will reabsorb calcium from the shell, softening it. A telltale sign is that the shell can begin to appear slightly green again. They will bloat with water to loosen the shell and then will shed muscle mass to become small enough to squeeze out of it. Such crabs do not make for good eating.

So pick it right, and you'll enjoy the taste more. You'll also enjoy the aroma of cooked crustaceans, which is unique. The chemistry responsible for this redolence turns out to be Maillard reactions (described further in Cooking Meat and Seafood, page 70), which normally require very high cooking temperatures. But because the flesh of crustaceans contains a lot of sugars and amino acids (such as glycine, which tastes sweet) to counteract the salinity of seawater, Maillard reactions can take place at unusually low temperatures in these animals.

Another reaction of interest—to the eye, if not the palate—is the change in color of the exoskeleton as it is cooked. This transformation comes about because of **carotenoid pigments**, which start out bound to proteins in the shell, creating the blue, green, and brown hues that serve as camouflage. When heated, the proteins of the exoskeleton release those pigments, which then take on their vibrant orange and red colors.

Both prawns and shrimp are members of the crustacean family, as evidenced by their rigid exoskeletons. Although similar in appearance, prawns and shrimp are really only distant relatives. The taxonomy suggested by their names, however, is very confused: the white prawn shown here, for example, is actually a shrimp.

As with all other crustaceans, the eating quality of these animals quickly degrades after the animal dies. Protein-cleaving enzymes found in the abdomen escape and turn the flesh mealy. Thus, they are at their best when cooked and eaten within hours—if not minutes—of being caught.

For true connoisseurs, the best way to enjoy a truly fresh prawn or shrimp is by sucking the intensely flavored juices from the head of the animal.

Defeating the long, sharp spines covering the hardened shell, or test, of a sea urchin is worthwhile because of the tongues protected within. Their creamy texture and oceanic flavor is simply incomparable.

CONVERTING MUSCLE INTO MEAT

You might think that turning muscle into meat entails nothing more than killing the animal in whatever way is most convenient, and then carving up the carcass. You might also presume that there's no need for you to ruin your appetite thinking about all the gruesome details involved. In fact, the process of converting muscle into meat is quite complex. And although the cook doesn't normally control how this conversion is accomplished, there are good reasons to understand it. Very little can be done in the kitchen to counteract the shortcomings of modern slaughterhouse procedures. But, armed with the knowledge of good and bad slaughterhouse practices, you may one day be able to influence them for the better through your buying and eating choices.

The first step in the transformation of muscle into meat is the onset of rigor mortis (Latin for "stiffness of death"). In a living animal, the main proteins in muscle, actin and myosin, move together or apart as needed to contract a muscle or relax it. But after slaughter, these proteins bind to each other, causing the muscles to become rigid. In time, enzymes break these bonds and tenderize the meat. What matters more to the cook is *brevis mortis*—the "shortness of death." It turns out that humane forms of slaughter, combined with humane rearing, also make for the best meat. And we're not just saying so to appear politically correct. Plenty of hardheaded scientific work shows a strong connection between meat quality and humane slaughtering. So there is every reason to want to see the animals we eat treated well both during their lives and at the end of those lives.

But what exactly makes for humane slaughtering? Proper practice depends on a lot more than just rendering the animal unconscious, killing it with as little pain as possible, and then bleeding out the carcass (a process called **exsanguination**). After death, the pH of the muscle tissue typically plummets from about 6.8 (nearly neutral) to around 5.5 (mildly acidic) as muscle cells burn through their reserves of energy. This occurs for the same reason your legs burn with pain after a long sprint: muscles accumulate acid as a byproduct of burning glucose, their natural fuel, in the absence of enough oxygen. Respiration and blood flow bring oxygen to your muscles to

The carcasses below and to the right might be an unappealing sight to some, but it's in a cook's interest to become educated in proper slaughter practices. How an animal is handled before, during, and after slaughter will make or break the quality of the meat.

prevent the pH inside these cells from falling dangerously low, but after an animal is slaughtered, with no respiration or blood flow, the excess acid in its muscles isn't neutralized, so the pH drops substantially.

As the pH of the cells nears 5.5, enzymes that drive metabolism are progressively degraded, and muscles cease functioning. In a sense, this is the ultimate death of a muscle. But it hasn't yet become meat. More biochemistry must take its course before that happens.

With energy supplies exhausted and metabolism shut down, actin and myosin bind together, and muscles no longer stretch. The actual stiffness of death sets in when opposing pairs of muscles—muscles that contract in opposite directions, such as the biceps and triceps—become equally inflexible, thus locking the limbs. Were you to cook a muscle in rigor, you'd find that the result is extremely tough.

Muscle ultimately becomes meat as rigor passes. Rigor passes as the process of aging meat begins. We discuss aging meat in depth later; for now it will suffice to understand that in death certain enzymes, ones that are carefully regulated in living muscle, become uncontrolled. Over time, they break down various protein structures in muscle fibers, allowing the stiffness of rigor mortis to pass. Protein fragments are a wonderful side effect of the job these enzymes do; the larger pieces (**peptides**) and individual protein building blocks (**amino acids**) contribute enormously to the taste of meat and are absolutely essential to the aroma of cooked meat. Thus, it is only at this point that muscle really becomes meat.

Unfortunately, a lot can go wrong during slaughter. If an animal is ill, malnourished, exhausted from heat, or otherwise under stress before it is slaughtered, its meat will be compromised. And make no mistake about it: getting killed can be awfully stressful.

Stress elicits what's called the fight-or-flight response, which causes an animal to produce several hormones, such as **adrenaline**, that prepare muscles for bursts of activity. If an animal is stressed from struggling or fear just before slaughter, for example, the adrenaline levels in its muscles will be high after it is killed. Adrenaline causes the animal's muscles to burn rapidly through their energy reserves, which makes the pH drop quickly—too quickly, in fact, because the resulting carcass is still near the animal's normal body temperature, and as the muscles become acidic the combination of warm muscle tissue and low pH causes the proteins in the muscle to unravel.

The result is meat that is pale in color, mushy in texture, and exuding moisture—known in the trade as **pale soft exudate**, or PSE for short. Although the meat of any animal can be damaged in this way, it's a common problem with pigs, often occurring during the summer when the weather is uncomfortably hot. Even heroic measures in the kitchen cannot save PSE pork; no matter what you do, the cooked texture will be mealy and dry to some degree.

A good butcher shop is an invaluable resource, but the events that determine the quality of meat have happened well before meat reaches the shop.

A different problem occurs when the pH of muscle doesn't fall far enough. Something as simple as an animal's being kept in the rain in cold weather before slaughter can cause shivering sufficient to leave its muscles depleted of energy. If an animal is killed before its muscles recover, they will have only a small amount of remaining fuel. When the fuel reserves are depleted, the decline in pH stalls, and rigor mortis sets in too soon. The result is that the quality of the meat suffers from a problem called **dry firm dark**, or DFD for short. The muscles of animals such as cows that provide red meat are especially prone to this problem. In the beef industry, affected carcasses are called **dark cutters** because their meat fails to bloom bright red when sliced open and exposed to air.

Dark cutter meat is tough. It also spoils quickly because its relatively high pH (low acidity) makes the meat more susceptible to bacterial growth. And the high pH also gives the meat the capacity to bind water strongly, which is what makes it appear dry. This high binding ability makes dark cutter meat useful for sausages and other forcemeats, but its inherent toughness makes it useless for steaks and roasts.

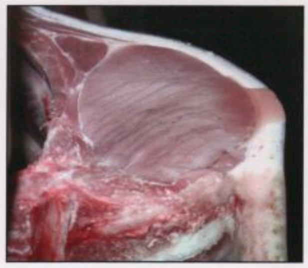
Assuming, for the moment, that an animal has been treated humanely and that its slaughter has been done swiftly, the conversion of its muscles into meat can still go awry. A carcass needs to be cooled after slaughter in part to prevent bacteria from growing rapidly on it. Chilling the carcass also protects the meat from being ruined by an excessively low pH at too high a temperature. So it might seem that rapid chilling would be advantageous. But quick chilling can turn out to be too much of a good thing.

If a carcass is cooled too quickly, another problem, called **cold shortening**, can arise. The biochemistry is complex, but the basic phenomenon is simple to understand: if a muscle is chilled to a temperature below 15 °C / 59 °F before rigor mortis sets in, proteins in the muscle retain their ability to contract. After rigor passes, the muscle fibers temporarily revive and undergo uncontrolled contraction. A severe case of cold shortening can cause a muscle to shrink irredeemably by more than 50% of its original length, but even a mild case will make for tough and dry meat.

Small animals, whose carcasses cool relatively quickly, are most prone to this problem, but in large animals, the muscles near the surface are also susceptible. Because the chilling rooms in slaughterhouses are kept very cold, there is always a risk of cold shortening. Better slaughterhouses combat this danger with an assortment of techniques that meat scientists have devised, but it is still common for many slaughterhouses simply to leave the outcome to chance.

And this brings up an important final thought: it is challenging for meat scientists to manage slaughter and the conversion of muscle into meat perfectly even under carefully controlled conditions. Practices at many slaughterhouses remain far from this ideal. That's because the emphasis in most of these facilities is on the quantity of meat they produce, not its quality.

There would certainly be a market for really good meat even if it cost somewhat more. So you might expect that smaller slaughterhouses would be springing up to cater to this need. We wish it were so, but there's a huge barrier for anyone trying to start such a facility in the United States: U.S. Department of Agriculture (USDA) regulations require the owners of slaughterhouses to pay for on-site government inspectors, which smaller operators generally cannot afford. Similar restrictions are also the norm in other countries.



Dark cutter beef (top) and pork exhibiting a condition known as PSE (bottom) are two of the most common examples of meat ruined by poor slaughterhouse practices.

Grading Meat

Americans have been using the USDA's meat-grading system since the early years of the 20th century. Consisting of prime, choice, select, standard, utility, cutter, and canner grades, it was the first formalized system in the world for meat inspection and grading. It was spawned in large part by public outrage after the publication in 1906 of Upton Sinclair's exposé *The Jungle*, which went into gruesome detail describing the deplorable meat-industry practices of the time. That same year, Congress passed the Meat Inspection Act, which set up government oversight of slaughtering and packing operations. That brought some much-needed reform. But as it stands, the USDA grading system leaves a lot to be desired, both for judging meat quality and for fostering innovation.

Although it has been copied in many places, the U.S. system is not universal. Some countries have applied their own interpretation. For more than a thousand years, for example, the Japanese

Fish are as prone as other animals to the problems of slaughter. Elaborate measures such as the Japanese practice of *ike jime* have been devised to avoid the worst of those problems (see page 38).

BIOGRAPHY

Dr. Temple Grandin

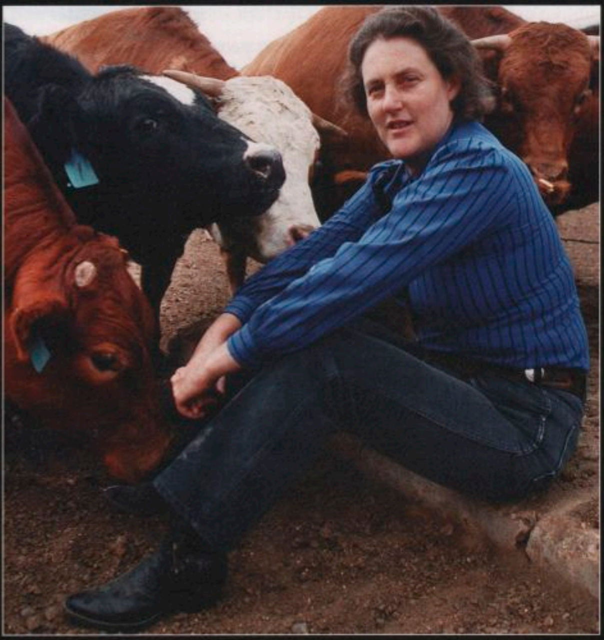
Dr. Temple Grandin, an animal scientist at Colorado State University, became widely known after Oliver Sachs described her experiences in his 1995 book *An Anthropologist on Mars.* She became even more famous from the 2006 BBC documentary film *The Woman Who Thinks Like a Cow.* She is well regarded both for her work on animal welfare and as a passionate advocate for improving public understanding of autism. Grandin, who was diagnosed with autism at the age of four, thinks visually rather than with words. She says she experiences and reacts to the world in a manner similar to that of many nonhuman mammals.

Using this talent, the Colorado scientist was able to establish an objective scoring system for assessing animal welfare at livestock facilities. And she designed many of the better handling systems used at meat plants today. These replaced older equipment that was grossly deficient.

As meat production became industrialized over the past century, no one paid much attention to how the animals reacted to the conditions they experienced before slaughter. Sheep, for example, become stressed if they are separated from the herd. Yet for a sheep to be slaughtered, it eventually needs to be funneled individually down a chute.

Grandin's response to this challenge was, in part, to equip the sides of the chute with fluffy, pillow-like padding to make the animal feel as if it is accompanied by other sheep.

Through her many published scientific reports, Grandin has shown, perhaps better than any other single person, how improper handling at the slaughterhouse causes both the animal and the quality of the meat to suffer. She has also devised workable solutions and contends that meat-eating can be done in a moral, ethical, and humane way.



had no need for a meat-grading system because of Buddhist prohibitions on consuming the flesh of four-legged animals. But as Western influence in Japan grew, so did beef consumption. After World War II, the Japanese embraced many aspects of American culture, including a beef-rich diet. In the 1960s, Japan adopted a meat-grading system, similar to the one in the U.S., that rates meat based largely on fat marbling. But Japan's system is more nuanced and has been adapted for grading the meat of Wagyu cattle, a specialized Japanese breed renowned for the intense marbling of the cuts it produces.

Europe, perhaps surprisingly, has no government-based meat-grading system at all. Large-scale purchasers and suppliers set their own proprietary standards. This has created an economic incentive for ranchers to concentrate simply on carcass yield rather than on improving meat quality. The quality of a lot of European meat, we believe, suffers as a consequence.

This isn't to say that there isn't excellent meat in Europe. On the contrary, the lack of a systematized European grading system has created a niche for small farmers and ranchers who work to stand out by producing superior meat. In comparison, the USDA's rigid grading system sets standards that ensure a certain level of quality but at the same time stifle innovation.

In the U.S., prime-grade meat constitutes about 2% of the market and tends to be found only in the finest restaurants. The big supermarket chains offer meat from the next two rungs down on the ladder: choice and select grade. Cuts below select

CONTROVERSIES

Apparently Cruel but Actually Humane

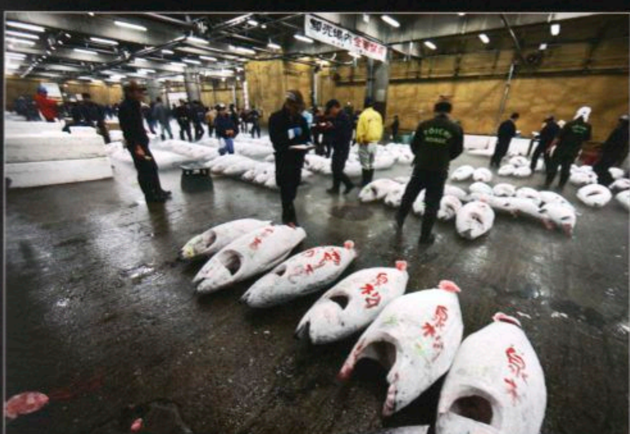
Sometimes, as the saying goes, things are not as they appear. That may be especially true of *ike jime*, the Japanese method of killing a fish by severing and destroying the spinal cord. *Ike jime* admittedly seems cruel. Nevertheless, it's actually very humane, and for the same reasons that swift and humane slaughter benefits land-dwelling animals, a quick death with minimal pain benefits seafood.

On fishing boats, large fish such as tuna are immediately stunned after being caught. A spike or coring tool is quickly inserted at a 45° angle into a soft spot on the head, midway between and slightly behind the eyes. This destroys the brain and kills the fish. If it is done right, the fish should give a shudder, its mouth should fall open, and the first dorsal fin should relax and fan out.

Time is of the essence now. A piece of stiff, large-gauge monofilament is quickly threaded into the brain cavity and down the neural canal to destroy the spinal cord. The fish gives one last shudder as this "pithing" (also known as the *Taniguchi* method) is done. This is an essential step when handling valuable fish like bluefin tuna. At Tsukiji, the world-famous Tokyo fish market, buyers expect to see a few centimeters of monofilament protruding from the fish's head and tail to prove that the very best handling techniques were used on a creature that may be worth as much as $100,000.

But why ream out the already-severed spinal cord? This is done, according to Japanese food scientists, because some nerve signals don't require directives from the brain. Destroying clusters of nerves in the spinal cord, called **spinal ganglia**, cuts off those signals and halts the resulting stress reactions in the muscles that otherwise would harm the texture and flavor of the flesh.

In a sense, *ike jime* is a technique that minimizes the suffering of an animal by mechanically short-circuiting the pain and stress response. And, as with any animal, this benefits the quality of the meat. Taste tests have consistently shown that fish slaughtered using the technique of *ike jime* have significantly firmer flesh, a sweeter taste, and better flavor than those slaughtered by other methods.

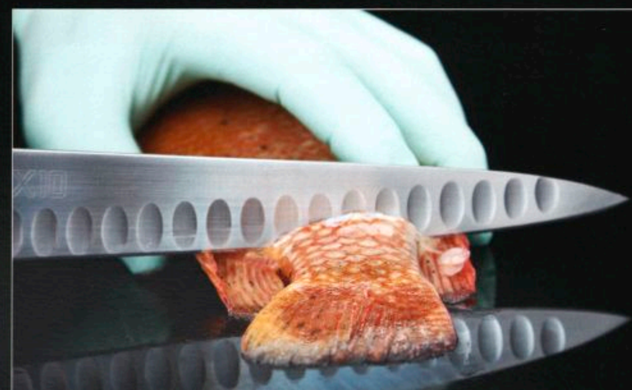


At the world-famous Tsukiji fish market in Tokyo, frozen bluefin tuna is sold with a small notch made in the tail so that buyers can judge the quality of the flesh. For larger specimens (those weighing more than 20 kg / 45 lb), a core sample of the frozen belly flesh is also taken from behind the gills. People tend to associate frozen fish with low quality, but in fact some of the most expensive, highest-quality fish in the world is sold only frozen. Why freeze the fish? Because after it is caught, it may spend weeks at sea before the boat returns to port and the fish makes it to market. Tuna, for example, are "superfrozen" to −60 °C / −76 °F soon after they are caught. When dealing with such ultralow temperatures, the freezing process must be carefully controlled to minimize the growth of damaging ice crystals in the flesh that would compromise the quality of these very expensive fish. For more on the effects of freezing and thawing on food, see chapter 6 on the Physics of Food and Water, page 1·292.

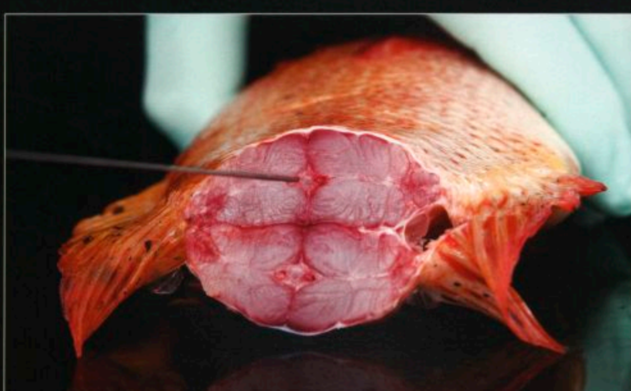
HOW TO Kill Fish with the *Ike Jime* Method

The flavor and texture of fish depend, to a remarkable degree, on how the animal was killed and handled immediately following death. *Ike jime* is a traditional Japanese technique for killing a fish, described by some as a way to kill the fish "without the flesh knowing it is dead." It involves a quick and humane dispatch followed by the destruction of the spinal cord and then the bleeding out and quick cooling of the flesh. The Japanese seafood industry has experimented extensively with this technique and has documented how it improves the quality of various fish. We recommend it for any circumstance in which you find yourself killing a live fish. In Japan, due to the labor involved, it is used primarily on higher-value fish like tuna; we describe the process on the previous page. Smaller fish can be dealt with more simply using the technique described here.

1 **Sever the spinal cord and major arteries.** Using a very sharp knife, place the tip under the gill flap and just behind the skull. Press firmly straight down to quickly and humanely kill the fish.



2 **Cut through the tail.** Again, cut firmly and quickly with a very sharp knife to sever the spinal column and the major arteries that run alongside the spine.



3 **Thread a long needle, piano wire, or stiff monofilament (150 kg / 300 lb test strength) through the neural arch.** The procedure destroys the spinal cord. In this photo the tail has been doubled back under the fish to expose the neural arch on both sides of the cut.

4 **Plunge the fish in an ice-water bath to bleed out.** When the fish has finished bleeding, butcher, slice, cook, and serve the flesh immediately, before rigor mortis sets in. Otherwise, store the fish on ice and wait until rigor passes before butchering the fish; doing otherwise will ruin the flesh.

grade are rarely seen as intact by consumers; instead, these cuts are used by food manufacturers.

USDA inspectors determine the grade of meat by considering such factors as age and marbling. The emphasis on marbling was based on the presumption that fat content is a good indication of the quality of the meat—and of its tenderness in particular. That yardstick is convenient, but it's not always reliable, especially for gauging tenderness.

The grade given by an inspector rewards meat producers in the U.S. for improving quality, but only for the characteristics that are graded and only to the point that the meat is judged prime. The same is true for Japanese meat producers, who work under a similar system. By comparison, the lack of an official grading system in Europe means that producers are not slaves to what is at best a limited measure of quality. On the other hand, if a farmer or rancher wants to benefit from producing superior meat, he or she either must remain relatively small, selling directly to the public and independent restaurants, or must become a successful marketer and build a recognizable premium brand, such as certified Angus beef.

Could the situation be better? Certainly. The Australians used to have a reputation for producing the worst beef in the world. Raising cattle in the Australian outback is a hard business, tough on both the cattle and the ranchers. Because the country's beef quality proved so inconsistent, the Australian government funded research in the 1990s with the aim of improving meat quality. The research showed that the degree of marbling, for example, didn't correlate very well with tenderness: marbling accounted for perhaps 20% of the variation measured. So rather than adopt the U.S. system, with its emphasis on fat content, the Australians identified markers for the complex conditions that truly affect tenderness, juiciness, and flavor.

In the end, the Australians established a beef-grading system, known as Eating Quality Assured, which uses a sophisticated statistical model to predict the quality of each cut of meat from a given animal. Producers are rewarded for doing the things that ensure the highest quality: careful breed selection, attention to the animals' diet and welfare, and perhaps most important, carefully managed slaughter—something that no other grading system recognizes. For the Australian consumer, the results are distilled to a grade of one to five stars, and each package of meat comes with a short set of cooking instructions for achieving the optimum result for that particular cut of beef. We believe it is the best and most innovative grading system on the planet.

Aging

The action of enzymes during aging turns stiffened muscles into soft, pliable meat. Aging also creates many of the tastes and aromas that give meat (or seafood) the flavors we carnivores crave. Much myth and lore surround this transformation. How long, for example, should meat age? Many people say the longer the better, but in truth, it depends on the kind of animal, the type of muscle, and what you want from your meat. What about dry-aging versus wet-aging? There are advocates for both, each claiming their preferred approach is superior. In reality, differences exist but neither is inherently better. Then there is the assertion that well-aged meat, although more tender, is inherently less juicy than fresher meat; however, the opposite is generally true. To separate fact from fiction, it's well worth learning a bit about the biochemistry that drives this key process.

Soon after an animal is killed, it is bled. Consequently, all of the cells in the animal's body are irreversibly deprived of oxygen and essential nutrients. Under these very harmful conditions, cells quickly lose the ability to regulate all of the intricate chemical and enzymatic reactions that sustain life.

The conventional wisdom among experts is that after rigor mortis sets in, two groups of enzymes, called **calpains** and **cathepsins**, begin to take apart components of the intricate contractile protein structure in muscle cells. More recent evidence shows, however, that turning muscle into meat is vastly more complicated than this; many interrelated biochemical and enzymatic processes are at work. Whatever the scientific intricacies involved, the tenderness that comes from aging meat is a result of enzymes dismantling parts of muscle fibers.

So for how long should meat be aged? The rate

The stamp of a USDA inspector ensures a certain level of quality, but not excellence. Although the United States was the first country to enforce standards for meat quality, using a system that was revolutionary in its day, that grading system is no longer the best in the world.

Angus cattle originated in the counties of Aberdeen and Angus in Scotland in the mid-19th century. The breed was largely developed by Hugh Watson from hornless cattle that had traditionally existed in the area. Watson's selective breeding created a variety of cattle that became famous for the quantity and quality of their meat. Most Angus cattle are black, but some purebred Angus are red. Today, in the United States, one can buy "Certified Angus Beef," but that certification has little to do genetically with Angus cattle. To qualify for "Certified Angus" status, the animal must merely be 51% black and meet some size tests. Purebred Angus that happen to be red aren't eligible, and cattle that are genetically not Angus but happen to be black are. The phrase ought to be "Certified Half-Black Cattle Beef."

For more on calpains and cathepsins, see page 76.

THE SCIENCE OF

Truite au Bleu and *Sole Meunière*

Generally speaking, muscle becomes meat after rigor mortis passes. There are very few culinary examples of the use of prerigor flesh for cooking, mostly because of the fleeting nature of this condition. There is, however, one classic French dish that does call for this exceedingly rare and perishable ingredient.

Truite au bleu (blue trout) was traditionally served at riverside restaurants in France and Switzerland. Though many popular *truite au bleu* recipes today fail to emphasize the critical time element (often just vaguely advising the use of "fresh" trout), the key to successful preparation is that the trout must be killed and cooked immediately after it is caught or otherwise removed from the water. Also crucial to properly cooking this dish is the preservation of the slime that covers the fish's skin. It is this slime that gives the poached trout its distinctive blue color. But for that color to develop, the trout must be cooked in a mildly acidic court bouillon. The acidic water of the bouillon transforms compounds present in the slime into pigments that give the skin a slightly opaque, blue-gray appearance. But the effect is possible only for a brief time after the trout is caught and killed. As time goes by, chemical reactions alter key molecules in the slime and render them incapable of bringing about this colorful transformation.

Less visible but no less important to what makes *truite au bleu* such a singular dish is its unique texture and flavor. In truly fresh trout, the energy reserves have not been exhausted, which gives the flesh a wonderful sweetness. Also, the pH of the flesh hasn't fallen, which makes the fish juicier. The enzymes that cause rigor to pass never become activated, and as a result, many of the tastes and aromas usually associated with trout are not created. Finally, fats in the flesh are impeccably fresh. If you didn't know better, you would wonder if this was even the same fish as the one you are used to eating. To emphasize its distinctiveness, *truite au bleu* is traditionally served with the tail curled—as if it had just recently flipped out of the water and into the pan.

Sole meunière offers an entirely different dining experience. Freshness is not the operating principle in this fish story—*au contraire!* Julia Child claims it was eating *sole meunière* in Normandy, France, in 1948 (while she and her husband Paul were on assignment for the OSS, the precursor to the CIA) that convinced her to dive headfirst into exploring French cuisine. This classic dish features a piece of sole, preferably Dover sole, dredged in flour (*meunière* means "miller's wife"), pan-fried in butter, and served in a sauce made from lemon juice and the browned butter left over from frying. Sounds simple enough, but it is what happens before cooking that makes the biggest difference.

Connoisseurs of *sole meunière* claim that the best results come from Dover sole aged for several days. Fish flesh goes through rigor mortis, and fish fats rapidly oxidize. This usually poses the risk of unpleasant rancidity in fish, but in Dover sole, this works more like aging in beef, creating pleasant aromatic and flavorful chemical changes. The unsaturated fats in Dover sole create a distinctive taste that the aficionados of this dish, including Julia Child, came to treasure.

Aging also alters the texture of the flesh. Chemical decomposition creates formaldehyde, which cross-links with the muscle proteins to firm up the flesh. Unlike the case with *truite au bleu*, the deconstructing enzymes are allowed plenty of time to do their work of cleaving the proteins into smaller peptides and amino acids that, upon cooking, create both the flavors and the characteristic aromas of this dish. Many feel that turbot benefits from the same process.

of tenderization varies among different species of animal. For reasons having to do with the relative activity of enzymes in different muscle-fiber types, red meat generally matures more slowly than white meat. Large animals require more time than smaller animals. And meat from younger animals ages faster than the meat of their more mature kin.

For example, at 5 °C / 41 °F, the tenderness of beef will reach 80% of what is possible through aging in about 14 days, and enzymatic activity, and thus tenderization, more or less ceases 21 days after slaughter. By comparison, pork sees most of the benefit of aging within five days of slaughter. Lamb falls somewhere in between. And chicken sees little benefit from aging beyond 48 hours, which is about the shortest time you'd want to age the meat from any land-dwelling animal.

Fish, being generally smaller and, for the most part, providing white flesh, seldom benefit from anything beyond the amount of aging needed for rigor mortis to pass. Indeed, aging raises the chance of letting unsightly tears and gaps develop in the flesh.

Worse, as the flesh ages, reactions that cross-link proteins occur, giving the fish a somewhat tough and woolly or cotton-like texture. And, of course, fish tend to quickly go rancid. So most fishmongers don't normally give much thought to how to age their wares; their usual concern is how to keep them fresh.

But those who sell other kinds of meat have to be more deliberate about this process and how it will affect the qualities of the flesh. It turns out that whether meat is wet-aged in a vacuum pack or is dry-aged in a meat locker makes no difference to the degree of tenderization; the enzymes that do the work are equally active in either case. What is different is the cost to the butcher and the flavor and juiciness of the meat.

Dry-aging meat requires more work and more refrigerated space, and by definition the meat loses moisture over time. With less water, a dry-aged cut weighs less, so it will fetch a lower price unless a premium is charged. Hence the financial incentives for producers favor wet-aging.

But dry-aging can profoundly improve the flavor of meat. The slow and steady evaporation of moisture concentrates sweet-tasting sugars as well as savory-tasting, umami-enhancing protein fragments and nucleotides that are by-products of the aging process. Concentrating molecules such as these makes meat taste meatier. When cooked, these concentrated molecules boost the creation of Maillard flavors, further enhancing the meatiness, as discussed more on page 89.

The oxidation of fat and other susceptible molecules also contributes to the aroma of dry-aged meat. In the case of meats high in saturated fats, beef being the prime example, the aroma can be pleasantly nutty, with mild cheesy notes. Indeed, it is the combination of concentration and oxidation that further enhances the flavor of meat as it continues to dry-age beyond the point at which enzymatic tenderization has come to a halt.

Both wet- and dry-aging also produce meat that, in general, is juicer than an equivalent cut of fresh meat. This is because the fragmented proteins that aging produces tend to improve the meat's ability to retain its natural juices during cooking.

Although beef that's been dry-aged for 40 days may be nirvana for some, attempting to get similar results for meats such as pork, which contain mostly unsaturated fat, would end in disaster. Seafood would fare even worse. Oxidation of unsaturated fat tends to produce rancid odors very quickly. In these cases, if aging is done at all, we recommend wet-aging as the better approach.

Contrary to what is often thought, aging meat does little, if anything, to tenderize tough connective tissue. That requires prolonged moist cooking or reaction with tenderizing marinades.

Bacterial growth on the surface of dry-aging meat also contributes something to its unique flavor. In the extreme, wild game birds are sometimes aged for a few days with their entrails left intact. The rampant bacterial growth occurring inside the carcass contributes a flavor to the meat that is described by some as "high" and by others as "foul."

Aged beef was the norm back in the 1920s and 1930s—so much so that Westinghouse developed what it called the Tenderay process, which dry-aged meat at temperatures up to 27 °C / 81 °F. This sped the time of aging from weeks to days. The key insight that allowed this time savings was the realization that harmful bacteria are killed when meat is bathed in rays of germicidal ultraviolet light. The tactic worked, but the demand for dry-aged meat slowed before the Tenderay process was widely adopted.

HOW TO Dry-Age Meat

Dry-aged meat has a wonderful, nutty aroma and is rightly praised for its superior tenderness, juiciness, and full flavor. Enzymes present in the muscle fibers deserve much of the credit: they break down proteins in the muscle tissue, making the meat more tender and capable of holding on to its natural juiciness during cooking. And these fragments can be especially flavorful and delicious.

Unlike the more common approach of wet-aging vacuum-packed meat, dry-aging evaporates water from the flesh and thus concentrates these flavorful molecules. But what sets dry-aged meat apart is the aroma, a result of slow oxidation of fat and fat-like molecules in the meat—something that simply cannot be replicated when it is sealed inside a bag. Dry-aging is, unfortunately, something of a rarity today. The amount of time, labor, and refrigerator space required to dry-age meat has caused most butchers and supermarkets to abandon the practice. The few that still go to the trouble charge accordingly. But you can dry-age your own meat by following these steps.

1 **Select a large cut of meat.** Large primal cuts of tender muscles work best because the yield after trimming is higher and because tender cuts benefit most from dry-aging.

2 **Elevate the meat on a rack with a drip tray beneath and plenty of air circulation.** Unrestricted airflow on all sides of the muscle is essential.

3 **Chill to 3–5 °C / 37–41 °F, keeping the relative humidity high (ideally 70%–80%).** To increase the humidity of your refrigerator, you can add a shallow layer of water to the drip pan beneath the meat.

4 **Leave the meat to age.** For beef, we recommend at least 18 days, although ideally you should do it for 30–45 days. Meat from smaller red meat-bearing animals needs less time. Likewise, pork, rabbit, and other white meats age very quickly and generally do not benefit from prolonged aging. Wet-aging is usually a better choice for aging these meats to prevent them from quickly going rancid.

5 **Trim away the dry crust and bone.** The aged meat can be portioned, vacuum-packed, and kept refrigerated or frozen until needed.

Starting cut

After 15 days

THE CHEMISTRY OF

Kæstur Hákarl, aka Rotten Shark Meat

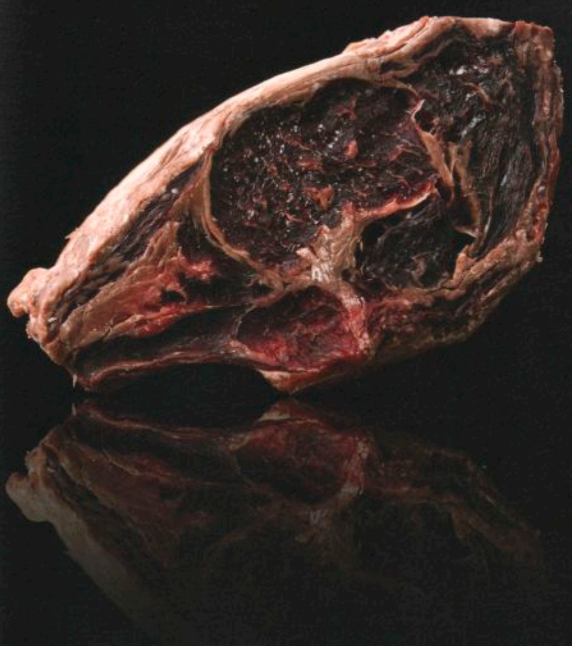
The large-bodied Greenland shark is native to the coastal waters of Greenland and Iceland. It leaves a lot to be desired as a food source: its flesh smells like urine and contains a large concentration of **trimethylamine oxide (TMAO)**, a potent neurotoxin that, if eaten, will leave you feeling staggeringly unwell. Equally unappealing is the uric acid that permeates the meat. Uric acid, you say? Yes, that's right. Sharks don't bother with a urinary tract; instead they expel this component of urine through their skin.

You might think that this would deter anyone from craving Greenland shark, but you would be wrong. Some rather desperate Icelander discovered that the flesh makes for a tasty snack if first left to rot. The recipe is easy: cut up a shark, bury it for a few months, dig it up, and hang it out to dry for several more months. The hanging slabs of shark take on an appealing mahogany hue as they dry. They look as though they have been smoked, but there is no smoke, nor any salting, marinating, or microbial fermentation. Just plenty of dry-aging, during which time enzymes in the flesh render the toxic compounds harmless.

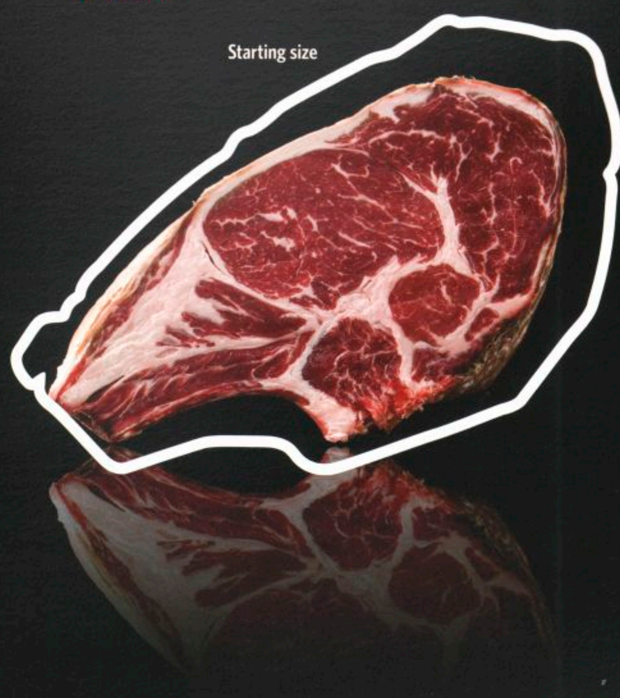
Once the shark meat is ready, the exterior is cut away and the interior white flesh is cut into cubes, packaged, and distributed to grocers and convenience stores across the island.

How does it taste? Not like chicken, although the texture is very firm, not slimy or mushy as you might expect. As you first begin chewing, it smells like earth and ocean. After a while, complex cheese-like aromas become noticeable, but eventually the smell of ammonia overwhelms all those unfamiliar with this Icelandic delicacy.

After 45 days



Trimmed



CUTTING

Butchering is the act of parting out the carcass of an animal, eventually yielding portions that are suitably sized for cooking and eating. To some people, the word "butcher" connotes a certain roughness to the process, as if the people who do it are sloppy in their approach or engage in the task with wild abandon. In fact, butchers are like surgeons. They have to be well schooled in anatomy, and they generally carry out their jobs with precision.

Butchers must also learn the standards of their profession as it is practiced in their particular region of the world because these traditions vary quite a bit from place to place, as Howard Swatland details in his excellent reference book, *Meat Cuts and Muscle Foods.* The English brisket cut in beef, for example, isn't found in Germany, where butchers divide this part of the steer into three different cuts: *brustbein, mittelbrust,* and *nachbrust* (breast point, central breast, and rear breast). So a cook who travels may have to do some homework to figure out the local butchering practices and naming conventions.

What is common to butchering all over the globe is that it begins with the separation of the carcass into what are called **primal cuts**, which correspond fairly closely to the units that a retail butcher might order from a wholesaler or slaughterhouse. The local butcher then breaks these cuts down into pieces that are small enough to be easily cooked and eaten. These cuts fall into three main categories: very tender ones that are intended for quick grilling, broiling, frying, or oven-roasting; medium-tender ones, which do better with slow, moist cooking; and tough cuts, which require lengthy braising, stewing, or pot-roasting.

The tenderloin, or filet mignon, of most quadrupedal animals is one cut that butchers everywhere remove as an intact muscle group because of its high value as a source of tender meat. But tougher muscles, like those of the shoulder or leg, have their attractions, too. In particular, they tend to have more fat (a biological necessity to keep these high-endurance muscles supplied with a long-term source of fuel), and fat enhances the taste of the meat. Tough muscles are also richer in the proteins that, as the meat ages, degrade into short, flavor-enhancing fragments. These include amino acids that boost the umami (savory) quality of the meat and add to the flavor by becoming potent Maillard aroma compounds during cooking (see The Maillard Reaction, page 89). Although they are more flavorful, cooking these tough cuts can be a challenge, as we describe later in this chapter in Cooking Meat and Seafood.

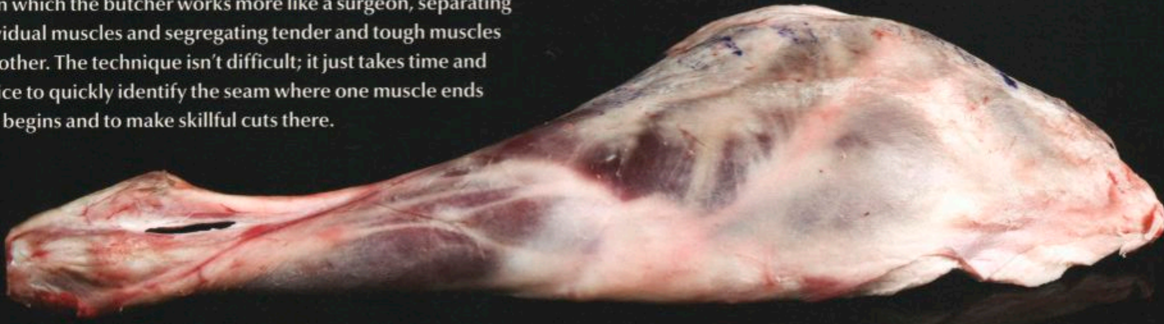
As a general rule, the smaller the animal, the smaller the number of primal cuts derived from it. So there are fewer primal cuts of veal than of beef, and fewer still of pork. Chickens and most other fowl are small enough that consumers can and often do buy them whole. When cooks quarter a chicken—splitting the bird in half through the spine and breastbone and then cutting each half in half, yielding a thigh and leg as one piece and a breast and wing as another—they are in essence breaking it into primal cuts. But chicken is rarely left quartered; more commonly, it is separated into leg, thigh, breast, and wing, all of which could also be considered primal cuts given the diminutive size of these animals.

Dutch butcher Wilhelm van Berkel invented a meat slicer with a spinning blade and an advancing carriage in Rotterdam in 1898. With it, he revolutionized the butcher's trade and created a company that manufactures rotary blade slicers to this day. You can find Berkel meat slicers at butcher shops and delicatessens throughout the world.

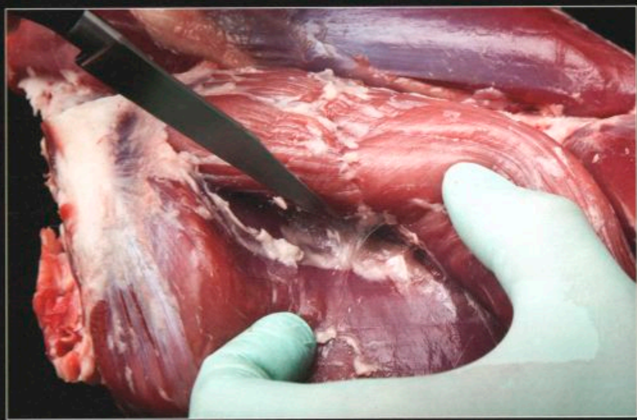
The major muscles in a leg of lamb are separated by seam cutting, a process we describe on the next page.

HOW TO Seam-Cut a Lamb Leg

Seam-cutting is a style of butchering, common in France and less so elsewhere, in which the butcher works more like a surgeon, separating out the individual muscles and segregating tender and tough muscles from one another. The technique isn't difficult; it just takes time and a little practice to quickly identify the seam where one muscle ends and another begins and to make skillful cuts there.



1 **Trim away any skin, membranes, and fat.** Once these are removed, the large muscle groups are easy to identify.



2 **Find a seam between two adjoining muscles.** Pull the muscles apart, and use the tip of a knife to cut through the connective tissue that binds them together. Avoid cutting into the muscles themselves.

3 **Lift the muscle free from the surrounding tissue.**

4 **Repeat until all of the muscles have been separated.** Use them individually, or reassemble them with Activa (see page 250). Some muscle clusters are so small that it is best to remove them as a single unit. These make excellent trim for stockmaking or forcemeats.

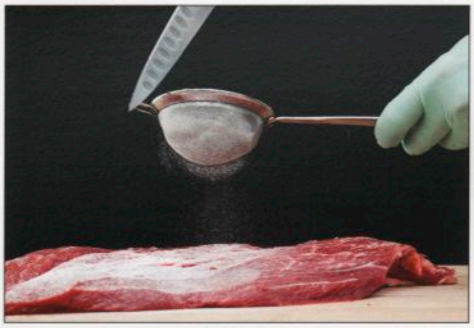
Seam Cutting

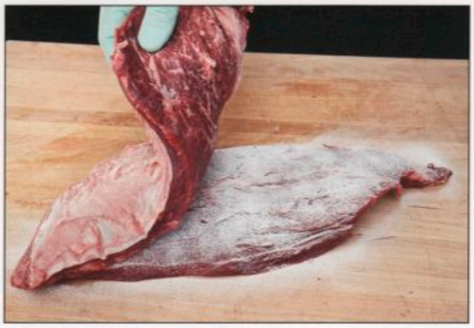
An interesting complement to standard butchery is a technique known as **seam cutting**, which is routinely practiced in France. Rather than just sawing across bone and muscle grain, French butchers and chefs often dissect sections of certain primal cuts to separate out muscles by size and function. This allows them to extract tender muscles from portions of the animal that mostly provide tough meat.

The flatiron steak, a recent American invention, is another example of this tactic. The muscle from which it is taken sits atop the cow's shoulder and runs across the back. It's a fine-grained muscle that doesn't exert much force when the animal is alive because a large tendon running through the middle carries most of the load. As a result, this muscle is not nearly as tough as other parts of the shoulder. The presence of the inedible tendon also makes it an inexpensive cut. So resourceful cooks will open the muscle, remove the tendon, and then sear the meat. Served rare to medium rare, it is both flavorful and reasonably tender.

Seam cutting takes a lot of time to perform but it is often well worth the additional effort, which is why it's practiced routinely in France. But it would be wrong to assume that France is the only place in the world this method is used. Japanese butchery technique (particularly for beef) is very much like extreme seam cutting. In Japan, butchers completely remove all bones and almost everything else that is not fat or muscle, including lymph nodes, sinews, skin, head-supporting ligaments, and so on.

Japanese beef is renowned for being extremely rich in fat, with major seams of fat found between muscles. Japanese butchers normally excise this intermuscular fat, leaving only highly marbled meat. They slice the beef very thinly for dishes such as shabu-shabu or sukiyaki, in which the slices of beef are cooked rapidly at the dinner table in a lightly spiced, simmering broth.





Sometimes the best way to deal with tough meat is to perform surgery. The popular flatiron steak, for example, is inexpensive because the cut contains a large tendon running through the middle of fine-grained muscle. You can open the muscle, cut the tendon out, and then use the two halves. Quickly seared and served rare to medium rare, they are flavorful and somewhat tender. A better approach is to cook the seam-cut steaks sous vide for 24–36 h at 55 °C / 130 °F (see page 109).

You can also reassemble the steak after cutting out the tendon by dusting the interior surfaces with Activa powder, which will glue the two portions together as if they were one piece of meat without the annoying tendon in the middle. For more on Activa, see page 250.

Slicing

Butchering transforms an animal carcass into pieces of meat of a size that is easy to handle, and in many cases this is all the preparation that's necessary before cooking. But there are times when you will want to do other things to a piece of

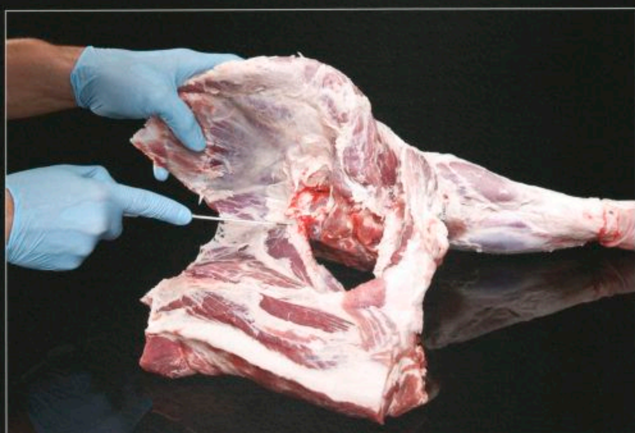
HOW TO Dissect a Pork Shoulder

The dissection of a pork shoulder involves the same technique used when seam-cutting a leg of lamb, but the shoulder is especially intricate. There are more tough, coarse-grained muscles intermingled with fine-grained, darker tender muscles. We learned about one special, and often overlooked, muscle from the London-based Irish butcher Jack O'Shea. Deep in the shoulder there is a large, flat muscle with three veins of connective tissue running partway through. If you use your knife to cut out these strips of connective tissue, you will get a cut that resembles a baseball mitt. The "fingers" yield four nicely shaped, tender blocks of meat that can be seared like a strip loin and sliced thinly. The same procedure also works on beef shoulders, which are much larger. The "baseball glove" cut is visible to the left of center in the last photo in this sequence. It makes a great steak.

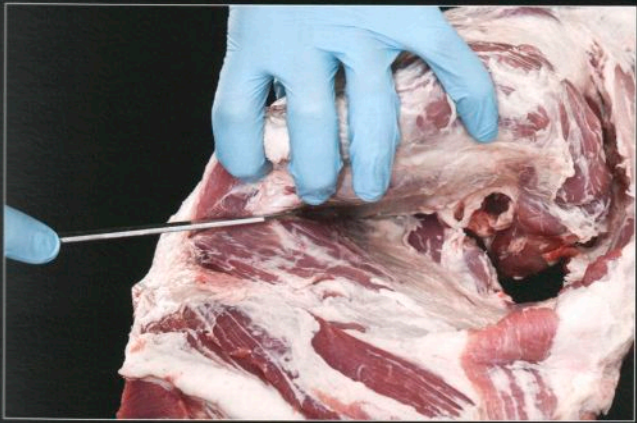
1 **Lay the leg and shoulder skin side down on a cutting board.** Use the tip of the knife to remove the scapula and remaining vertebrae.

2 **Flip the leg over, and cut away the skin.** Reserve the skin for crackling or another purpose.

3 **Save the bones for stockmaking.**



4 **Divide the shoulder (Boston butt) from the forelimb (picnic ham).** Let the knife follow the muscle seam that runs between them.



5 Pull apart the muscles while using the tip of the knife to cut through the membranes. Avoid cutting into the actual muscle tissue. Pull the pieces free, and trim off unwanted parts.

6 Find another muscle seam, and repeat the pulling, cutting, and trimming until all of the muscles are removed and separated. In the shoulder, look for a flat, oval piece with three veins of connective tissue. This is the "baseball glove" cut.

For more on sausage making, see page 234. For more on crackling, see page 126. For more on making stock, see page 2·296.

Divide the pieces into tender cuts and tough cuts. In general, fine-grained, darker muscles will be relatively tender, while coarse, lighter-colored muscles ① will be tougher. Reserve the trotters ② for braising or pickling, the skin ③ for crackling, and the meaty bones ④ for stock. Grind any trim ⑤ for sausage. The "baseball glove" ⑥ is an underutilized tender cut.

Pounding meat is a time-honored way to tenderize by rupturing connective tissue and muscle fibers. Vacuum-packing the meat before pounding is less messy and more hygienic.

meat before cooking it. The simplest mechanical restructuring of meat is to slice it thinly. Doing so makes chewy roast beef, ham, and other meats tender enough to put in a sandwich. This might seem a trivial accomplishment, but the tenderness requirements for sandwiches are in fact quite extreme: if the meat is any tougher than the bread around it, the meat tends to pull out of the sandwich when you take a bite. Paper-thin slices of roast beef or ham that are cut perpendicular to the grain of the meat have very little bite resistance, and thus, a stack of them make a very good sandwich filling.

In general, cutting meat across the grain produces enormously more tender slices than what you'd get by cutting with the grain. Indeed, the bite forces required to tear apart meat cut with the grain are 10-fold higher than they are for meat cut across the grain. The effect can be even greater for meats that have a lot of texture, such as beef flank steak.

Most people who are carving or cutting a roast try to exploit this phenomenon by always cutting across the grain. In some cases, however, the presence of bones creates an obstacle. Tradition also matters. Italian *prosciutto di Parma* is normally cut across the grain, whereas Spanish *jamón ibérico* is typically cut parallel to the bone and with the grain, making it much tougher. But don't try to tell a Spanish butcher that he's cutting it wrong. The chewy nature of with-the-grain slicing is valued in Spain, even if the opposite preference prevails in Italy or at your corner deli.

The best way to get very thin slices is to use a meat slicer with a sharp spinning blade and an advancing carriage. Such machines are found in butcher shops and deli counters throughout the world. They work best when the meat is cold, with the bulk of it held tightly in plastic wrap or, even better, in heat-shrink sous vide bags that are peeled back as the meat is sliced.

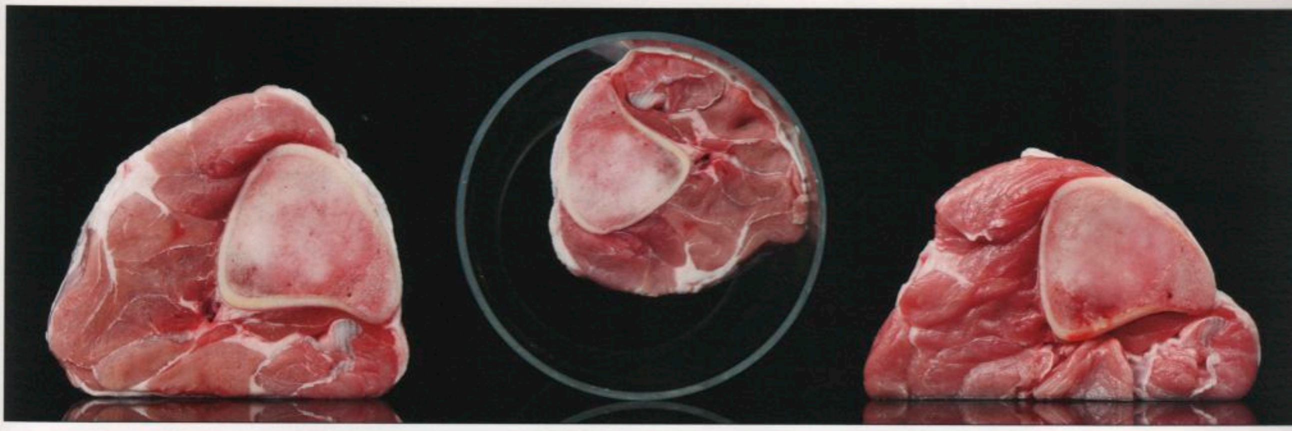
Raw meat is harder to slice than cooked meat because it is softer and more likely to deform or tear. If you need very thin slices of raw meat, as required for carpaccio or Japanese dishes like sukiyaki or shabu-shabu, it is even more important to slice them very cold, just as pathologists working with tissue samples often do. If you cool the meat to −1.5 °C / 29 °F, some of the water in it freezes, thus stiffening the meat and making it easier to slice. But enough water remains unfrozen that you can still cut through it without difficulty. If the temperature drops even a degree or two lower, however, the meat will become too hard for the slicing blade to cut through easily.

The best way to handle very thin slices of meat is to let them fall from the slicer onto sheets of waxed paper because the paper has more tensile strength than the thin slices of meat do. Handling the paper thus lets you move the meat slices around with less risk of tearing them.

Pounding, Tumbling, and Poking

There are many other mechanical means of tenderizing meat besides slicing, such as pounding and puncturing. In Greece and other parts of the Mediterranean, octopus is traditionally tenderized by whacking it, and then hanging it out in the sun on clotheslines to dry partially. The drawback to pounding is that it produces deformation. You end up with thin pieces of meat that have had their natural appearance dramatically altered—and not usually for the better (although a pounded-flat escalope of veal or pork loin is a must for a proper schnitzel).

Another way to tenderize meat mechanically is to put it in a tumbler. The tumbling action loosens



and tears the collagen sheathing around muscle fibers, making the meat more tender to eat and improving its ability to hold its juices during cooking. Its appearance can suffer, however, so consider this when choosing meats to be tumble-tenderized. Our favorites for tumble tenderization are braising cuts like shoulder, leg, or shank meat. Typically, tumbling is done under vacuum with the meat immersed in a brine, cure, or marinade, as discussed on page 170.

Of all the means of mechanical meat tenderization, the Jaccard tool is most discrete. The Jaccard tenderizer contains a set of small blades (each about 2 mm / 1⁄16 in wide) that are poked through meat in a regular pattern. The common handheld Jaccard has 48 such blades, but models with several hundred blades are also available for high-volume operations. The slender blades cut through the meat fibers but leave the basic structure of the meat intact. Indeed, it is very difficult to see—or even to feel—the Jaccard blade cuts on a piece of raw meat. Only when the blades penetrate covering fat will you sometimes notice puncture wounds as telltale signs.

A Jaccard can be used on nearly any piece of meat, although caution is needed on cuts containing bones, which will block or even break the fine blades. After cooking the meat, you will find its having been run through a Jaccard virtually impossible to detect—until you bite into it. By cutting some but not all of the muscle fibers, the Jaccard makes the meat much more tender, while still preserving its basic texture and mouthfeel.

But won't poking your meat full of holes let the juices leak out? Surprisingly enough, using the Jaccard will make the meat juicier! Tenderized this way, meat often retains 5%–15% more of its moisture content during cooking than does non-tenderized meat cooked to the same degree. The hotter the cooking temperature, the bigger the difference in weight—a proxy for moisture content—between the two.

This result doesn't at all match what your intuition might suggest would happen when you perforate a piece of meat. Indeed, it was so puzzling to us that we repeated our experiment several times to convince ourselves of the result. Again and again, we got the same outcome: using a Jaccard does indeed help meat to retain its juices.

One reason is that the blades of the Jaccard tend to break many of the collagen fibers in the meat. Collagen shrinks when meat is cooked, squeezing out juices (see illustration on page 80). So breaking collagen fibers with the Jaccard reduces the amount of contraction that takes place in the muscle during cooking. Some contraction still occurs, but the weakened fibers can't wring out as much juice.

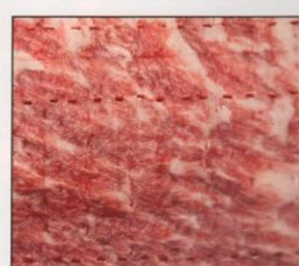
The second and possibly the more important effect at work is the leakage of myosin out of muscle cells through the many slender cuts. Thus freed, the myosin can bind and thicken juices that would otherwise escape from the meat when the cut is cooked.

Extra vigilance regarding food safety is called for when Jaccarding meat. By puncturing the meat, you are allowing any surface contamination to enter the muscle tissues, which slightly increases the risk of foodborne illness. Proper adherence to safe cooking times and temperatures—as covered in chapter 3 on Food Safety, page 1·162—will, however, mitigate this risk.

Tumbling is another traditional approach for tenderizing tough cuts of meat by weakening and tearing connective tissue and muscle fibers. This versatile technique also aids the penetration of brines, cures, and marinades, as well as in the preparation of sausage (see page 166).

Searing meat with a torch or in a hot pan (see page 2·267) before Jaccarding helps prevent external contamination from getting into the meat. For more on the special safety considerations involved in puncturing meat, see page 1·176.

Jaccarding, sometimes called blade-tenderizing, is a powerful and discrete way to make meat especially tender and juicy.



Cutting Seafood

Fish are usually sold whole, and some smaller fish are even cooked this way. Or before sale, the fish may be eviscerated and scaled and have its head, tail, and fins removed. The flesh of a small roundfish is often cut into just two fillets, and flatfish of similar size are separated into four fillets because the relatively uniform musculature of fish readily allows this simple partitioning. Larger fish fillets can be subdivided into belly (lower) and loin (upper) cuts or split into portion-size strips or blocks. Occasionally fishmongers take both left and right fillets off the bone and leave the belly skin intact, creating what's called a butterfly fillet: two fillets held together by the belly skin. Big fish can simply be crosscut into steaks, such as the ever-popular salmon steak.

But very large and expensive fish, as well as certain other creatures of the sea, require a more strategic deconstruction. The best practices can be seen in Asia, most notably in Japan, where you can find quite elaborate and nuanced methods for the butchery of fish. There a tuna, for example, is broken down into rectangular blocks for sushi and triangular and wedge-shaped pieces for sashimi, while the head, collar, and tail are reserved for traditional braised dishes. Every last bit of meat can be scraped away from the bones for tartare-like presentations, and for true aficionados, the marrow is removed from the spine. This might seem extreme until you consider how highly these fish are valued in Japan: one 232 kg / 511 lb tuna recently fetched $175,000 at a Tokyo auction.

For more on preparing squid, abalone, and sushi, see the step-by-step procedures on pages 56, 58, and 60.

With so much at stake, it's easy to understand why Japanese chefs put considerable effort into dividing up the flesh of a tuna, a skill that takes a great deal of practice to acquire. If you'd like to give it a try, see How to Block Tuna, page 54. Sushi chefs are experts in specific ways to slice each "block" of tuna—or any other seafood for that matter—to create the right texture. Each type of fish flesh has its own grain pattern and level of toughness, so sushi chefs have developed slicing techniques specific to each fish they use for sushi and sashimi.

Japanese chefs also use elaborate knife cuts on some tougher sea creatures, such as cuttlefish and abalone. In preparing those invertebrates for the table, you must remove their membrane, which is rich in incredibly tough **elastin.** Often it is also necessary to pry out parts made from inedible cartilage. And an understanding of how to use a knife to slice the flesh thinly, or to score that flesh in order to create weak spots in the collagen, will help you to create tissue that is more tender and easier for your guests' teeth to chew apart. Depending on the thickness of the slices and how you score them, the texture can be made hard and crunchy, firm and chewy, or firm but yielding.

The preparation of other sea creatures requires a less nuanced approach. Scallops, for example, are simply "shucked": usually only the abductor muscle, which pulls the shell together, is kept, while everything else is discarded. Other bivalves, like oysters, mussels, and clams, are left as is. And crustaceans are frequently sold whole (and alive), although they are sometimes cut up and sold as tails, claws, legs, or "picked" flesh that has been removed from the shell. These parts are commonly cooked and then frozen for distribution.

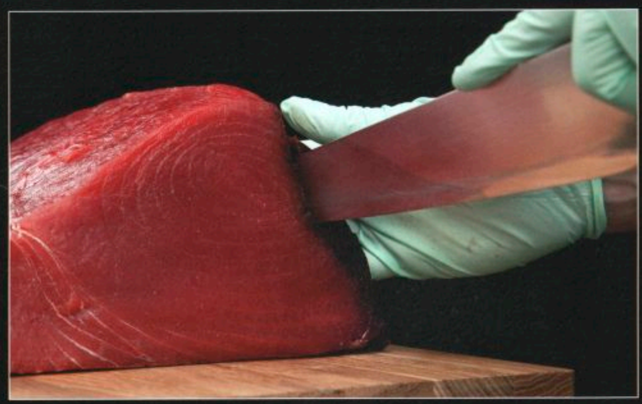
Expert butchers at Tokyo's famous Tsukiji fish market use a samurai sword-like knife, called an oroshi hocho, to carefully fillet a whole tuna, which may cost as much as a car—or even a house.

A painstakingly skinned monkfish fully reveals a musculature that is uniform, unlike that in meat. This uniformity permits simple partitioning of the fish's flesh.

HOW TO Block Tuna

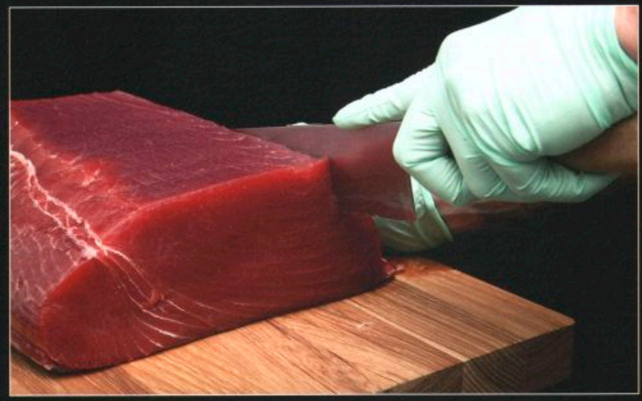
In Japan, where fish are revered, refined butchery techniques for seafood have evolved that maximize the potential of every part of the animal. To illustrate the potential of fish butchery, Kyle Connaughton, a former head development chef at The Fat Duck who also spent years in highly respected kitchens in Japan, demonstrates below how a skilled chef in Japan would begin blocking a tuna. Each white line on the fish in the images represents a sheet of connective tissue dividing one muscle from the other, while each ring of flesh is an individual muscle seen in cross-section. The dark "bloodline" visible on the side, despite its name, contains no blood. Its highly aerobic muscle fibers contain huge amounts of iron-bearing myoglobin, lending it a dark color and a slightly metallic taste. In Western kitchens, chefs often simply skin the fish, trim out the bloodline, and then cut steaks to sear or grill. Not so in Japan, where the key to refined butchery is to cut each piece for its best use, whether that use be nigiri-zushi, sashimi, rolled sushi, or tartare.

Moreover, nothing is wasted. Every piece of fish has a given purpose: the collar and head are commonly set aside for braising, and even the bone marrow from the spinal column is considered a delicacy.



1 **Remove the bloodline.** The knife should make a drawing stroke while also exerting downward pressure. Use this strong-flavored flesh for tartare or other preparations in which aggressive flavors are appreciated.

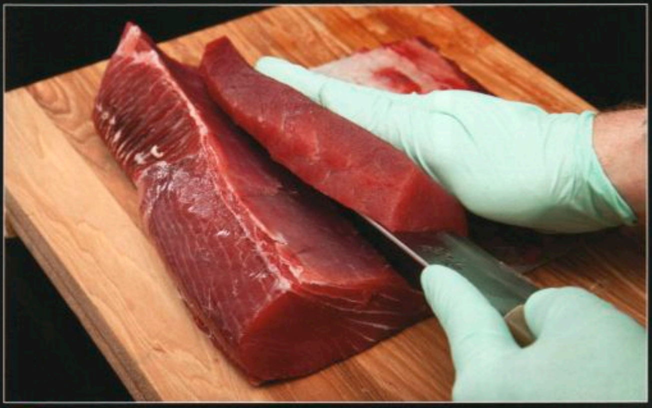
2 **Square off the top.** Removing the triangular piece on top is necessary to create a rectangular shape for slicing nigiri-zushi. Connaughton measures four finger widths, the ideal for a nigiri block, to locate the best spot to cut. Reserve the top piece for searing (tataki), sashimi, or maki-zushi preparations.



3 **Square off the right edge.** This requires removing the sheath of connective tissue that was adjacent to the bloodline.

4 Cut the first block. Measure one thumb width, and draw the knife along the flesh. This piece is best for tataki, maki-zushi, or tartare.

5 Repeat. The next three blocks, from the core of loin, are considered ideal for sashimi or nigiri-zushi. Stop when the remaining fish can no longer be sliced into even rectangles.



6 Remove the narrow triangular block along the connective sheath. This piece can be used for scraping maki-zushi, tataki, or tartare. Note how the knife scoops as it draws back, rather than making a straight cut. This maximizes the yield of meat.

7 Cut away the skin. The last triangular piece is ideal for maki rolls, which do not require geometric perfection. It can also be used for tataki or tartare.

Demand for fish trickles down from the top. Overfishing, declining stocks, increasing pollution, and ineffective government regulations have reached such an alarming state that forward-thinking chefs feel a responsibility to channel their demand. With a little exploration, it's possible to find responsible choices that are just as delicious as old menu standards, educating diners without compromising enjoyment of their meals. As bluefin tuna stocks are collapsing, for instance, we instead opt for U.S. Atlantic bigeye tuna, a recommended choice of the Monterey Bay Aquarium's respected Seafood Watch program (www.seafoodwatch.org).

HOW TO Prepare Tender Squid

The same anatomy that makes cephalopods capable of astonishing feats of muscular movement also makes them a challenge to cook. Their muscle fibers are reinforced by a sheath of collagen fibers that shrinks when cooked, toughening the meat. Desirable textures come either from charring the meat so briefly that the collagen does not shrink or from cooking it for so long that the collagen melts. There is no middle ground.

Cuttlefish, abalones, conchs, and their kin also feature unusual cross-layered muscle fibers and pigment molecules. This clever construction lets them shimmer and change colors. The long muscle fibers running in different directions also lend tremendous structural strength. There is no way to cut against the grain in order to create shorter fibers and more tender cuts, as you can in the flesh of mammals.

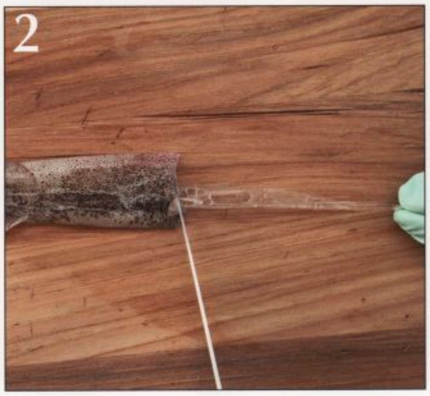
Some cultures have traditions of beating the creatures to loosen and tear the collagen sheaths; these practices vary from bashing conchs with coconuts in the Caribbean and against sea rocks in the Mediterranean to scrubbing octopuses in ribbed ceramic mortars in Japan. A more elegant solution is to use skilled butchery to engineer the texture, creating weak spots that allow teeth to fragment the muscle fibers more easily. Scoring the flesh with a knife creates these lines of weakness.

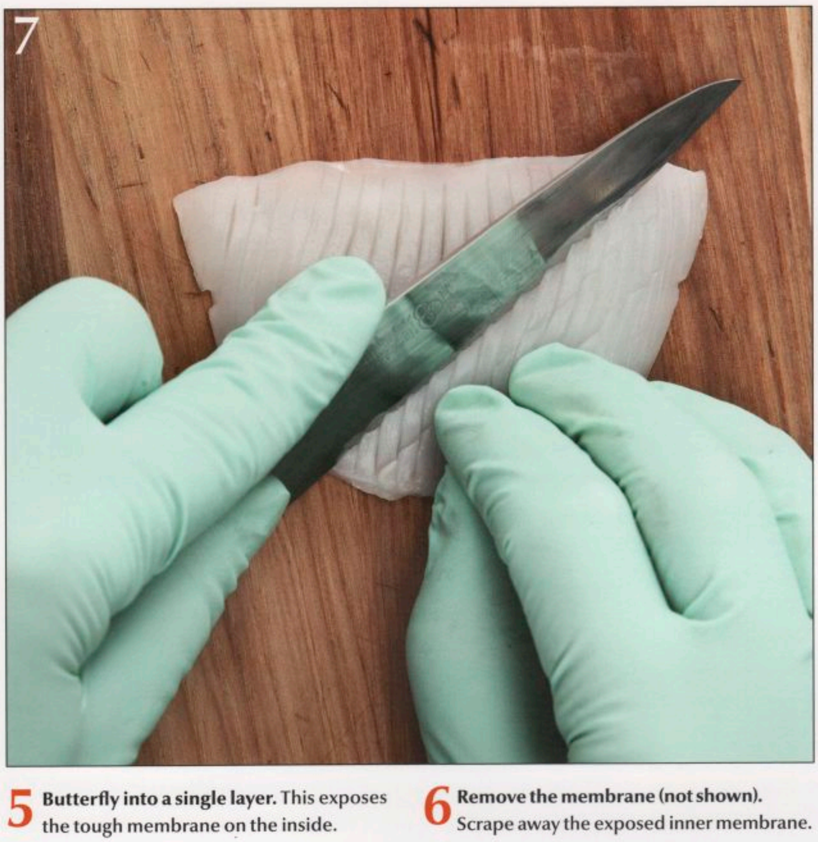
1 **Remove the entrails and head (not shown).**

2 **Remove the beak.** Use a knife tip to hold the mantle steady while pulling away this rigid piece of cartilage.

3 **Peel away the tough outer membrane (not shown).** The edge of the knife is best for pulling it off.

4 **Peel away the fine membrane underneath (not shown).**





5 **Butterfly into a single layer.** This exposes the tough membrane on the inside.

6 **Remove the membrane (not shown).** Scrape away the exposed inner membrane.

7 **Score the meat.** Cut a crosshatch pattern most of the way through the flesh.

HOW TO Fillet a Flatfish

Although fundamental, the technique of breaking down a flatfish can be intimidating to the inexperienced cook. The fish should yield four evenly sized fillets and a clean skeletal frame for making stocks. (Fluke and flounder frames make especially clean, light fish stocks.) Using a knife with a narrow, flexible blade makes the job easier. The same technique can be used for virtually any flatfish, from sole to turbot.

1 **Carefully remove the head.** Follow the shape of the gill flap, and cut through the spine.

2 **Clean thoroughly (not shown).** Remove the entrails and clean the body cavity, taking care to fully rinse the bloodline.

3 **Cut off the tail.**

4 **Cut the upper fillets.** Slice into the fish along the backbone, using a long cutting stroke and being careful not to cut through any of the bones.

5 **Remove the fillet.** Run the blade of the knife carefully underneath the fillet, with the blade flat against the skeleton, using long slicing strokes from head to tail until the fillet can be lifted away. Repeat with the remaining fillets.

6 **Trim and skin the fillets if desired.**

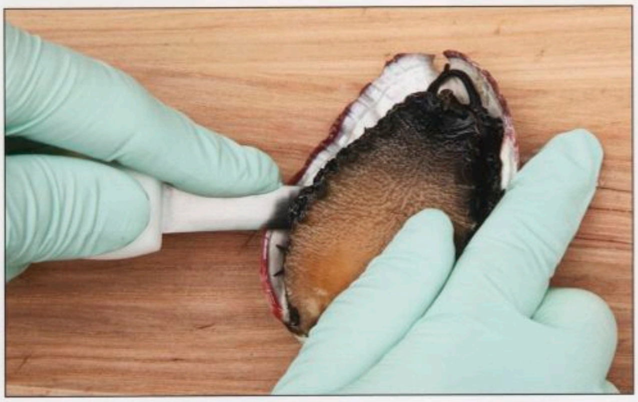
HOW TO Prepare Abalone

Abalone, a delicacy far more common in Asian kitchens than in American ones, can be presented as either a slippery, crunchy dish or a chewy, tender one. It all depends on how you prepare it and, more important, how you slice it. The abalone foot is tough and unyielding by nature because the creature uses that part of its body to bind itself to rocks.

To release the foot from the shell, it's useful to flash-steam the abalone, which not only kills the creature but also denatures the proteins that bind the foot to the shell. You can control the texture by choosing how to cut the meat: the thinner the slices, the more tender the texture; the thicker the slices, the crunchier they will be. Be aware that abalone are filter feeders; use the same care as you would with oysters to avoid toxic harvests.

1 **Release the abalone from the shell.** Place the abalone shell-side down in a hot pan. Pour in hot water, which will flash to steam.

2 **Cover the pan for 30 s, and then remove the abalone from the pan.**



3 **Shuck the foot from the shell.**

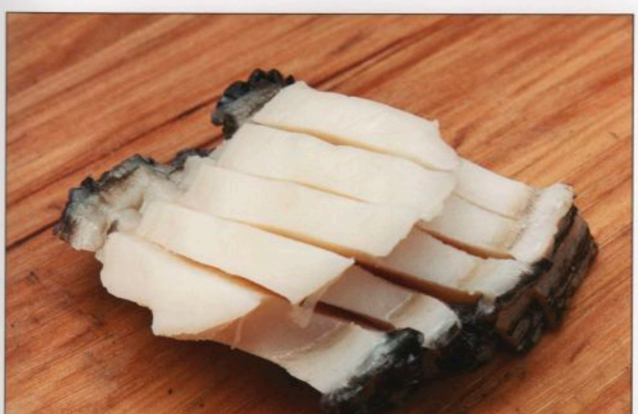
4 **Pull away the entrails with a knife.** Reserve the stomach; it can be fried, pureed, sieved, and used in a sauce.

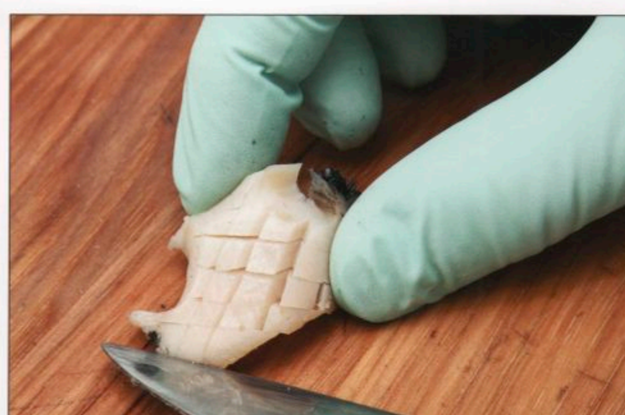
5 **Submerge in water for 30 min to remove any dirt and debris.**

Indigenous abalone on the Pacific coast of the U.S. have been depleted, but farmed abalone are abundant. We recommend Seafood Watch (seafoodwatch.org) to chefs and diners interested in making responsible choices.

6 **Scrub off dirt and debris.** Use a stiff brush to clean around the edges of the foot, and then rinse it carefully in water.

7 **Slice the meat to the desired thickness.** We recommend 5 mm / ¼ in thick; thicker slices will yield a crunchy texture, whereas thinner slices will be more tender.





8 **Cut a cross-hatch design in each slice (optional).** This will give the chewy meat places to fail when it is bitten, thus making it easier to eat.

HOW TO Slice Fish for Nigiri-zushi

The flat appearance of a rectangular slice of nigiri-zushi is an optical illusion. It's clear that the fish can't be truly flat when we consider that chefs pat sushi rice into a block that has a curved top. An evenly thick slice of sushi would create an unsightly bulge when draped over that curve. Instead, when drawing a knife over a block of fish to cut nigiri slices, the trick is to slice with an almost scooping motion as the blade is drawn back. This will create a slightly curved slice with a thinner middle that will lie evenly over the rice.

1 **Block the fish fillet, as shown on page 54.**

2 **Place the knife carefully so that the heel of the blade is not beyond the near edge of the fish fillet.**

3 **Start the slice with the knife at an angle of 20°–30° toward the bulk of the fillet.** Slice in a single smooth, long movement.

4 **While slicing the fish, roll your wrist in a controlled manner so that the knife straightens to vertical.** The finished slice will be thicker on the edges than in the center.

HOW TO Flash-Cook Sushi

Flash-cooking melds the texture and flavor of raw and cooked fish. A quick blast of intense heat cooks the surface and enhances the flavor—and for some people the appeal—of the flesh, while preserving the underlying moist and tender qualities of raw fish. Nobu Matsuhisa popularized this technique, calling it "new-style sashimi," as a way to convert guests who were uneasy with the thought of eating raw fish.

Although simple in concept, searing each slice without overcooking or undercooking the flesh can be difficult. To strike the balance between raw and cooked, the seafood should always be thinly sliced and chilled to just above the freezing point. The potent heat of hot oil, a blowtorch, or a broiler will flash-cook the surface and raise the temperature of the flesh from ice-cold to refreshingly cool.

1 **Arrange the slices so that they overlap slightly.**

2 **Heat neutral oil to just below its smoking point, and then carefully baste the fish slices with the oil until their surfaces blister slightly.**

VARIATION: Flash-Cooking with a Torch

2 **After arranging the slices as in step 1 above, use a blow torch to char the surface.** This approach works best for fish, such as tuna, that have a texture similar to red meat. To avoid tainting the fish with the taste of fuel, be sure that the blowtorch is burning cleanly, with only a blue flame, before searing the food.

VARIATION: Flash-Cooking with a Broiler

2 **After arranging the fish slices as in step 1 above, place the food under a broiler for about 60 s.** The radiant heat from the broiler flash-cooks delicate fish such as salmon quite well, but to get the best result, position the fish in the "sweet spot" where the heat is both intense and even. The exact location of this spot depends on your broiler—for instructions on how to find it, see page 2·18.

TARTARES AND RAW MEAT

Typically, tartares have been hand-chopped or mechanically ground. New tools expand the possibilities of texture and variety. For intriguing natural shards of fish or meat, fully freeze the food with liquid nitrogen, and then shatter it with a mallet or hammer. (Be sure to use the safe handling techniques described on page 2·464.) Then shape, thaw, and serve. This technique is especially good for fish fillets, scallops, and tender slices of meat like beef tenderloin. The cryogenic-freezing step has the added benefit of killing any potential parasites that fresh fish may harbor.

You can also create a tartare with a very unusual consistency by grinding the raw ingredient to a fine powder in a Pacojet (for more on this tool, see page 2·406). Pack the meat or seafood into the canister of a Pacojet along with some liquid to fill the spaces between pieces. Freeze it completely, and then Pacotize it to get a fine, frozen powder. To maintain the delicate texture, plate the semifrozen tartare immediately and dress it lightly rather than folding in the seasonings. Alternatively, season the meat boldly before packing, freezing, and Pacotizing it.

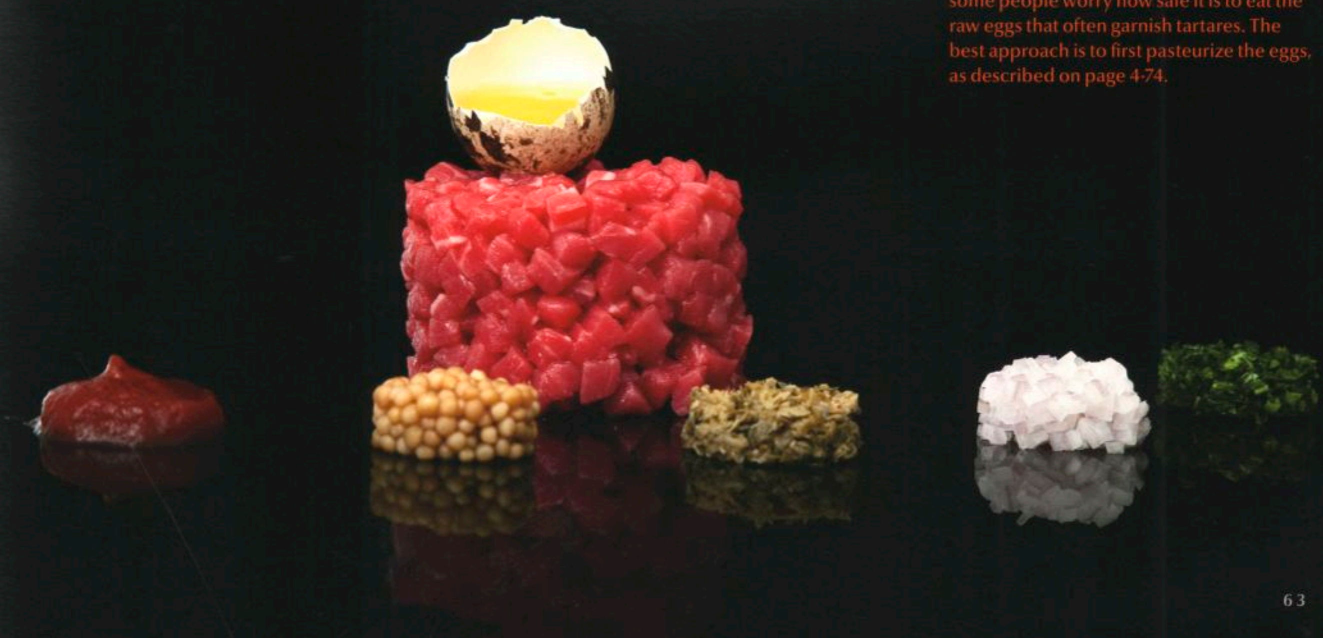
Rather than tenderizing flavorful but tough cuts of meat by grinding, try tenderizing them sous vide. Short ribs can be cooked slowly to dissolve the connective tissues while maintaining the raw, rare flavor. This meat can then be carefully diced for a more appealing texture and presentation.

Chopping with a knife by hand is a traditional way to make tartare. The Pacojet (see page 2·406) will grind meat to a frozen powder that, when thawed, makes a unique tartare.

Best Bets for Tartares

Meat	Recipe	Texture	Seasoning	Note
beef	traditional French steak tartare	coarse	raw shallot, raw egg yolk, ketchup, capers, parsley, mustard, Worcestershire, Tabasco sauce	the classic tartare
	Syrian kafta nayyeh	fine	mint, hot mustard, allspice, raw onion, olive oil	
	Ethiopian kitfo	fine	chili powder, niter kibbeh	traditionally served with injera or kocho
	Wylie Dufresne's hanger steak tartare	coarse	Béarnaise ice cream, scallion, pickled Asian pear, amaro	hanger steak is tenderized sous vide (see page 65)
lamb	Lebanese kibbeh	fine	bulgur wheat, raw garlic, cinnamon	young lamb is best
langoustine	Pierre Gagnaire's langoustine and poppy seed tartare	fine	green mango, thyme nougatine	use only extremely fresh langoustines
mackerel	horse mackerel (aji) tartare with ginger	moderately coarse	young ginger, shiso, sansho pepper	
musk ox	René Redzepi's musk ox tartare with oxalis and tarragon cream	fine paste	oxalis, juniper, tarragon	musk ox is dry-aged for 48 days
oyster	David Kinch's oyster and beef tartare	fine	mustard, horseradish, hot sauce	
salmon	salmon tartare with citrus	coarse	makrud lime, sesame oil, chili, yuzu	do not add citrus until just before serving; otherwise, it will cook surface of fish
scallop	Alain Passard's scallop and truffle tartare	small cubes	truffle, artichoke, hazelnut oil, lemon, tarragon	sear quickly over high heat before chopping to develop sweetness
	Heston Blumenthal's scallop and white chocolate tartare	fine	preserved lemon, white chocolate, caviar	
tuna belly	Nobu Matsuhisa's toro and caviar tartare	fine paste	soy sauce, caviar	
tuna loin	Hawaiian poke	medium cubes	ogo, candlenut, sweet onion, toasted-sesame oil	
venison	cured venison tartare with coffee	small cubes	blackberry, fennel, coffee, smoked salt	

In addition to worrying about raw meat, some people worry how safe it is to eat the raw eggs that often garnish tartares. The best approach is to first pasteurize the eggs, as described on page 4·74.



HOW TO Cryoshatter for Tartare

Cryogenic freezing makes meat so brittle it can be shattered like glass or ceramic. This creates shards of flesh and is a good choice for delicate meats.

1 **Freeze the flesh using liquid nitrogen.**

2 **Use a mallet to shatter the vitrified flesh.** This can be done with the frozen flesh sealed in a sous vide bag to keep the work area clean.

3 **Gather the frozen shards of flesh together and season them appropriately.**

4 **Fully thaw the cryoshattered flesh before serving.**

EXAMPLE RECIPE

HANGER STEAK TARTARE ADAPTED FROM WYLIE DUFRESNE

Yields 650 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Champagne vinegar	500 g	125%	① Combine, and reduce until syrupy.
White wine	400 g	100%	② Strain.
Shallots, diced	290 g	72.5%	③ Measure 45 g, and reserve.
Tarragon stems	five stems		
Water	260 g	65%	④ Combine in small pot.
Sugar	140 g	35%	⑤ Heat while whisking until sugar has dissolved completely.
Glucose	60 g	15%	⑥ Remove from heat, and cool syrup slightly.
Egg yolks	625 g	155%	⑦ Temper with warm syrup.
			⑧ Hand-blend.
Béarnaise reduction, from above	45 g	11.25%	⑨ Add to egg mixture, to taste.
			⑩ Blend mixture.
Salt	5 g	1.25%	⑪ Freeze in Pacojet containers, or churn in ice cream maker.
Hanger steak	400 g	100%	⑫ Vacuum seal, and cook sous vide in 50 °C / 122 °F bath for 3 h.
			⑬ Cool quickly in ice-water bath, and refrigerate.
Extra-virgin olive oil	6 g	1.5%	⑭ Sear one side of steak.
			⑮ Cool completely, and dice finely.
Salt	4 g	1%	⑯ Season steak tartare.
Tarragon, minced	3 g	0.8%	⑰ Pacotize ice cream, if using Pacojet.
Tabasco sauce	1.5 g	0.4%	⑱ Spoon steak onto plates, and garnish with spoonful of ice cream.
Black pepper	0.75 g	0.2%	

(original 2006)

EXAMPLE RECIPE

BEEF AND OYSTER TARTARE ADAPTED FROM DAVID KINCH

Yields 680 g (four to eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
American Wagyu beef bavette or rib eye	400 g	100%	① Trim off fat. ② Dice finely.
Pemaquid oysters	80 g	20%	③ Shuck, reserving juices. ④ Keep refrigerated.
Ketchup (Heinz brand)	60 g	15%	⑤ Combine. ⑥ Adjust ketchup mixture to taste.
Extra-virgin olive oil	40 g	10%	
Orleans mustard	18 g	4.5%	
Hot sauce (Crystal brand)	8 g	2%	
Worcestershire sauce	5 g	1.25%	
Lemon juice	3 g	0.75%	
Whipping cream	120 g	30%	⑦ Whip to stiff peaks. ⑧ Refrigerate.
Cream cheese (Philadelphia brand)	100 g	25%	⑨ Soften with paddle mixer until silky.
Horseradish root, finely grated	40 g	10%	⑩ Fold into cream cheese. ⑪ Fold cream cheese mixture carefully into cold whipped cream.
Rice vinegar	to taste		⑫ Season whipped horseradish cream carefully to taste; chill. ⑬ Mince raw oysters, and combine with reserved oyster juices. ⑭ Fold oysters into diced raw beef, and season with ketchup mixture as desired. ⑮ Place spoonful of beef and oyster tartare on each plate, and garnish with spoonful of horseradish cream.
Lime juice	to taste		
Salt	to taste		

(original 2000)

EXAMPLE RECIPE

SCALLOP TARTARE INSPIRED BY ALAIN PASSARD

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Mayonnaise (Kewpie or other good quality brand)	30 g	15%	① Whisk to form truffle mayonnaise.
Black truffle concentrate see page 2·427	20 g	10%	
Black truffle, minced	10 g	5%	
Lime juice	3 g	1.5%	
Roasted-hazelnut oil	3 g	1.5%	
Lime zest	1 g	0.5%	
Sea scallop (sushi quality), minced	200 g	100%	② Fold into truffle mayonnaise.
Fuji apple, peeled and minced	40 g	20%	
Chives, minced	0.75 g	0.4%	
Lime juice	to taste		③ Season scallop mixture generously.
Salt	to taste		④ Chill.
Brioche, frozen and sliced 2 mm / 1/16 in thick	10 g	5%	⑤ Dust brioche slices with powder.
Freeze-dried scallop powder see page 2·451	8 g	4%	
Clarified unsalted butter	25 g	12.5%	⑥ Panfry brioche until golden. ⑦ Drain on paper towels. ⑧ Cut into desired shapes.
Chive blossoms	as desired		⑨ Spoon scallop tartare into serving bowls. ⑩ Garnish with brioche and chive blossoms.

(published 1997, adapted 2010)

EXAMPLE RECIPE

SALMON TARTARE CORNETS ADAPTED FROM THOMAS KELLER

Yields 400 g (24 cornets)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the cornets:			
All-purpose flour	65 g	4.5%	① Combine and reserve.
Sugar	20 g	13.5%	
Salt	4 g	2.5%	
Unsalted butter, softened but still cool to touch	115 g	77%	② Whisk until completely smooth and texture resembles mayonnaise.
Egg whites, cold	90 g	60%	③ Beat egg whites into flour mixture until smooth.
			④ Whisk in softened butter by thirds until batter is creamy.
			⑤ Place circular stencil, 10 cm / 4 in. in diameter, on silicone mat.
			⑥ Spread some batter evenly inside stencil.
			⑦ Lift stencil off sheet, and repeat process to make 24 circles.
Black sesame seeds	20 g	13.5%	⑧ Sprinkle over each batter circle.
			⑨ Bake in 205 °C / 400 °F oven until batter is set and rippling, 4–6 min.
			⑩ Transfer sheet with circles to open oven door to keep warm.
			⑪ Flip one circle over, sesame seed side down; place an 11.5 cm / 4½ in cornet mold (size #35) at bottom of circle.
			⑫ If you are right-handed, place pointed end of mold to your left and open end to your right. Tip of mold should touch lower left edge of circle. Reverse if left-handed.
			⑬ Fold bottom of circle up and around mold.
			⑭ Roll carefully upward and to left to wrap circle tightly around mold. Leave circle wrapped around its mold.
			⑮ Repeat cornet molding process for remaining circles.
			⑯ Arrange cornets seam side down and leaning against each other.
			⑰ Bake in 205 °C / 400 °F oven until golden brown, another 3–4 min, to set seams.
			⑱ Take out of oven, and cool slightly for 30 s. Remove from molds.
			⑲ Store in airtight container for 48 h maximum.
For the salmon tartare:			
Salmon fillet, preferably belly	150 g	100%	⑳ Remove skin and pin bones.
			㉑ Mince finely.
Shallot, finely minced	7 g	4.5%	㉒ Add to minced salmon.
Chives, finely minced	5 g	3.5%	㉓ Fold in to combine.
Extra-virgin olive oil	2 g	1.5%	㉔ Adjust for seasoning, if necessary.
Kosher salt	2 g	1.5%	㉕ Cover salmon tartare, and refrigerate for at least 30 min.
Lemon zest	1.6 g	1%	
White pepper, freshly ground	to taste		
For the red-onion cream:			
Red onion, finely minced	9 g	6%	㉖ Rinse onion in strainer under cold water, and dry.
Crème fraîche	115 g	77%	㉗ Whisk until soft peaks form.
			㉘ Fold onions in.
Salt	to taste		㉙ Season.
White pepper, freshly ground	to taste		㉚ Transfer onion cream to pastry bag.
			㉛ Refrigerate for at least 1 h to firm up.
Chive tips, 2½ cm / 1 in long	24 tips		㉜ Pipe onion cream into each cornet.
			㉝ Spoon 3 g of salmon tartare over cream.
			㉞ Garnish with single chive tip.

(original 1990, published 1999)

11

This modern classic by chef Thomas Keller shows his characteristic sense of whimsy and humor which lightens what could otherwise be a very formal dining experience at his restaurants The French Laundry and Per Se. This mock ice cream cone of salmon is usually served as an amuse-bouche to start the meal off.

COOKING MEAT AND SEAFOOD

As a culinary phenomenon, cooking meat is easy to define. It is the process of changing the texture, juiciness, flavor, and appearance of meat by applying heat to raise its temperature. Yet the simplicity of that definition belies the fact that the actual chemical and physical changes are incredibly complicated—in some cases, they aren't even fully understood. Many transformations happen when we heat a piece of meat. Insights into the dynamics of those changes can give cooks the ability to get high-quality and repeatable results.

We have organized this topic by separately considering the four primary characteristics that concern us in cooked meat: tenderness, juiciness, flavor, and appearance. These factors are all interrelated, of course, but it is helpful to consider them independently.

Tenderness

Although there are many nuanced differences in mouthfeel between tender and tough meat, research has shown that the principal difference has to do with the peak force necessary to bite through a piece of meat.

Raw meat is soft but, with few exceptions, you wouldn't call it tender. Indeed, if you watch lions eating raw meat, it is striking how difficult it is for them to chew through it, despite their sharp teeth and powerful jaw muscles. That is why steak tartare and carpaccio are served chopped or sliced: the cutting does most of the hard work for us.

Meat is muscle, and the role of most muscles is to power the animal. That role requires strong tissue. So it should not be surprising that it takes force to bite through raw muscle. As explained earlier in this chapter, meat is a composite structure with many components, including fibers that contribute to both the strength and the toughness of raw muscle.

In this way, both muscle and meat are roughly analogous to man-made composites like reinforced concrete, fiberglass, or carbon-fiber composites. Concrete, for example, is strong in compression (that is, pushing together), but weak in tension (pulling apart). Embedding steel reinforcing bar, which has great tensile strength, makes concrete strong enough to use for myriad building purposes. Similarly, plastic resin by itself is not very resilient, but the addition of fibers made of glass or carbon makes it very strong.

There are many types of fibers in meat, but the two most important are the muscle fibers, which change length in order to make the muscle operate, and collagen fibers that run through the meat, reinforcing it much as fiberglass or carbon fiber reinforces composites.

The web of collagen fibers is our main adversary in the struggle to make meat tender. Biting into meat involves tearing the collagen sheaths that surround the bundles of muscle fibers, and then ripping the bundles apart. This is the job of chewing. The ease with which the collagen sheathing around the muscle fibers comes apart determines whether the meat will seem tender or tough while you are chewing it.

In fine-grained meats, the collagen mesh is so weak and thin that it easily becomes stretched beyond its breaking point and snaps. With more chewing, the fine bundles of muscle fibers readily fragment, maintaining that initial sensation of tenderness.

Coarse-grained meat responds quite differently to chewing. The collagen mesh that surrounds

Myosin and many of the other proteins in meat bind to each other as they are heated, forming a network of molecules that traps water. This is an example of a gel; gels are the subject of chapter 14, page 4·64. The fact that meat gels during cooking is critical to binding sausage, discussed in Restructuring, page 220. You can even extract enough myosin from meat or fish to make a soft gel with a flan-like texture—for a recipe, see page 4·119.

A superbly baked ham exemplifies the high-quality results cooks can get when they better understand the changes that occur in meat during cooking.

BOILING A STEAK FROM THE INSIDE OUT: THE BIG PICTURE

Intuition might suggest that when you throw a cold steak into a hot skillet, the heat will flow evenly and steadily from the pan through the meat and into the air, warming the food gradually until it is cooked all the way through. But that isn't what happens at all. Instead, the surface of the steak cooks unevenly and much faster than the interior does. For cuts of beef thicker than about 2 cm / ¾ in, the upper surface will remain rare even after the steak has been frying for an hour on one side.

The main reason for this counterintuitive behavior is that meat is mostly water, and water absorbs a tremendous amount of heat energy as it boils into steam. The steam then both cools the pan as it condenses and insulates much of the meat from the heat. As a result, the temperature inside the steak falls off steeply with increasing distance from the pan, and the decrease follows a steep curve with three plateaus (see graph on next page), rather than a simple straight line.

For more on heat absorption during boiling, see page 1·260.

A steak frying in a 190 °C / 375 °F skillet takes much less time to progress from rare (left segment, below) to medium (center segment) than it does to go from medium to well done (right segment). Meat conducts heat so poorly that if a thick steak such as this one is not flipped, some of the top surface will remain raw even after nearly two hours of cooking.

Cooking vaporizes water inside the meat, causing the middle of the steak to swell. As the water boils off, the meat dries out and shrinks back down again.

In the crust, even the most desiccated part is still porous and allows moisture to escape from the meat. Searing meat thus does not seal in its juices.

15 °C / 60 °F
Meat surface is close to room temperature

50 °C / 120 °F
Muscle fibers contract, squeezing droplets of water from the meat

60 °C / 140 °F
Meat starts changing from red to pink

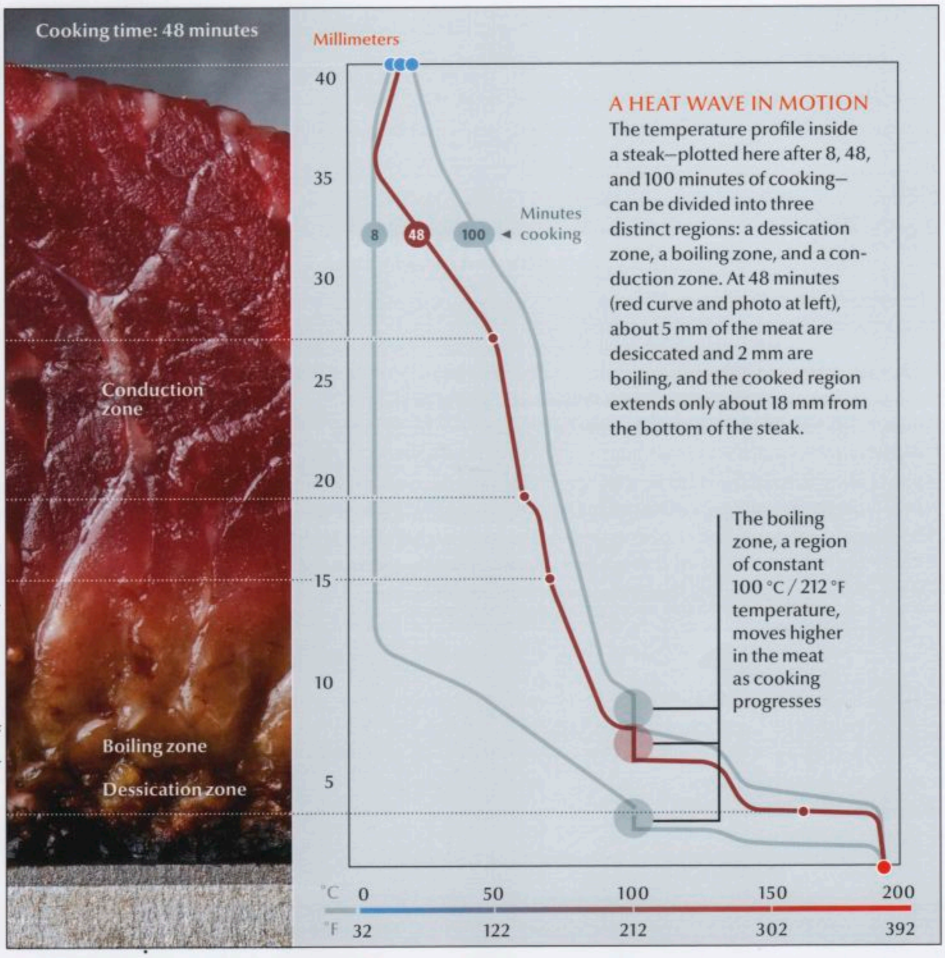
70 °C / 160 °F
Myoglobin pigment denatures, changing meat color to grayish brown

70–90 °C
160–195 °F

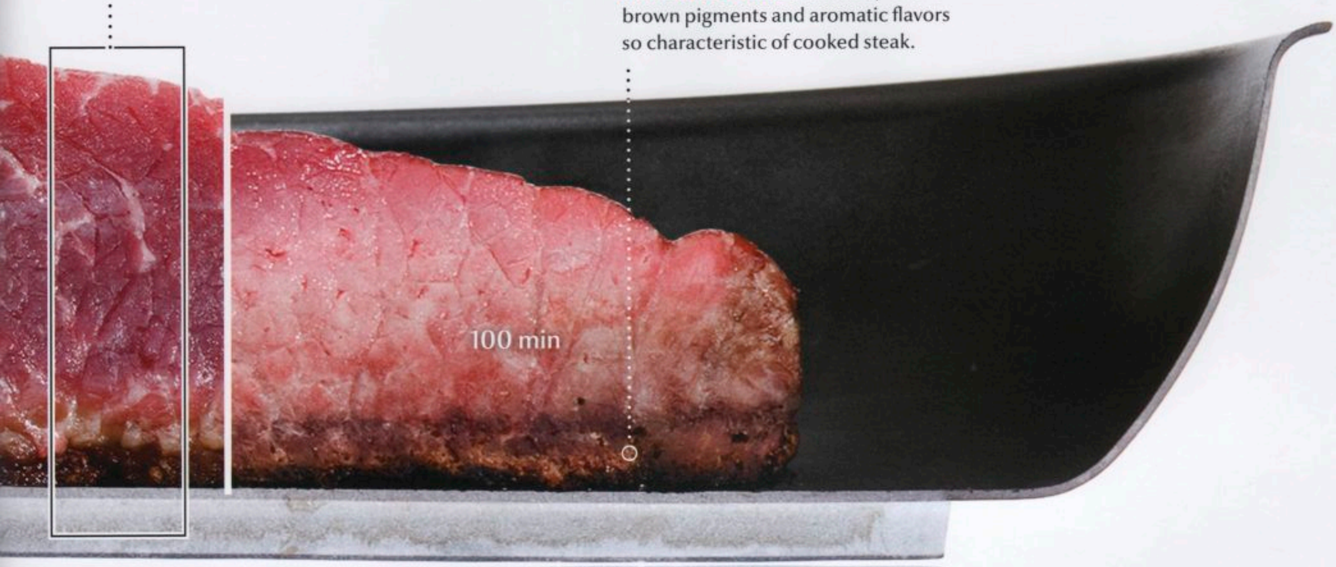
100 °C / 212 °F
Meat boils in its own juices

160+ °C / 320+ °F
Carbonization turns the meat black

190 °C / 375 °F
Pan temperature



Maillard reactions form many of the brown pigments and aromatic flavors so characteristic of cooked steak.



BOILING A STEAK FROM THE INSIDE OUT: A CLOSER LOOK

The strikingly nonlinear fashion in which heat moves from the pan through the steak reflects the variety of ways that heat interacts with the water and proteins in meat. Cooking occurs differently in each of the steak's distinct heating zones, from the hot, dehydrated crust at the lower surface of the meat (far left in the photo below) to the cooler, uncooked meat in the meat interior (far right).

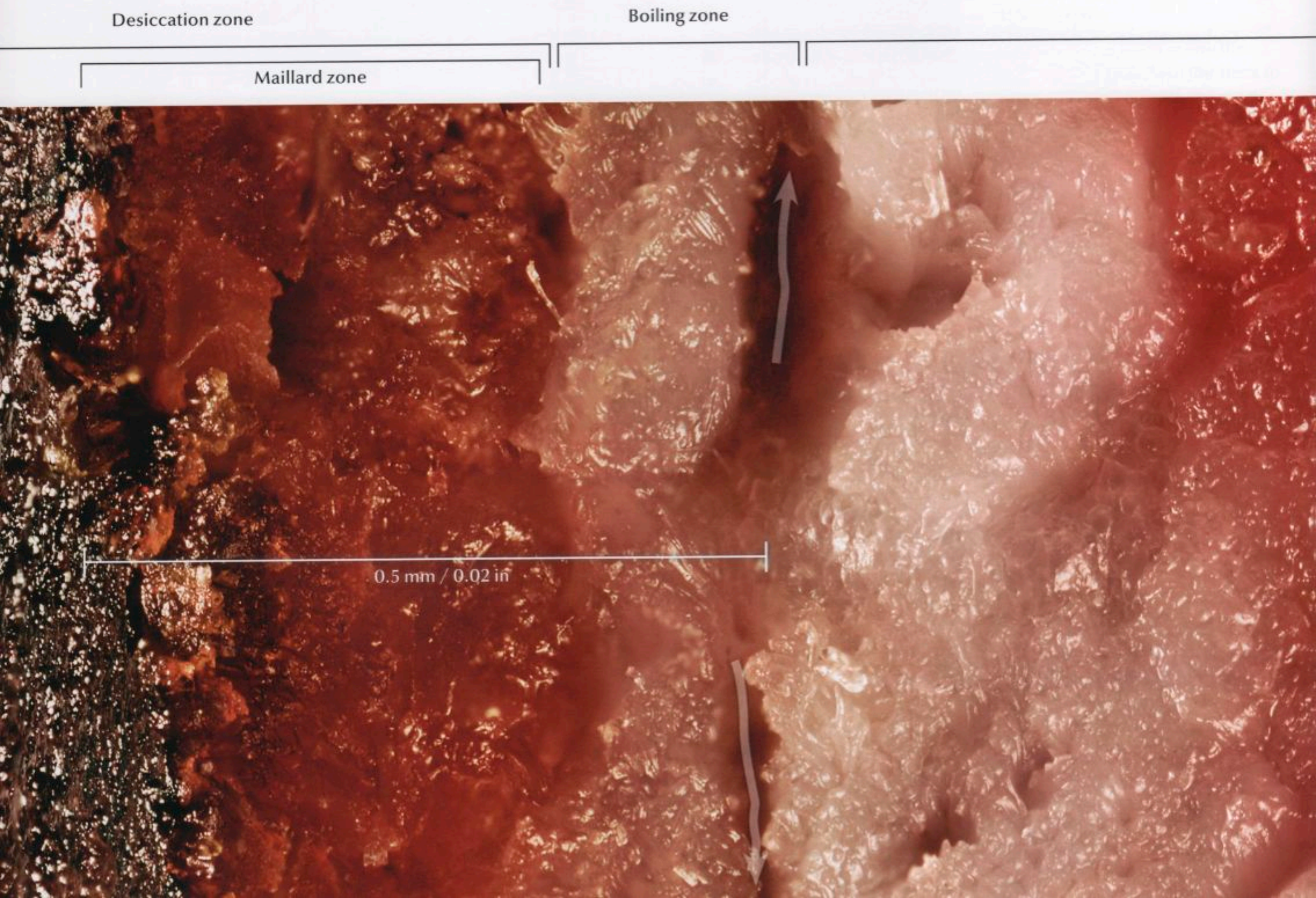
The dark tan color of the crust comes from brown pigments formed by the Maillard reaction, which in moist foods occurs rapidly at temperatures above 130 °C / 265 °F. Despite its solid appearance, the crust is actually a translucent gel.

Desiccation Zone

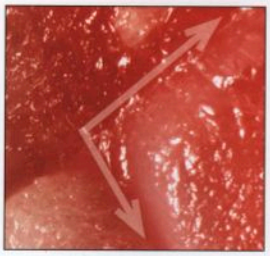
When you slap a steak into a hot pan, it sizzles with a puff of steam. The water in the lower surface of the meat quickly boils away, creating a dehydrated region in which the temperature rises quickly. The higher the heating power of the pan, the faster the temperature will rise and the crust will form. This desiccation zone grows slowly because so much energy is required to boil the juices that trickle through from above. The crust acts like thermal insulation, reducing the speed at which heat can move from the pan into the steak. At its upper boundary, the temperature drops suddenly.

Maillard Zone

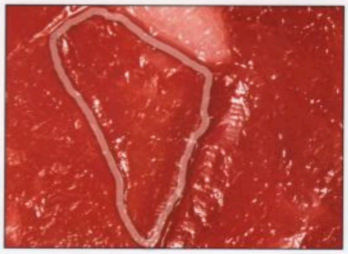
The Maillard reaction occurs only in a very thin region (about 0.5 mm / 1⁄64 in thick) where the temperature of the meat has been raised well above 130 °C / 265 °F. The reaction creates aromatic flavors and brown colors in the crust. Steam moving downward breaks through the crust and into the pan. The force of the steam is so strong that it actually lifts the meat slightly as the vapor escapes at the edges of the steak. Steam also forces its way upward, diffusing into the meat above the boiling zone and thereby heating it and advancing the boiling zone farther toward the upper surface. Much of the heat energy flowing through the pan is devoted to the work of boiling the water inside the meat. The greater the power (measured in watts or BTUs per hour) flowing into the pan, the faster the water boils away.



Steam escaping through the fissures in the meat (arrows) heats proteins, causing them to coagulate. Coagulated proteins scatter light, so cooking turns most meat bright white.



The easiest place for steam to rupture meat is between bundles of muscle fibers called fascicles (outline). As fascicles contract, they squeeze out droplets of moisture.



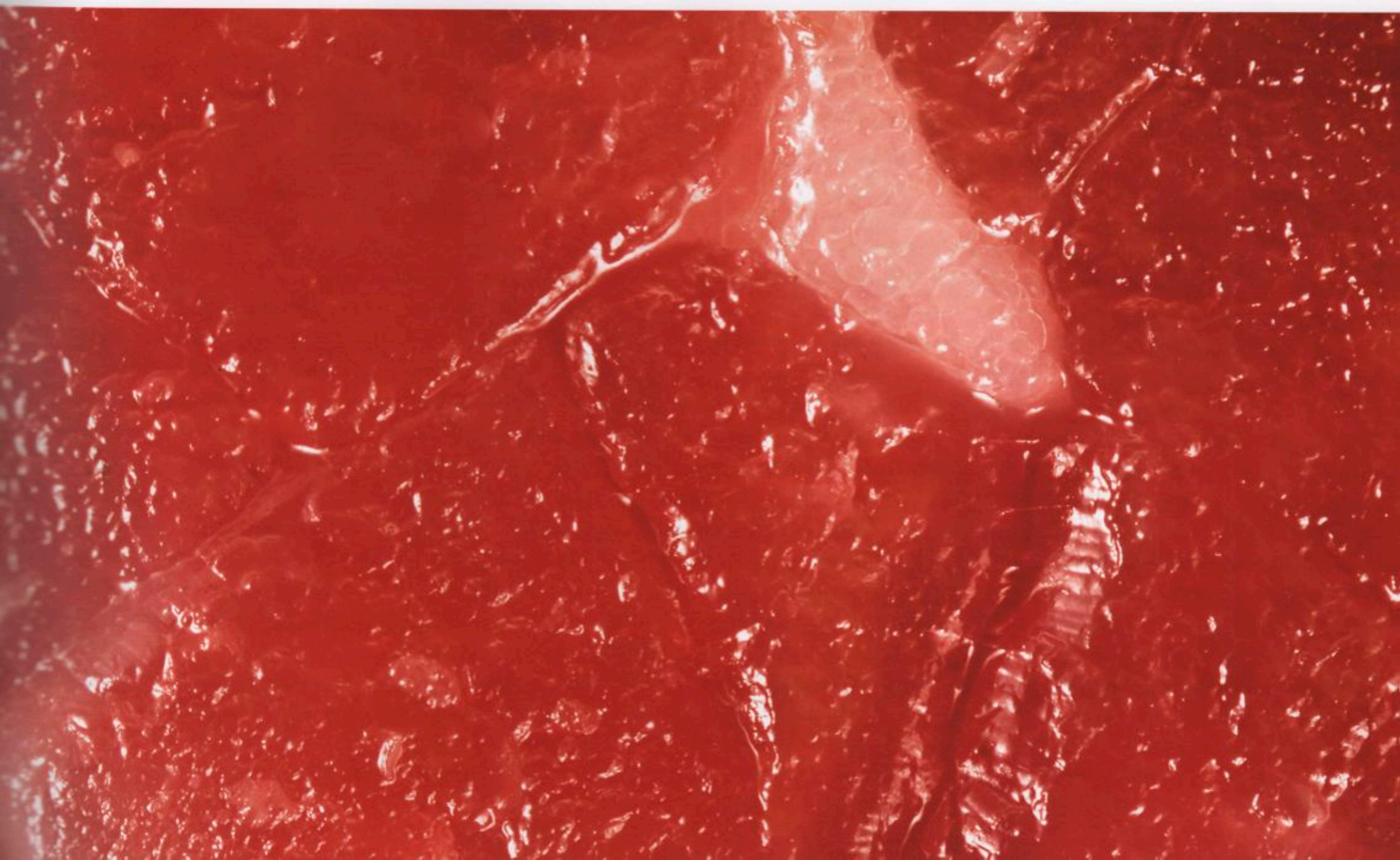
Boiling Zone

The temperature falls to precisely 100 °C / 212 °F beyond the desiccation zone because here so much water remains in the meat that the steak is literally being boiled from the inside out. This zone of constant temperature can range from less than 1 mm / 1⁄32 in to nearly 1 cm / 3⁄8 in thick, depending on the moistness of the cut and the rate of heating. As the water boils, it expands into steam, increasing in volume by a factor of more than 1,600 (see page 1·316). The steam forces its way through the meat, tearing apart bundles of muscle fibers. The steam follows the paths of least resistance, which for most cuts run both upward and downward with the grain, rather than horizontally.

Conduction Zone

Fat renders above the boiling zone, melting and leaking out of the steak. Empty channels left behind allow steam to migrate out of the boiling zone. Most kinds of meat start changing to a cooked texture at around 50 °C / 122 °F (40 °C / 104 °F for most seafood). Although the outside of a thick steak may be seared to temperatures far above the boiling point of water, the meat in the conduction zone is actually poached in its own juices at temperatures well below the boil. Muscle fibers conduct heat very slowly, so the deep interior of the steak is warmed primarily by indirect heat from steam and hot juices percolating up through the meat. It can take the better part of an hour in a hot pan for the core of a steak 4 cm / 1½ in thick to rise to the temperature at which the meat turns gray, around 70 °C / 158 °F.

Conduction zone



coarse bundles of muscle fibers is strong enough that it stretches without breaking when you first bite into the meat. Because the collagen mesh in tough cuts tends to be stronger and thicker, it has a ripstop effect. That makes it hard work for your teeth to cleave completely through the mesh and then push the bundles of muscle fibers apart.

Fortunately, cooks have many methods at their disposal for breaking or weakening collagen. One approach is mechanical. Slicing or grinding cuts the collagen mesh. A Jaccard meat tenderizer cuts through just enough fibers to weaken them while leaving most of meat structure intact.

For more on slicing meat, see page 47. For more on grinding, see page 228. Jaccard tenderization is discussed on page 50.

Cooking works chemically. As the meat reaches elevated temperatures, the collagen mesh gradually degrades and dissolves, and muscle fibers change as well. The result is a much weaker mesh of reinforcing fibers that can be ruptured with less forceful bites.

Cooking meat properly helps to enhance tenderness, but it can do only so much. Cooking, after all, is merely the last act in a long and elaborate drama that begins with a living animal. As we noted earlier, how that animal was raised, whether it was slaughtered in a humane fashion, and what kind of handling turned its muscles into meat all have enormous influences on meat quality. Sadly, these factors often go unappreciated—and thus are often poorly managed.

For more on marinating, see page 174.

As a cook, typically all you can control directly are the final steps of butchering, selecting the cut, and cooking it. These are arguably the easiest steps to get right. Cooking meat and seafood properly requires nothing more complicated than accurately controlling the length of time a food is exposed to a particular temperature—something that modern techniques such as sous vide cooking have made easier to master.

From Raw to Cooked

The transition of meat from raw to cooked includes a number of stages, and each can have a big impact on how tender the meat will become. Depending on how cooking proceeds, various enzymes in the meat will dissolve or degrade proteins in muscle fibers and collagen in connective tissue. Much remains to be learned about the precise role of these enzymes in cooking, but their general response to heat suggests some strategies for optimizing tenderness.

In the living animal, collagen molecules commonly unravel (or **denature**) and reform themselves in order to stay both strong and flexible. The enzymes at work in this reconstruction include proteases: enzymes that degrade meat proteins by literally clipping the molecules into pieces. One family of proteases, the calpains, includes two enzymes that are considered to be most important for tenderness. Although these calpains do not attack collagen itself, they do cut many meat proteins in muscle fibers that contribute to enhanced tenderness.

When the animal is alive, an enzyme called calpastatin regulates the action of calpains. The higher the level of calpastatin, the less protein clipping the calpains do. The conditions of slaughter, the age of the animal, and its breed or genetics all affect the level of calpastatin in meat. Japanese Wagyu cattle, for example, have less than one-third the amount of calpastatin that Brahman cattle have, and this is one reason that Wagyu beef is the more tender of the two kinds.

After slaughter, calpains remain active during meat aging, but they react very slowly, which is why beef is typically aged for three weeks or more. For the calpains to remain active, they require calcium ions, so one factor that controls meat aging is the presence of calcium, which you can add by injecting the meat with a marinade containing calcium chloride.

Earlier in the chapter, we mentioned the cathepsins, a large family of proteases that degrade collagen, myosin, and actin. The calpains and cathepsins are just two groups among hundreds of enzymes in living muscle tissue. The details are complicated, and in some cases not fully understood. The basic picture is that reaction rates for calpains, cathepsins, and nearly all enzymes rise exponentially with increasing temperature. A general rule of thumb for enzymes is that a 10 °C / 18 °F increase in temperature doubles reaction rates.

In some cases, however, the rate may rise as much as tenfold for the same increase in temperature. Reaction rates continue to speed up until the temperature gets high enough to cause the enzymes themselves to break apart or denature from the heat. An enzyme's highest reaction rate thus typically occurs just below the temperature at which it denatures.

THE SCIENCE OF

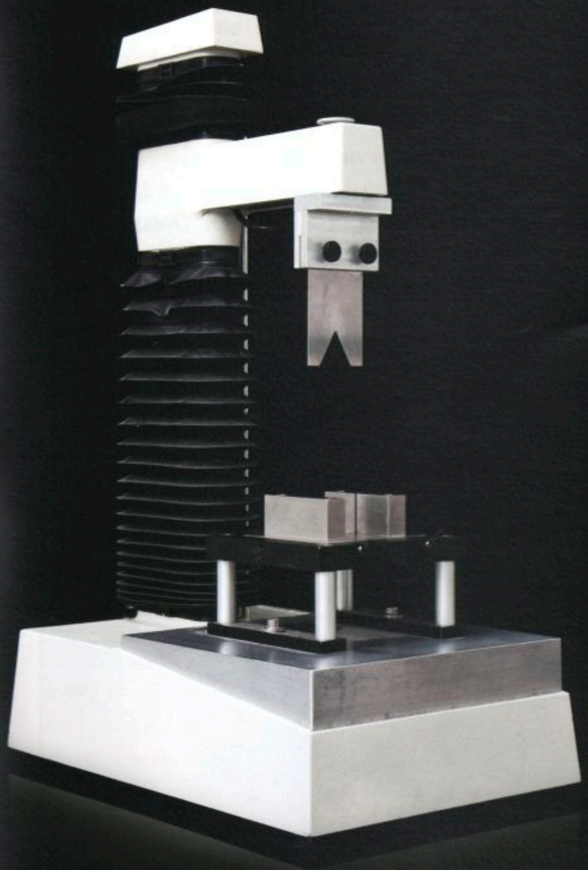
Estimating Tenderness with a Warner-Bratzler Tenderometer

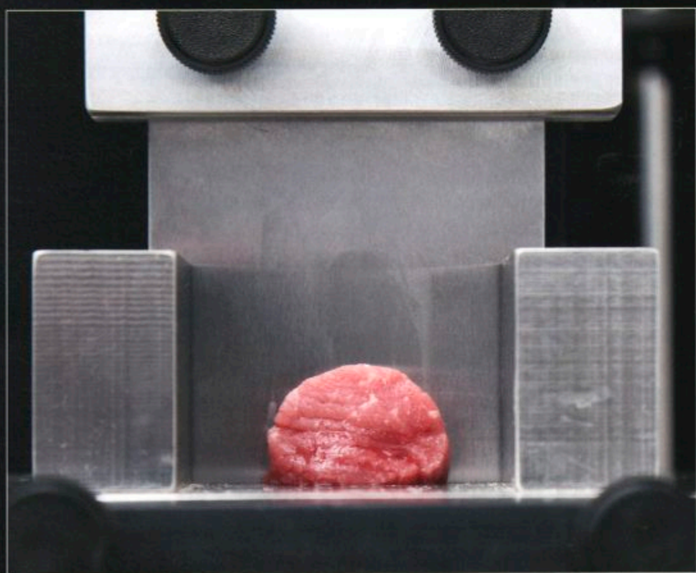
Meat tenderness is a difficult thing to quantify. No mechanical device precisely mimics the act of chewing. Data produced by an instrument called the Warner-Bratzler meat texture analyzer correlate very closely, however, with people's subjective impressions of how appealing or tender a particular piece of meat may be.

The concept for the machine was developed by a USDA scientist named K.F. Warner in 1928 as part of the U.S. government's early attempts to regulate meat quality. L.J. Bratzler made some modifications to the machine's design in 1932 and standardized the equipment. The device has since become the most widely used method for determining the tenderness of meat.

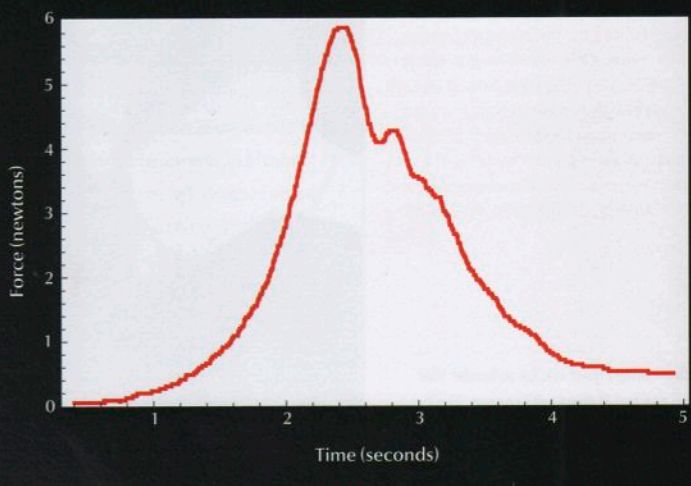
In essence, the machine is a guillotine with a blade that has a triangular notch cut into it. Digital sensors measure the force required to shear a half-inch, cylindrical core sample of meat. The cutting force is recorded in Newtons (a unit of force) as the notched blade shears the meat.

Research has demonstrated that the peak force measured by the machine correlates strongly with human ratings of tenderness. It can't tell you what the meat will taste like, but it can predict how hard you'll have to chew.





The shear force needed to push a guillotine-like blade through a piece of beef is recorded by a texture analyzer, yielding a graph like the one at right.



For more on aging meat, see page 39.

Marbling in meat is fat embedded in the collagen mesh that surrounds the larger bundles of muscle fibers. Marbling has little effect on tenderness; it contributes only about 20% of the overall tenderness effect. The fat does make the meat considerably more succulent and flavorful, however.

Holding meat at temperatures just below 50 °C / 122 °F can have consequences for food safety, so must be done with caution and for only brief holding periods—generally not more than 4 h. For more details, see page 1·175. The Tenderay process described on page 41 uses ultraviolet light to compensate for this limitation.

One way to improving the tenderness of meat is to age it, which allows time for calpains, cathepsins, and other enzymes to degrade tough meat proteins. The enzymatic reactions occur at refrigerator temperatures, but they happen so slowly that it takes weeks to get the desired effect.

A different approach is to use temperatures that are higher—but not too high. The exact reaction rates of calpains and cathepsins have not yet been published, but we do know that, in beef and other mammalian meats, calpains denature at about 40 °C / 105 °F and cathepsins unravel at about 50 °C / 122 °F. Their reaction rates will be highest just below those temperatures.

Slow cooking at low temperature thus maximizes the amount of time that the enzymes work at their peak reaction rates. To improve tenderness, hold the meat at temperatures just below 40 °C / 105 °F, and then heat it to just below 50 °C / 122 °F and hold it again.

This strategy works well for only certain meats. In others, the tenderizing enzymes can go too far and make the flesh mushy. In most red meats, the enzymes are relatively slow-acting, while in lighter meats such as pork, poultry, and most seafood, the enzymes work faster, so there is a risk of overtenderizing the flesh. The more tender cuts of meat and seafood are generally best when quickly cooked to the desired core temperature and then served promptly.

When meat is cooked at temperatures above 50 °C / 122 °F, a different kind of chemical reaction—the conversion of collagen into gelatin—becomes prominent. Collagen and gelatin have the same chemical formula; the difference is that collagen has a more complicated molecular structure.

The transformation from collagen to gelatin goes by several names. Sometimes it is called denaturing, the process by which protein molecules lose their intricately folded shape. Sometimes it is called **hydrolysis**, the general name for chemical reactions that happen in the presence of water. You might also see the term **gelatinization** used, which is confusing because that is also the name of a different process that occurs in starches (see page 4·20). Whatever the name, the conversion of collagen to gelatin is irreversible—once it happens, there's no going back.

Cookbooks and some scientific sources commonly claim that collagen converts to gelatin "at" some particular temperature. Usually the cited threshold lies between 60 °C and 75 °C / 140 °F and 167 °F. In reality, the hydrolysis of collagen is simply another example of a chemical reaction whose rate varies exponentially with

Slow-cooked meat can be so tender that you can pull it apart with spoons. The key ingredients are low temperature, the right cut of meat, and a long cooking time.

temperature. The exact reaction rate for collagen hydrolysis has not been measured, in part because it depends on the specific attributes of the collagen (such as the degree of cross-linking), which in turn depend on the cut, breed, and age of the animal it came from.

The reaction rate is so strongly linked to temperature that at low temperatures it might not seem to occur at all. If, for example, the reaction speeds up by a factor of four when the temperature increases 10 °C / 18 °F, then it would take 48 hours at 55 °C / 130 °F to achieve the same amount of tenderness that would result from three hours of cooking at 75 °C / 167 °F. A cook who tried heating the meat to 55 °C / 130 °F for a short time might notice the small amount of conversion and conclude that the reaction does not happen at that temperature. But it does.

The reaction rate continues to rise with temperature, at least those temperatures that are within practical limits. Pressure cookers, for example, allow us to heat meat above 100 °C / 212 °F by elevating the boiling point of water, and at those temperatures the conversion process speeds up as expected, making very tough, collagen-rich meats tender. Similarly, gelatin for cooking purposes is produced commercially by chemically treating pork hides and other connective tissue, and then boiling or pressure-cooking them to release the gelatin.

Besides enzymatic activity and hydrolysis, heat spurs a third set of chemical reactions that affect tenderness in meat. During cooking, the collagen sheaths surrounding the various bundles of muscle fibers contract (see illustration on next page). This "collagen shrinkage" compresses the bundles of muscle fibers, particularly the fascicles that define the grain of the meat. The compression squeezes moisture out and makes the meat less juicy, more dense, and much tougher to bite through.

Collagen shrinkage begins as soon as the meat starts to heat up. When its temperature reaches 58 °C / 135 °F, enough collagen will have contracted to cause the meat to shorten visibly. By 65 °C / 149 °F, more than half of the collagen in a piece of meat will have shrunk, and by 85 °C / 185 °F nearly all of it will. A simple way to see this effect for yourself is to trim a piece of silverskin off of a tenderloin or other cut and toss it in a hot pan with oil. The collagen-rich silverskin will immediately start to shrink and curl up.

Collagen shrinkage happens quickly—much faster than the conversion of collagen to gelatin occurs. When meat is quickly brought to between 65 °C and 85 °C / 149 °F and 185 °F, it undergoes rapid collagen shrinkage and will be at its toughest. Then, slowly, the collagen-to-gelatin conversion takes place, turning the meat tender. Thus it is a mistake to think of meat tenderness in terms of temperature only—cooking time has a crucial effect as well.

In conventional cooking, tough meats are often braised, boiled, or pressure-cooked to yield a result that is ultimately tender but also gray and dry. The elevated temperatures used to reduce the collagen to gelatin also compromise color and juiciness, as we discuss in the sections below. But you can get around this limitation by exploiting the effects of cooking time. Tough meats can be cooked until tender at any temperature above 55 °C / 130 °F (and even a bit below this, if you are patient enough). Cooking at a lower temperature takes more time, but it spares you from having to trade juiciness and color for tenderness.

Juiciness

Making meat tender is important, but most of us want our meat to be juicy and flavorful as well. Juiciness, thank goodness, is a great deal less complicated than tenderness. It is important to distinguish, however, between juiciness and succulence. Juiciness describes the burst of moisture that you get when biting into a piece of meat or seafood. Succulence refers to how moist the flesh continues to be as you keep chewing.

Juiciness is determined in large part by the cut and quality of the meat, the degree of marbling, how much the meat has been aged, and any treatments, such as brining or marinating, that the meat has undergone. When it comes to the actual cooking, however, juiciness is almost entirely a function of the meat's temperature.

Raw meats and seafood are typically 65%–75% water by weight. About 90% of this water is contained in the spaces between the various protein filaments that make up the muscle fibers. As temperatures near 40 °C / 105 °F, the contractile proteins begin to denature, and the core of each muscle fiber starts to collapse. The collapse relieves the tension that was pushing outward

As of this writing, the only precise measurement of the reaction rate for the hydrolysis of collagen to gelatin has been reported in scientific literature on the collagen in tendons of rat tails. Unfortunately that kind of collagen isn't very relevant to cooking.

The Jaccard-style meat tenderizer (see page 50) keeps meat juicier, too. By cutting into meat fibers and collagen sheaths, the device helps to prevent collagen shrinkage from wringing juice from the meat.

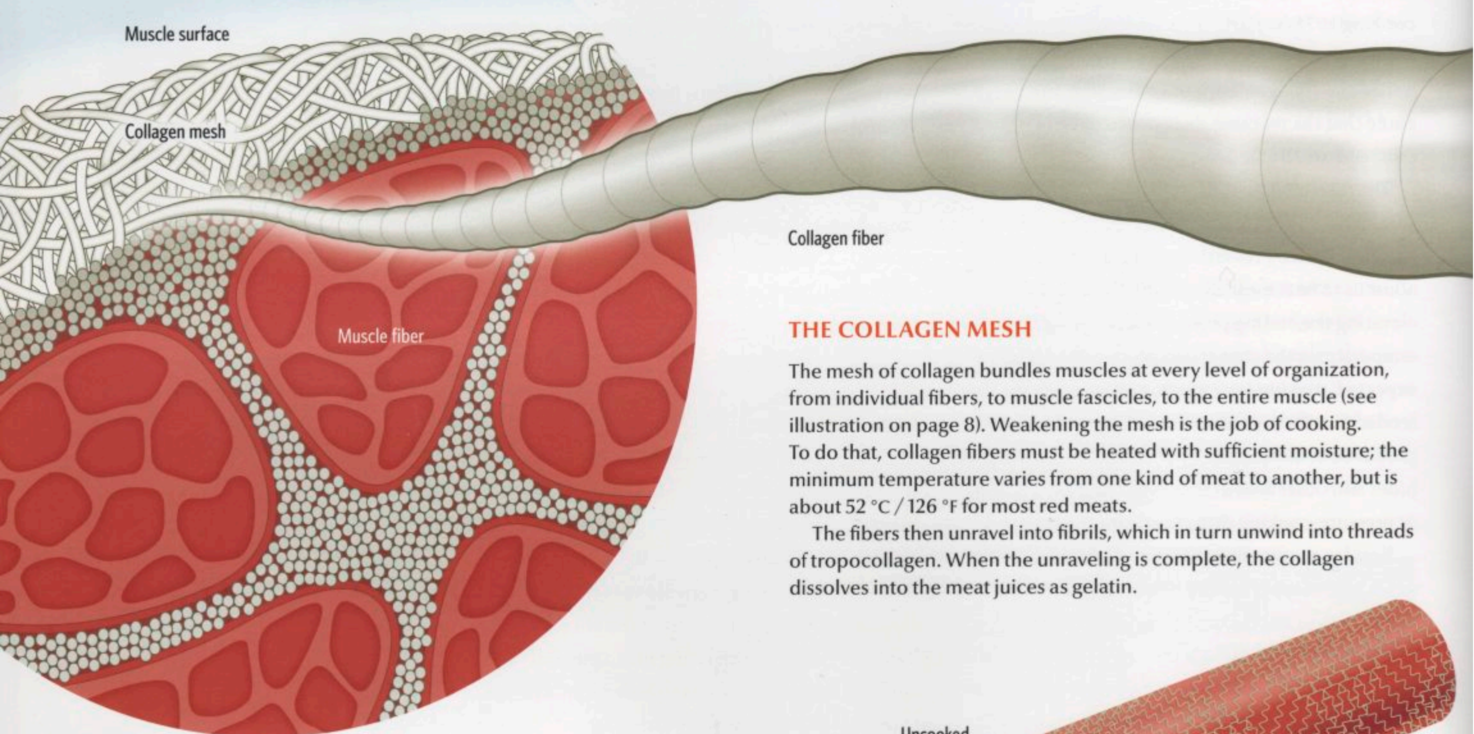
The meat of a young animal is almost always juicier than that of an older animal. A young animal's muscles have more water and less protein than those of an older animal, and collagen is weaker in a young animal than in an older one, so the collagen squeezes out less liquid during cooking. But a young animal's meat also tends to be less flavorful and succulent.

THE ROLE OF COLLAGEN IN COOKING

The nature of collagen controls to a large extent whether cooked meat ends up tender or tough. It is also the determining factor in how long you should cook a given cut of meat. Collagen fibers are the biological equivalent of steel cabling, forming a mesh that holds bundles of meat fibers together. Proper cooking unravels the cable-like structure of collagen fibers and dissolves them into the juices, transforming the tough collagen to tender gelatin.

In order to unravel collagen fibers, you have to heat them. The heat causes the fibers to shrink, and the contracting mesh squeezes juices out of the meat. The hotter the cooking temperature, the more the collagen mesh contracts, and the more juices are lost.

If you cook the meat at lower temperatures, fewer of the collagen fibers shorten at any given point in the cooking process, so the mesh constricts the meat less. This is why meats retain more of their juices when cooked sous vide or by other slow-cooking processes. But at lower temperatures more time is needed to shrink, unravel, and dissolve enough of the collagen fibers to make the meat pleasantly tender.



THE COLLAGEN MESH

The mesh of collagen bundles muscles at every level of organization, from individual fibers, to muscle fascicles, to the entire muscle (see illustration on page 8). Weakening the mesh is the job of cooking. To do that, collagen fibers must be heated with sufficient moisture; the minimum temperature varies from one kind of meat to another, but is about 52 °C / 126 °F for most red meats.

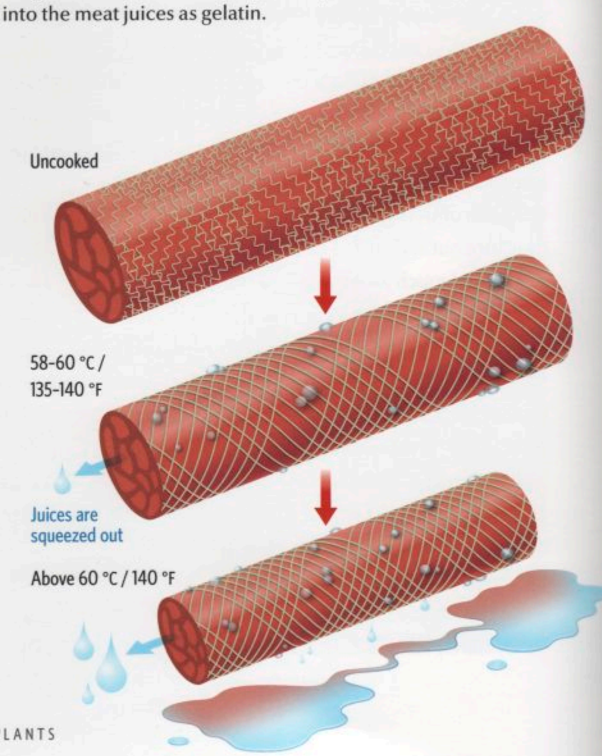
The fibers then unravel into fibrils, which in turn unwind into threads of tropocollagen. When the unraveling is complete, the collagen dissolves into the meat juices as gelatin.

COOKING THE COLLAGEN

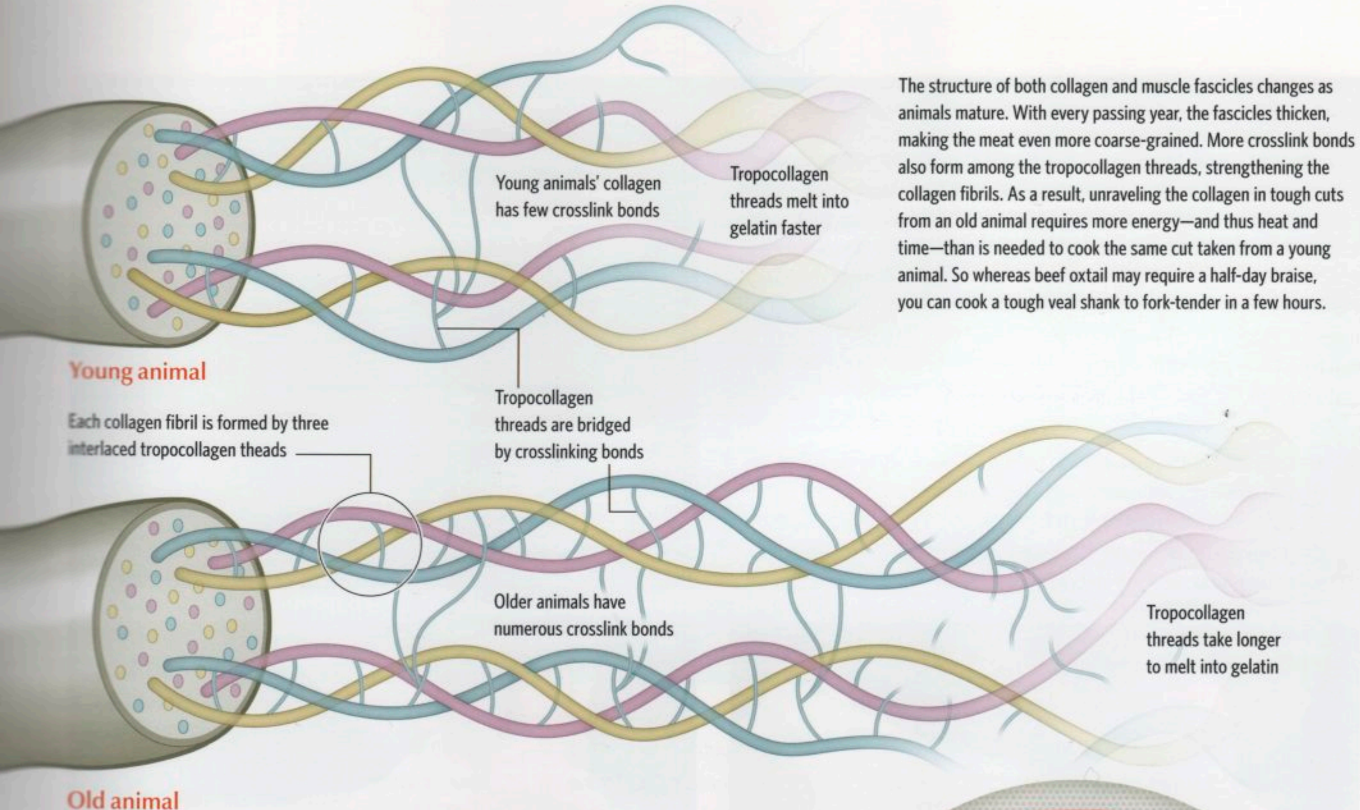
Cooking meat causes the collagen sheath surrounding each muscle fascicle (as well as individual muscle fibers) to contract in two stages. By the time the meat reaches 58–60 °C / 135–140 °F, the initially wavy pattern of the collagen mesh has become taut, constricting the fascicles and fibers enough to produce a trickle of juice.

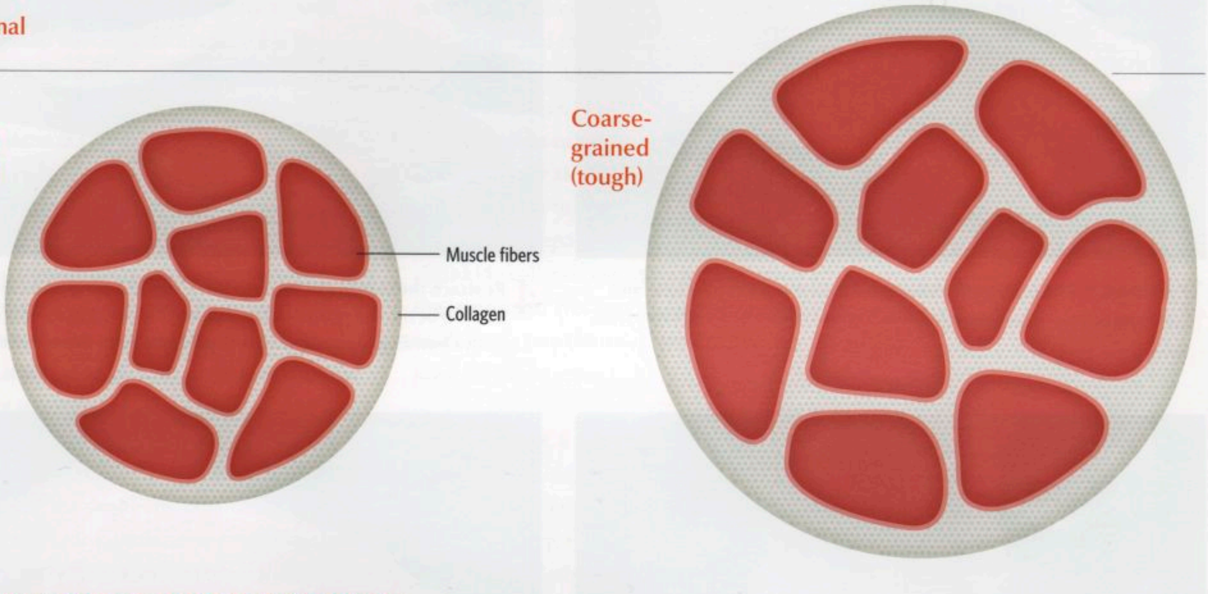
Above 60 °C / 140 °F, further contraction of the collagen fibers causes the muscle fascicles to both constrict and shorten, which forces a flood of juices from the meat. The higher the temperature, the greater the fraction of collagen fibers in the mesh that reach this shortened state, and the more juices are squeezed from the meat. Once shortened, fibers start to unravel and then dissolve.

In meat that is slow-cooked at temperatures below 60 °C / 140 °F, a smaller fraction of collagen fibers are shortened than in meat cooked at higher temperature. This makes for juicier meat but requires longer cooking times to dissolve enough collagen to achieve tenderness.



The structure of both collagen and muscle fascicles changes as animals mature. With every passing year, the fascicles thicken, making the meat even more coarse-grained. More crosslink bonds also form among the tropocollagen threads, strengthening the collagen fibrils. As a result, unraveling the collagen in tough cuts from an old animal requires more energy—and thus heat and time—than is needed to cook the same cut taken from a young animal. So whereas beef oxtail may require a half-day braise, you can cook a tough veal shank to fork-tender in a few hours.





COLLAGEN AND THE COARSENESS OF MEAT

The collagen surrounding muscle fascicles is different in fine-grained cuts than in coarse-grained cuts, and these differences largely explain why we cook tender and tough cuts differently.

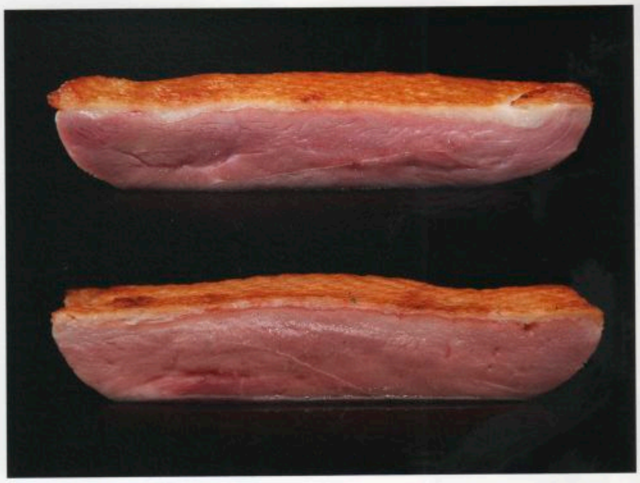
In tender cuts, the collagen sheath is relatively thin and weak—that is what makes them tender. In most fine-grained cuts, you don't have to transform much of the collagen to gelatin in order to get a tender piece of meat. Gelatinizing even a small fraction of the collagen weakens the mesh-like sheaths enough to cause mechanical failure.

In tougher, coarse-grained cuts, in contrast, the layers of mesh are thicker, the collagen itself tends to contain more crosslinking bonds, and the sheaths are more resilient. So the collagen layers are more resistant to mechanical force, they require more time and heat to convert to gelatin, and the cook must convert a larger fraction of the collagen to gelatin in order to achieve tenderness.

Jaccard tenderization works on the collagen mesh by mechanically damaging some of the sheaths and the muscle fibers they enclose. The punctures create points of mechanical failure that aid chewing and create the effect of tenderness. For more on Jaccarding meat, see page 50.

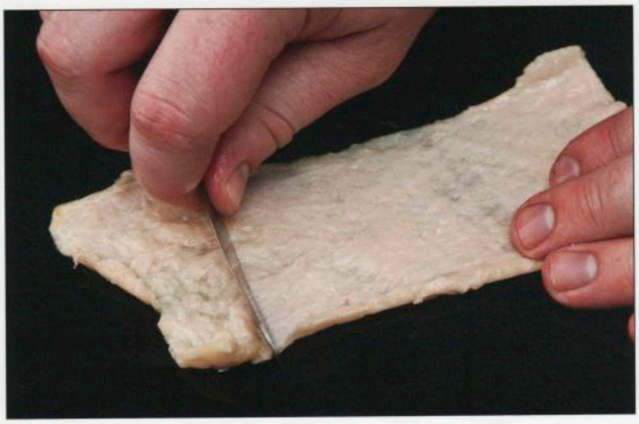
HOW TO Precook Duck Skin

Beneath the skin of a duck lies a thick layer of fat that helps insulate the bird when it is in the water. When cooking duck breast, the key problem is dealing with the rubbery texture of the fatty skin. You can sear the skin to crisp it, but it is hard to heat the fat enough to soften it. Cryosearing, described on page 124, is a better way to improve the skin's texture. Yet another approach is to take the skin off, precook it sous vide, and then reattach it (upper duck breast at right). The fat then becomes tender—much as it is in pork belly. Alternatively, you can scrape off the fat and reattach only the skin (lower duck breast at right).



1 **Remove skin and its attached fat layer from the duck breast (not shown).** Reserve the breast meat in the refrigerator.

2 **Cook the skin (not shown).** Cook sous vide in 55 °C / 131 °F bath for 24 h. Remove bag from bath and cool completely.



3 **Remove the fat (optional).** Bring the skin to room temperature, and scrape the softened fat from the skin with a spoon or an offset spatula.

4 **Reattach the skin to the breast.** Use Activa RM or GS and either the powder or the slurry method (see pages 254 and 256 for more on Activa bonding). Vacuum pack the pieces to hold them together.

5 **Cook the duck breast sous vide in a 56 °C / 133 °F bath to a core temperature of 55 °C / 131 °F for about 30 min.** This not only cooks the breast but also causes the Activa to set.

6 **Sear the skin in a very hot pan or plancha until golden, about 90 s.** The goal is to make the skin crispy. The fat will be softened and no longer rubbery.

THE SCIENCE OF

Fat, the Other Tough Cut

It's common to call the white, highly fatty tissue surrounding a steak "fat," but there is a big difference between fatty tissue and pure, rendered animal fat. Fatty issue is composed of fat cells, which are tiny storage tanks for accumulations of fat molecules. The fat molecules themselves melt between 15 °C and 40 °C / 59 °F and 105 °F, but fatty tissue includes collagen and other proteins that make it tough and rubbery, even after extensive cooking.

One extreme remedy is to render the fat from the tissue—in effect breaking into the cellular storage tanks and releasing the fat molecules. Rendering uses heat to tenderize in two ways (see page 145). First, collagen expels the melted fat as it shrinks; we render at 85 °C / 185 °F or above to maximize this effect. This method is particularly effective when we grind or puree the tissue first to break up the fat cells. Second, long-term cooking degrades the collagen and ruptures any remaining fat cells, thereby releasing their contents.

In some cases, though, we want to cook fatty tissue so it can be eaten rather than rendered. Pork belly is a good example; it wouldn't be the same without the fat. This task of tenderizing fat was a big challenge before sous vide cooking enabled lengthy cooking at low temperatures. Now it is easy. Depending on the cut and the desired result, cooking fatty tissue for 24–72 hours at 60 °C / 140 °F does wonders. It removes the rubbery texture without totally rendering the tissue.

on the collagen sheaths enveloping the fibers, causing the sheaths to tighten slightly around each shrunken fiber. The combination of the collapsing at the core of each muscle fiber and the tightening of the collagen sheath around it squeezes some of the water in the muscle fiber out into the spaces between fibers.

The water that is squeezed out of muscle fibers is far from pure: it contains sugars, salts, protein fragments, nucleic acids, and other dissolved components of a muscle cell. The leaking water also mixes with fats and oils, the source of the flavors that we associate with particular animals. Thus there is not just moisture but also plenty to taste in the resultant meat juices.

As the temperature of the meat climbs above 50 °C / 120 °F, the slow but steady trickle of juice leaking from inside muscle fibers continues. Just how much of the juice escapes the meat depends very much on the size and shape of the cut. In thin cuts, much of the leaking juice is near the surface, where it can readily escape during cooking. In thick cuts, a lot of the juice resides too far beneath the surface of the meat to be lost quite so easily.

What begins as a mere trickle of juice turns into a steady flow by 60 °C / 140 °F and a gushing flood above 65 °C / 150 °F. The juices both inside and outside of muscle fibers are literally squeezed out of the meat as the collagen sheaths surrounding the large bundles of muscle fibers shrink in length. Collagen shrinkage also shortens the meat dramatically. By about 85 °C / 185 °F the meat will be at its driest and toughest.

Meat overcooked to this degree is still typically 55%–60% water. But the remaining water can't erupt in bursts of juiciness during chewing because nearly all of it is trapped by gelled proteins or bound to the surface of the various molecular components of cooked flesh. The shrinking collagen has squeezed out nearly all of the important "free" water, and the force of your teeth biting into the meat won't release any more juice for you to enjoy.

Succulence

Cooks (and those for whom they cook) have known for millennia that certain cuts of meat and parts of poultry, and even some kinds of seafood, turn out wonderfully juicy with prolonged cooking. Indeed, as we note in chapter 9, one of the biggest benefits of Modernist sous vide cooking is the remarkable tenderness and juiciness you can achieve when you are able to cook accurately at a specific temperature for uncommonly long stretches of time.

The juiciness that comes from prolonged cooking is, however, a different kind of juiciness than the kind you get from briefly cooking tender cuts of meat or seafood. With long cooking times, the free-flowing juices that are squeezed out by

The flesh of tuna, swordfish, and other very active ocean swimmers overcooks at temperatures as low as 55 °C / 130 °F because proteins leaking from the muscle cells of these fish bind the cells together, making the flesh seem dry and firm in your mouth. It's a culinary crime to cook these fish above 50 °C / 122 °F, and frankly we prefer much lower temperatures, as highlighted in orange in the table on page 102.

For more on the difference between free and bound water, see page 1·321.

Salting meat and seafood profoundly influences the quality of the protein gel in cooked muscle fibers. Overall, salt makes the gel stronger, firmer, and more elastic, giving brined meats and seafood their characteristic moist but chewy (even rubbery) texture.

For more on how salt affects meat, see Salting and Drying, page 152.

shrinking collagen are gone forever, but there is a persistent moistness as you chew that is best described as "succulence." This quality of cooked meat has a lot to do with how easily the various fibers come apart in your mouth and how slippery and moist they seem as you chew them. A mixture of gelatin, oils, and your own saliva are what provide this pleasant sensation.

The gelatin, of course, is converted collagen, and it provides a melting tenderness. Tougher cuts of meat, as well as some fish and seafood, are well suited for long, slow cooking precisely because they contain plenty of collagenous connective tissue. An ample supply of collagen, coupled with a suitably long cooking time and plenty of moisture (or a humid cooking environment), gives muscle meat the potential to become both tender and succulent. Inherently tender cuts, on the other hand, simply don't contain enough collagen to benefit. Cooking such cuts for too long will give them a mushy texture that is simply unpleasant.

The oils that enrich the mix during chewing come from the meat's original marbling of fat. As we described earlier in this chapter, the same biological necessities that make some cuts tougher than others also tend to lead to more marbling in those cuts. So fatty, tough cuts have an inherent advantage over lean, tender ones in terms of succulence (and also in terms of the flavor that they ultimately produce). Eating fatty foods lights up pleasure centers in our brains, stimulating our appetites and getting us salivating for the next bite.

Fat contributes so much to the pleasure we get when eating meat or seafood that most cuisines have developed a variety of techniques for putting more fat into meat. This practice may seem to run counter to contemporary trends in diet. But while larding (inserting fat into meat) and barding (wrapping the meat in fat as it cooks) are something of a novelty today, we still prize highly marbled meat and rich, fatty fish. The most extreme examples, such as *shimofuri* beef from Wagyu cattle and *toro* from the belly of bluefin tuna, command truly extraordinary sums of money around the world. In no small part this is because the fat they contain makes for particularly pleasurable eating.

Fat is plentiful in many inherently tough cuts of meat. That's obvious to the naked eye. But there is a more elusive reason that tough cuts tend to be the most flavorful: their bigger and stronger muscle fibers contain a lot more of the molecular condiments that excite our taste buds. Dissolved salts, sugars, and, crucially, savory protein fragments and nucleotides from these big muscles become dissolved in the meat juices during cooking, with potent flavor-enhancing effects. With so much more of all these substances to contribute, tougher cuts create more intense flavors that keep our saliva flowing and the meat succulent to the end.

CONTROVERSIES

What Happens When Meat Rests?

After meat is cooked, it is customary to let it sit—or "rest"—before eating it. The conventional wisdom is that this delay allows moisture that cooking had forced to the interior of the meat to move back toward the surface. Resting can improve juiciness slightly, but not for the supposed reason; water diffuses through meat too slowly to migrate far during cooking or resting.

The water inside any muscle food—meat or seafood—is mostly trapped between the contracting protein filaments inside each muscle fiber. Cooking releases a lot of this water, and forces some of it outside of the muscle fibers. If you slice into a steak hot off the grill, the juice flows freely out of the meat and onto the cutting board or plate. But if you rest that same steak for a few minutes so that it cools slightly, less juice leaks out when the meat is cut. Why?

The answer is that degraded and dissolved proteins slightly thicken the natural juices as they cool during resting. The thickened liquid then escapes more slowly when the meat is sliced.

Resting also allows the steep temperature gradient inside the meat to come closer to equilibrium. The core temperature of the meat continues to rise after you stop cooking it because heat in the surface layers continues to diffuse inward. Because this "heat wave" has already been set in motion, the peak temperature reached at the core is practically the same whether you rest the meat in a low-temperature oven or dunk it in an ice bath—see illustration on page 2·254.

Flavor

The flavor of meats or seafood, or any food for that matter, doesn't reflect what happens in your mouth; it's a result of what happens in your brain. You might think that the flavor is coming from your taste buds, because that's where the food is. In fact, what we experience as flavor has many other sensory components.

MYTHS

Searing Does Not Seal in the Juices

It is one of the more persistent myths in cooking: that searing meat "seals in the juices." Yet careful research shows just the opposite is true. Harold McGee publicized this in his landmark book *On Food and Cooking* (see page 1·42), but many people still haven't gotten the message.

We know now that high heat causes collagen to shrink and actually squeezes out more juices. McGee cites evidence that cooks can see for themselves.

Exhibit one: the telltale sizzling of searing meat. What produces this sound? It comes from escaping juices flashing to steam as they trickle onto the hot pan. If searing sealed juices in, there would be no sizzle.

Exhibit two: the red liquid on the surface of the meat. These are droplets rich in red-pigmented myoglobin, which can only have come from within the meat. If the seared crust of the steak held these juices in, they wouldn't be visible on the meat surface.

Exhibit three: the brown pan. A cursory examination of the pan after the steak has been fully cooked shows a puddle of brown juice covering the bottom. Where did this juice come from? Clearly, it leaked out of the meat.

Exhibit four: the steam. That cloud you see wafting from the surface of a seared steak is nothing but pure water vapor escaping from the meat and condensing into tiny droplets.

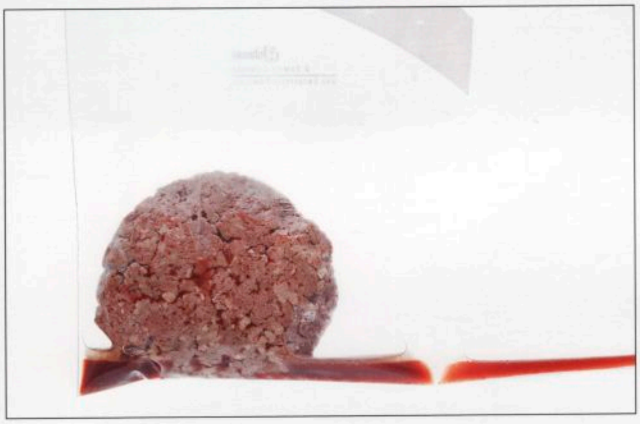
Exhibit five: the juices on the plate. The meat's juices start to leak onto the plate even before the cooked steak is cut, whether or not you have seared the surface.

Why sear, then? Creating that delicious browned crust is all the reason you need. Just don't do it for the juices.

HOW TO Cook the Perfect Hamburger Sous Vide

The dilemma in cooking the perfect hamburger, as in cooking any tender meat, is how to keep as much of it as perfectly done as possible while still producing a seared crust. The solution has two parts: first, cook the patty sous vide to perfect doneness, and second, cryofry the meat to create the perfect crust. Although searing the burger with a torch or on a plancha or a smoking-hot pan also works, deep-frying does not risk breaking up or burning the burger. The same freeze-fry approach also works well with that other backyard barbecue classic, the frankfurter. For more on the best method of grinding the burger meat, see page 228. You'll find our favorite hamburger-meat mixes on page 234.

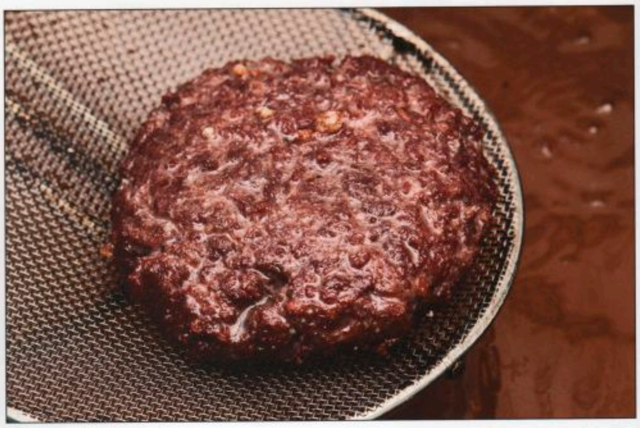
1 **Form loose patties (not shown).** We prefer larger patties of about 200 g and 3 cm / 1¼ in thick.



2 **Cook in a zip-closure bag.** A sous vide bag sealed without vacuum by an impulse sealer also works. Do not vacuum seal the meat because compression yields an undesirable texture. We prefer a final core temperature of 56 °C / 133 °F, which is reached after about 30 min of cooking for a patty of this size. Alternatively, use a combi oven or CVap.

3 **Drain the cooked patty and dip it in liquid nitrogen for 30 s to freeze the meat surface.**

4 **Fry in 232 °C / 450 °F oil for 1 min until brown.** Drain on paper towels.



5 **Serve on a toasted bun with your favorite condiments.** For instructions on how to make flexible slices of your favorite cheese, see page 4·224. And see our take on the Mushroom Swiss Burger on page 5·11.

We removed the shell of this lobster to show the distribution of meat.

Strictly speaking, taste is sensed by the tongue and smell by the nose—or more accurately, by the olfactory bulb, a small part of the brain that reaches out to the world via the nose. These are, of course, key senses in eating. Our brains combine them with the look and feel of the food to come up with the impression we call "flavor."

Neuroscience and sensory science, its more food-focused subdiscipline, are two of the most exciting areas of scientific research today. Investigators are just beginning to demystify why we like some foods and not others, why great cooking can provide so much pleasure, and how foods can be fine-tuned to be more satisfying. Some leading chefs are just beginning to explore these questions in their restaurants. There is no doubt in our minds that the application of sensory science will eventually change how people cook.

Of course, a cook doesn't need to understand the intricate details of sensory science any more than a painter needs to understand the elaborate chemistry of color pigments. Nevertheless, a skilled painter must have some knowledge of the difference between oil-based and acrylic paints and must be adept at blending colors to achieve just the right hue. Without such knowledge, it would be hard to express yourself on a canvas. Similarly, we believe that a cook should understand the basics of taste and aroma and of how cooking manipulates, creates, and enhances them.

For meat and seafood, taste comes predominantly from the various molecular components dissolved in the water inside the muscle fibers. But the taste of raw meat is, in fact, rather bland. That's because it contains only small quantities of the minute protein fragments, salts, sugars, and nucleic acids that give cooked meat its savory taste. Raw red meats also tend to have a slightly metallic taste, possibly due to the presence of iron-containing myoglobin.

Raw seafood can be quite a bit tastier. Fish, crustaceans, mollusks, and essentially every other creature that lives in salty water concentrate various small molecules in their flesh to maintain the necessary salt balance with their watery environments. These molecules help to ensure that water flows out of their bodies at the same rate at which it flows in, which prevents them from drying out. It may be hard to imagine that anything could dry out while submerged in water, but that is precisely what would happen to sea creatures if their cells weren't packed with those small molecules.

For most fish, the principal molecule involved is trimethylamine oxide (TMAO), which reacts with fatty acids in fish oils to create the telltale unpleasant fishy aroma in fish flesh that's past its prime. But seafood, especially crustaceans and mollusks, also contains tasty amino acids like savory glutamate, which provides an umami taste, and mildly sweet-tasting glycine. In general, the saltier the water, the more concentrated these compounds are and thus the more intensely flavored the seafood will be.

The fat found in meat and seafood also provides an important dimension to the overall taste of these foods. As fat melts in the mouth, it creates a rich and pleasing sensation. More important, it generates a taste-enhancing aroma. Indeed, most of what we smell in raw muscle foods comes from the fat contained within the muscle; what we actually smell are molecules derived from the fat as it breaks down. In aged meats, the aromas can range from nutty, buttery, and even slightly cheesy to fruity, floral, or grassy.

Extremely fresh fish, by contrast, often smells intensely of fresh leaves. This is because, like

In many aquatic animals, particularly crustaceans and mollusks, the Maillard reaction begins at much lower temperatures (even below the boiling point of water) and under much wetter conditions than it does in other flesh. That happens because the high concentrations of amino acids and simple sugars that help these creatures to maintain the salt balance in their tissues also promote the Maillard reaction.

leaves, fish flesh contains a high proportion of unsaturated fats (fats that have fewer hydrogen atoms than their saturated cousins). With death of the living tissue, enzymes common to both fish and plants break down all these odorless oils into the same leafy-smelling compound. Unfortunately, this wonderful aroma is unstable and disappears not long after a fish is caught and killed. In its place come less-pleasant smells from continuing chemical changes to the flesh.

Seasoning meats and seafood too mildly is a common failing of inexperienced cooks. Properly seasoning meats and seafood enhances their flavor, which keeps the saliva flowing for a lasting sensation of succulence. Salt is a key flavor-enhancing seasoning, but so is acid. It's unfortunate that acids are so often overlooked because nothing else comes close to getting the mouth watering the way an acid can.

Fish and other creatures of the sea also tend to accumulate molecules from their diets and environment that give rise to other aromas. Ocean-dwelling fish, for example, often contain a group of chemicals called **bromophenols**, which are synthesized by the algae eaten by the fish (or, in the case of carnivorous fish, by the algae eaten by their prey). These compounds are actually part of what makes the seashore smell as it does: winds whipping over the ocean pick up some of the volatile bromophenols and carry them onto the beaches and strands.

Some freshwater fish, particularly bottom feeders and river fish, accumulate molecules that give them strong earthy aromas, which are sometimes described as "muddy." These smells come from several potent chemicals, such as **geosmin**. These compounds are synthesized by actinomycetes—microorganisms growing in the muddy sediments of rivers, ponds, and lakes—and are taken up by the bottom-feeding fish as they scavenge the sediments.

Similar effects take place on land. In particular, the aromatic fatty acids in plant foods accumulate in the fat of grazing animals, influencing the flavor of their meat. Another expression of diet in the flavor of land-dwelling animals comes from the population of microorganisms living in their gut. These microbes also influence the composition of an animal's fat, and hence the flavor of its meat.

Temperature Makes Flavor

The taste and aroma of raw meat and seafood pale in comparison with what you get when you cook these foods. That's because most of the molecular components in muscle actually act as flavor precursors. Relatively small chemical changes can convert them to potent taste and aroma compounds that transform the meat's flavor.

This transformation can even start in the refrigerator, where the natural enzymes found in meat slowly work to break down proteins, fats, and other molecules, producing new tastes from the proteins and new aromas from the fats. Heating the meat to cooking temperature speeds these reactions, increasing the concentration of tasty amino acids and peptides from degraded proteins. Savory salts and nucleotides also accumulate in the juices. And the delicious smell of cooked meat becomes more pronounced as the components of melting fat react at an increasing rate to yield a diverse collection of aromatic compounds.

As the cooking continues, those aromatic molecules keep increasing in diversity and effect, but the intensity of the taste compounds tends to diminish. The reason is that many of those taste-enhancing molecules become involved in the very reactions that are creating the new aromas. Amino acids and peptides, simple sugars and more complex carbohydrates, savory-tasting nucleotides and salts, and of course fats and oils all begin reacting together. The initial changes in these molecules prompt hundreds of further, interrelated reactions that in turn produce thousands of different chemicals. This reactive cascade forms a host of aromatic compounds that define or contribute greatly to the cooked flavor.

Fats, oils, and other fat-like components play a particularly important role here, because they provide the characteristic flavors of various meats. They largely account for why a beef rib eye steak tastes different from a pork chop and why a salmon fillet is unlikely to be mistaken for a chicken breast, even if you're blindfolded. Remove all the fat from cooked meat or seafood, and those foods will still taste meaty or fishy, but the aromas that distinguish one species from another will largely be gone.

Not only does the fat add to the overall cocktail of chemicals present during cooking, but it can also fundamentally change the course of the reactions that take place. Many of the compounds that form as food cooks are to some degree soluble in either water or fat. So there is a continuous division of the various chemicals between fat and water during cooking, and the kinds and relative quantities of the chemical products formed depend on the amount of fat and water present. The presence of herbs, spices, and vegetables only adds to the chemical complexity of the situation. Indeed, it's hard to overestimate just how complex the reactions that form flavor in cooked meat and seafood can be.

The Maillard Reaction

One of the most important flavor-producing reactions in cooking is the **Maillard reaction**. It is sometimes called "the browning reaction" in discussions of cooking, but that description is incomplete at best. Cooked meats, seafood, and other protein-laden foods undergoing the Maillard reaction do turn brown, but there are other reactions that also cause browning. The Maillard reaction creates brown pigments in cooked meat in a very specific way: by rearranging amino acids and certain simple sugars into novel molecules, which then arrange themselves in rings and collections of rings that reflect light in such a way as to give the meat a brown color.

The important thing about the Maillard reaction isn't the color—it's the flavors and aromas. Indeed, it should be called "the flavor reaction," not "the browning reaction." The molecules it produces provide the potent aromas that are responsible for the characteristic smells of roasting, baking, and frying. What begins as a simple reaction between amino acids and sugars quickly becomes very complicated: the molecules produced keep reacting in ever more complex ways that generate literally hundreds of new kinds of molecules. Most of these new molecules are produced in incredibly minute quantities, but that doesn't mean they're unimportant.

Consider roast beef. One of its most salient flavor reactions begins with the meat sugar **ribose** and the sulfur-containing amino acid **cysteine**, which is derived from proteins in the beef. From these two molecules, the Maillard reaction creates a host of ring-shaped molecules. Although they are produced in trivial quantities, people can smell the resulting sulfurous molecules in concentrations as dilute as a few parts per trillion. Tony Blake, a flavor chemist, calculated that if just 2 g / 0.07 oz of one such aroma compound, **bis-2-methyl-3-furyl-disulfide**, were dissolved in a lake 2 m / 6 ft deep and some 8 km / 5 mi in diameter, the water would have a noticeably beefy taste!

The Maillard reaction takes place in other cooked meats and seafood as well. Indeed, it occurs in cooking of almost all kinds, although the specific sugars and amino acids present produce distinctly different aromas. This is why baking bread doesn't smell like roasting meat or frying fish, even though all these foods depend on Maillard reactions for their flavor. The Maillard reaction or its absence distinguishes the flavors of boiled, poached, or steamed meat and seafood from the flavors of such foods grilled, roasted, or otherwise cooked to temperatures that are high enough to dehydrate the surface rapidly—temperatures above the boiling point of water, in other words. These two factors, dryness and temperature, are the key controls on the rate of the Maillard reaction.

The relevance of the Maillard reaction to cooking first became known after scientists began studying slow flavor changes and browning in powdered foods, such as eggs and milk, that were part of army rations (see page 92). Because these foods are so dry, the amino acids and sugars in them react, albeit slowly, at the relatively low temperatures of ambient storage. High-temperature cooking speeds up the Maillard reaction because heat both increases the rate of chemical reaction and accelerates the evaporation of water from the surface of food. As the food dries, the concentration of reactant compounds increases and the temperature climbs more rapidly.

The different ideal cooking temperatures for various meats depend in part on the original animal's body temperature. Beef cattle and most mammals generally have a body temperature of about 37 °C / 98.6 °F. Medium rare is about 55 °C / 131 °F—or about 18 °C / 32 °F higher than body temperature. Chickens and other poultry have a body temperature of 42 °C / 108 °F. We prefer poultry cooked to 60 °C / 140 °F, which is also 18 °C / 32 °F above body temperature. Fish have the lowest body temperatures of all, ranging from below 5 °C / 41 °F to 30 °C / 86 °F in tropical waters. As a result, fish require the lowest cooking temperatures.

Grill marks show grid lines of intense Maillard reactivity, which creates both an attractive appearance and a rich flavor. In between the grill marks, the Maillard reaction has occurred only in part.

Poulet Au Feu D'enfer (see page 100)

In most foods, the Maillard reaction acts very slowly when the surface of cooked food reaches temperatures around 90 °C / 195 °F. At that point, most of the water has evaporated and the remaining water is tightly bound to other components of the food. By the time the surface of a cut of meat or a piece of seafood has dried out enough for its temperature to reach 115 °C / 240 °F, the pace of the Maillard reaction, as judged from the developing aroma and color, will have picked up. By 130 °C / 265 °F, the reaction is going at full tilt.

Temperatures need to be high to bring about the Maillard reaction, but as long as the food is very wet, its temperature won't climb above the boiling point of water. At atmospheric pressure, only high-heat cooking techniques can dry out the food enough to raise the temperature sufficiently. It's not the water that stops the reaction, but rather the low boiling point at atmospheric pressure. In the sealed environment of a pressure cooker or an autoclave, the Maillard reaction can—and does—occur.

So in boiled, poached, and steamed muscle foods, an entirely different set of aromas dominates the flavor. Drying and browning the surface first will, however, allow the reaction to proceed slowly at temperatures below the boiling point of water. This is why we tend to brown our meats and seafood before braising, stewing, or making brown stocks from them.

One of the challenges to getting the Maillard reaction going is making the surface hot and dry enough without overcooking the flesh beneath—or at least overcooking it as little as possible. Cooks have developed several strategies to this end, some simple and some fairly baroque. One

For centuries, people have cooked meat with onions, leeks, garlic, and other vegetables of the genus Allium. These vegetables contain sulfur compounds that supplement the Maillard reaction to produce tantalizing aromas.

that works well is to remove as much water from the surface of the meat as possible before cooking it (via blotting, or drying at low temperature). Fast heating using deep fryers, superhot griddles and grills, and even blowtorches are also helpful tactics. We've developed some even more elaborate maneuvers, such as using dry ice and liquid nitrogen prior to searing.

Among the more subtle techniques for fostering the Maillard reaction is raising the food's pH (making it more alkaline). Chinese cooks often marinate meat or seafood in mixtures containing egg white or baking soda just before they stir-fry it. These alkaline marinades raise the pH and make the surface brown and become flavorful more quickly in the wok. Conversely, lowering the food's pH (making it more acidic) stalls the Maillard reaction, which is why meats and seafood soaked in an acidic marinade don't brown very well when cooked.

Another trick is to add sugars to help drive the reaction, or at least to keep the sugars that are already in the flesh from leaching out. Brined meats and seafood, for example, often brown unevenly because soaking them in brine draws out sugars from the surface and infuses water, which dilutes the sugars and amino acids that remain. A simple fix is to add sugar—especially glucose, fructose, maltose, or more exotic meat sugars like ribose—to the brine. Indeed, the deep mahogany color of classically prepared Peking Duck owes a lot to the dipping the duck gets in a malt sugar solution just before being roasted.

You might think that raising the temperature even higher would enhance the Maillard reaction. It does, up to a point, but above 180 °C / 355 °F a different set of reactions occur instead—**pyrolysis**, aka burning. People like certain foods a little charred, but with too much pyrolysis comes bitter taste. The black compounds that pyrolysis creates also may be carcinogenic. So go easy when you're charring meat for its visual appeal.

THE CHEMISTRY OF

The Flavor of Leftover Meats

The flavor, or rather aroma, that meat acquires after being cooked, cooled, and later reheated was first scientifically recognized in 1958. It goes without saying that people knew about it well before then. But the increasing sales of refrigerated precooked meats after the Second World War made the scientific study of this phenomenon economically important.

The technical term for this telltale flavor is "warmed-over." The smell is slightly stale, even slightly rancid, and it develops when meat is reheated after being precooked and stored, for even a few hours, in the refrigerator. The aroma is entirely different from the smell of aged raw meat.

The underlying cause is the oxidation of unsaturated fats found in muscle-cell membranes. When first cooked, these unsaturated fats in meat remain reasonably stable, but after cooling the cell membranes readily break down, making these fat molecules available for the oxidation that can occur during reheating.

So the greater the quantity of unsaturated fats, the more likely that a warmed-over flavor will arise after reheating cooked meat. This is why it is common in seafood, poultry, and pork–approximately in this order; these meats are all high in unsaturated fat. But it can also occur in lamb and beef.

Iron catalyzes these oxidation reactions, and there is no shortage of iron in meat, even in white meat. The protein myoglobin, which transports oxygen in live muscle, contains iron. Again, this iron only drives the reaction after the cooking, cooling, and reheating cycle associated with warmed-over flavor.

Interestingly, iron's ability to promote these reactions also explains why this flavor problem is so prevalent in leftover Chinese food. It's not anything about the food per se: the woks used to cook it are, however, made from iron and iron-containing steel!

A cook has a couple options to mitigate the problem of warmed-over flavor when it is necessary to precook meat. Brining with curing salts can help because the nitrite found in curing salts inhibits these reactions. But be aware that salt alone makes matters much worse. And, although these reactions do take place in products cooked sous vide, keeping the cooked food tightly packaged in the air-free environment after cooking helps slow the development of warmed-over flavor.

Color and Appearance

Cooking meat and seafood so that it is tender, juicy, and flavorful is important, but a lot of the enjoyment of eating also comes from how the food looks. We're not just talking about the aesthetics of presentation. Someone who prefers meat well done simply will not enjoy a steak that is pink when cut open. Those of us who opt for medium rare are equally unhappy at the sight of a uniformly gray piece of meat on our plate. The appearance of food colors our perceptions. That's why for some people a juicy but slightly pink piece of chicken may "taste" raw and unpleasant. Other people have a similar reaction to rare red meats.

Carotenoid pigments are also part of the reason that butter from cow's milk is yellow, and that goat's milk is so white. Goats and cows both obtain the pigments from their diet, but goats break down the carotenoids differently, so the pigments do not appear in their milk.

Raw muscle foods vary in color, from pale white to light pink to bright cherry red to a deep shade of red so intense that it appears almost black. Old or improperly stored meat and seafood also develop less attractive shades of grays and browns. All of these colors reflect the quantity and condition of the myoglobin present in the muscle.

As we described earlier in this chapter, some kinds of muscle fibers contain large quantities of myoglobin for greater endurance; they therefore appear red. Other fibers contain very little of this oxygen-supplying pigment because they're geared for short bursts of speed; hence, they tend to appear white. Within an individual muscle, some fraction of the muscle fibers will be red and others white. The distribution even varies from one part of a muscle to another, as is readily apparent in seafood. Meat is like a pointillist painting: the color we perceive comes from averaging the proportion of minuscule flecks of red and white.

But the appearance of myoglobin is also complicated because it can change color. Under the right conditions, myoglobin combines with oxygen and appears bright red. In the absence of oxygen, it takes on a deep purplish-red hue. This color shift is reversible: slice deep into a piece of meat, or open a bag of vacuum-packaged meat, and expose it to air for 10–20 minutes. The surface will slowly "bloom" to vibrant shades of pink and red.

Unfortunately, under certain conditions the iron atoms in the myoglobin molecules change configuration, causing the color of the pigment to turn a grayish brown. Most people believe that this indicates that the meat or seafood is old, and it may be. But this reaction can actually happen in minutes. It occurs when meat and seafood are exposed to neither too little nor too much oxygen. Storing meat and seafood in airtight containers, wrapped loosely in plastic wrap, or partially (but not fully) under vacuum causes oxygen levels at the surface of the meat to plummet but not to drop to zero. These are the conditions that cause this unattractive color change. The only way to

THE HISTORY OF

The Maillard Reaction

Louis Camille Maillard was a French physician whose work unexpectedly wound up revolutionizing food science and the flavor industry. Maillard studied kidney disease in the early years of the 20th century. His efforts to puzzle out how to synthesize peptides in the laboratory led him to investigate whether sugar could promote the joining of two amino acids to form a simple peptide. He learned that the reaction produced color but, alas, no peptides. Maillard published a report in 1912 describing slightly different versions of this fundamental interaction between proteins and sugars.

Maillard's findings received little attention until the Second World War, when the U.S. Army asked scientists to determine what was causing dehydrated stores of eggs, milk, and other staples to turn brown and deteriorate. The scientists failed to identify the culprit. It wasn't until after the war that H. M. Barnes and C. W. Kaufman at the General Foods laboratory in Hoboken, N.J., attributed this browning to the Maillard reaction. They were the first to suggest that the chemical reaction "may also be the contributing factor in the development of many of our characteristic food flavors."

That was quite an understatement. Today we know that the Maillard reaction is responsible for most of the flavors we experience not only in cooked meat and seafood but also in toasted bread, roasted coffee, chocolate, cooked onions, malted barley in beer, and many other foods.

make it go away is to totally remove the oxygen by vacuum packing the food and then refrigerating it for a day or two while the pigment slowly changes back to the inky purple color. Once this happens, myoglobin will react with fresh air again and take on attractive pink and red hues.

Myoglobin is not the only pigment in meat, although it is the most important one and the one most involved in the color changes that go on during cooking. In some animals, diet also influences the color of the flesh. Salmon and trout, for example, develop shades of orange because of a **carotenoid pigment** called **astaxanthin** present in the minuscule crustaceans that they eat. Many ocean-dwelling animals consume these crustaceans, but only salmon and trout distribute the pigment throughout their flesh. Other sea creatures excrete the pigments or concentrate them in their skin and other organs.

Birds also accumulate dietary pigments in their flesh. The slightly orange-yellow color of some poultry comes from another carotenoid pigment, called **xanthophyll**, which is common in many plants; it colors the flowers of dandelions and marigolds. This pigment accumulates in the fat and fat-like molecules in the flesh of birds. It also accumulates in the fat in their egg yolks. So differences in diet account for why some yolks are pale yellow and others deep orange. These pigments also come into play during cooking, mostly because they are partly broken down and react to provide some of the bird's characteristic flavors.

The Optics of Cooking

Because muscle is filled mostly with water, light penetrates some distance into it before being reflected, while scattering only slightly. This is what makes the tissue shiny and translucent. Often it glistens with beads of moisture. But the characteristic appearance of raw flesh swiftly disappears with cooking.

One of the first changes is that the meat becomes increasingly opaque. This happens as proteins start to unravel and precipitate out of solution in clumps that reflect and scatter light much more. Juices trickling to the surface also begin to appear opaque for the same reason.

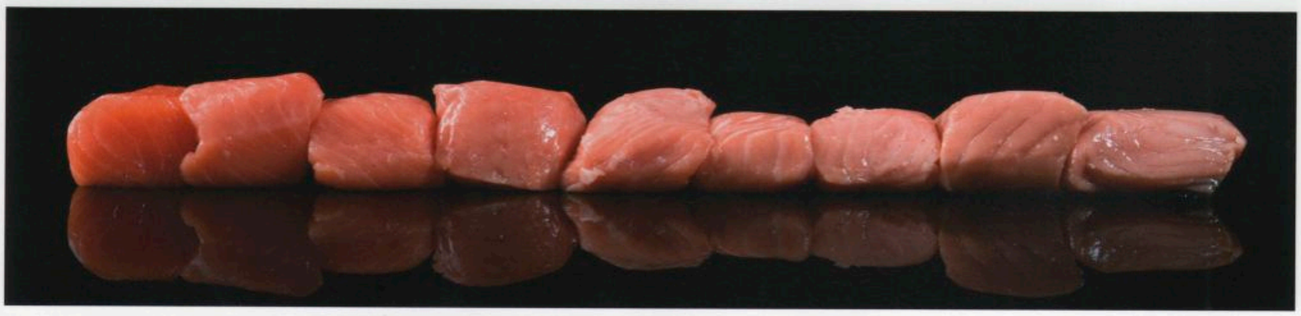
In the meat of land-dwelling animals, this change begins at the same temperature at which proteins first start to unwind and the first beads of juice begin to appear on the surface, around 50 °C / 120 °F. For most seafood, the starting temperature is somewhat lower, 35–40 °C / 95–105 °F, simply because the proteins of seafood are less stable than those of animals that are adapted to life on land. The degree of opacity increases as the temperature rises, causing a greater fraction of proteins to unravel, precipitate, and ultimately form into a gel. As the flesh becomes more opaque, its colors tend to appear more muted, too.

Up to about 60 °C / 140 °F, the myoglobin in muscle remains intact, although the heat of cooking causes it to release the oxygen that is bound to it. Because the myoglobin is much darker in its deoxygenated condition, meat or seafood cooked to this temperature often appears somewhat gray and drained of color. But if you stop cooking it, expose it to fresh air, and let it cool slightly, the myoglobin will again bind oxygen, and over time the meat will revert back to an attractive shade of bright white, pink, or red.

Often an inexperienced cook will think that he or she has overcooked a piece of meat because the flesh looks gray throughout when it is sliced open. This happens often with red meats, in which an appropriate shade of red or pink in the center signals a degree of doneness between medium rare

Scientists distinguish among three kinds of myoglobin, calling them by different names depending on whether the molecule is oxygenated and bright red **(oxymyoglobin)** or deoxygenated and purplish **(deoxymyoglobin)** or contains iron oxidized to a semipermanent brown **(metmyoglobin)**. The myoglobin in meat can readily switch back and forth between the first two of these states as oxygen levels change. The last state is more intractable, although it can be reversed slowly in the near total absence of oxygen.

Salmon pieces cooked from 38–46 °C / 100–115 °F (left to right) show the albumin (white) that begins to coagulate at 42 °C / 107 °F. Brining or curing salmon before cooking will prevent albumin from leaching to the surface (see page 152).



Many people wonder about the white and gray droplets that dot the surface of meats and seafood. These are nothing more than juices laden with proteins and pigments that have leaked to the surface. When the cooking temperature at the surface is high enough, the proteins and pigments unravel, changing the droplets from clear to opaque, usually with an unattractive gray cast.

and medium well done. In reality, the meat may not be overcooked at all, but just needs time to absorb oxygen from the air.

Above temperatures of around 60 °C / 140 °F, the myoglobin molecule begins to degrade, so its color changes permanently. It remains gray even with cooling and exposure to oxygen. What's actually happening is that myoglobin-rich fibers become much darker than what you'd call gray, but other fibers that don't contain myoglobin remain an opaque white. Your eye averages the combination of these colors at a microscopic level and sees gray.

Starting at about 90 °C / 195 °F, new colors appear. In particular, yellows and browns from the Maillard reaction start to show up at the surface. Many of these Maillard pigments are water soluble, so they diffuse some distance into the meat from the surface where they've formed. This gives the graying meat a slightly brown quality on the crust and just beneath it.

As the temperature continues to rise, the crust itself becomes an ever-darker shade of brown. This progression continues up to about 170 °C / 340 °F. But as the temperature goes beyond this, the Maillard reaction is supplanted by pyrolysis reactions that produce black carbon (along with acrid tastes). In moderation, charring can impart pleasant flavors and even define the cooking technique, as sear marks from grill bars do. But when taken to excess, our taste buds tell us that the food has simply been burned.

Putting It All Together

Cooking meat has a number of inherent trade-offs. Low heat will tenderize, but takes a very long time to do it. Higher temperatures will also tenderize, but they will toughen and dry the meat first. Each of the processes involved has strengths as well as weaknesses; no single approach is perfect.

Traditional cooking methods generally focus on the best single method of cooking for any given circumstance, minimizing its drawbacks while exploiting its benefits. Traditional cooking methods usually employ a single temperature setting that is higher than we want the meat temperature to be. As a result, timing is critical: it's important to put just enough heat in the meat, and no more, in order to cook it to the desired temperature. With this approach, a thermal gradient develops in the meat, and a significant portion of it overcooks.

Modernist techniques assume a dramatically different perspective on cooking. Instead of picking one method that has trade-offs, most Modernist approaches use more than one technique. Instead of using high heat, most Modernist approaches use temperatures no more than a degree or two above the temperature you want the meat to reach. This strategy takes time, but makes timing less critical. That first phase is then followed by cooking at high heat by using a blowtorch, plancha, or other high-temperature heat source. In this second phase, cooking times are

THE CHEMISTRY OF

Why Is the Turkey Still Pink?

Several phenomena can cause discoloration in cooked meat. By far the most common, and to some people the most off-putting, is the pink discoloration that frequently occurs in poultry and pork that have been overcooked to temperatures above 80 °C / 175 °F or so. This pink tint makes some people think that the meat is still slightly raw—a common complaint with Thanksgiving and Christmas turkeys. In pork, the pink hue may even lead diners to suspect that a sneaky cook has injected nitrites or nitrates into the meat.

In fact, a pigment known as cytochrome is to blame. Cytochrome helps living cells to burn fat. At high temperatures, it loses its ability to bind oxygen and turns pink. Over time, the pigment does regain its ability to bind oxygen, and the pink tinge fades. That is why the leftover meat in the refrigerator rarely seems to have this unseemly blush the next day.

Pink discoloration can also come in other forms, such as spots and speckles. Nearly all of these blotches are the result of the unusual ways that various protein fragments and thermally altered pigment molecules bind oxygen. None of them indicate that the meat is still raw or that it will make you ill. Nor do they implicate a sneaky cook.

very short, and only the top millimeter of meat is singed. In some cases, you might combine cooking with extreme cold—plunging meat into liquid nitrogen, for example—to be able to cook the skin or exterior to a seared crust without overcooking the interior.

Our recommended approach for cooking tender cuts of meat is to use sous vide or related low-temperature techniques, as explained on page 96. The goal in this technique is to bring the meat to the appropriate temperature for doneness by using a heat source that is only a degree or two hotter. The fact that no thermal gradient develops means that you can maximize the proportion of the meat that is perfectly cooked. You'll need patience, because cooking to equilibrium is slow (see page 2·242). But cooking times can be trimmed simply by cutting the food into thinner pieces.

Low-temperature cooking takes us only part of the way, however. To create Maillard reactions on the surface, the meat must be seared over extremely high heat. The hybrid use of extremely low heat (one degree above desired doneness) and extremely high heat (1,000 degrees above doneness) gets us the best of both worlds. No single approach can do as well.

Tough cuts are also best cooked sous vide—see page 108. But instead of cooking just to reach a certain temperature, we cook to spend time at a temperature. That time can be very long: 8, 12, 24 hours or even more. One recipe in this book calls for a 100 hour cook time (it is for oxtail, and appears on page 5·50). Such long cooking times are needed to tenderize while avoiding the deleterious effects on juiciness, succulence, flavor, and color that higher temperatures produce. Pair the low-temperature cooking with a superhigh heat method to create Maillard flavors and colors.

Where temperature isn't such a critical factor, a pressure cooker is the way to go. Freed of the 100 °C / 212 °F limitation, we can wreak high-temperature havoc on meat proteins, rendering fat, extracting flavor, or tenderizing even the toughest cuts.

For more on pressure-cooking, see page 2·294. For more on pressure-rendering fat, see page 145. Flavor extractions are covered in chapter 10 on page 2·288. You can find tips for tenderizing tough cuts in a pressure cooker on page 108.

THE CHEMISTRY OF

Gassing Meat for Color

You can accelerate the blooming of myoglobin by exposing meat to oxygen at higher concentrations and pressures than those found in the air. Gases other than oxygen work, too: carbon monoxide (CO), for example, or nitrogen dioxide (NO_2). These gases tend to stabilize myoglobin enough that the red color survives intact through most kinds of cooking.

Both of these gases are, however, poisonous. CO kills the same way that it makes meat red: by binding to myoglobin and hemoglobin. The binding blocks oxygen from doing the same, and so oxygen-starved tissues suffocate. NO_2 is a deep-lung irritant that is nasty enough at low levels and fatal if you breathe too much of it.

Obviously, both of these gases need to be handled carefully. Gas suppliers can provide guidance and training. Then look forward to the kind of amazing results that transformed the pale cut on the left to the vibrant one at right.

TENDER MEATS SOUS VIDE

Cooking tender cuts of meat sous vide is a matter of getting the core of the meat to a desired temperature. Portion the meat carefully to speed up the process: the thicker the pieces, the longer the cooking time, which increases by approximately the square of the thickness (see page 1·279). Add any flavoring or liquids to the sous vide bag before sealing. The times needed to cook the meat vary according to the starting temperature of the food, the size and thickness of the meat, and the recovery time of the sous vide tank you are using. We recommend using the equilibrium cooking technique, in which the bath is set to a temperature just above the final desired temperature. But you can also cook hotter than core (see page 2·245). Tender cuts are generally intact muscles, which are safe to cook sous vide if the exterior is seared (see page 1·182). In most cases, however, you could hold the meat at the final core temperature long enough to pasteurize it without harming the meat.

COOKING TENDER CUTS SOUS VIDE

1. **Select an ingredient and target temperature.** The table below provides final core temperatures for many popular tender cuts; our preferences are highlighted in orange.
2. **Set sous vide bath to 1 °C / 1.8 °F above the target temperature selected.**
3. **Vacuum seal the meat with any flavorings, fats, or liquids desired.**
4. **Cook sous vide until the core temperature of the meat reaches the target.** Use a digital probe thermometer, as described on page 2·243.
5. **Optionally, sear the meat by using whichever method you prefer.** For options, see page 2·270.
6. **Season as desired.**

For holding times and temperatures that will pasteurize the meat, see page 1·193.

Best Bets for Cooking Tender Meats Sous Vide

	Core temperature for doneness									
	Rare		Medium rare		Pink		Medium			
Ingredient	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	Note	See page
beef, filet mignon	**50**	**122**	53	127	56	133	62	144		
beef, flank	54	129	**56**	**133**	59	138	62	144	cut thinly against the grain for maximum tenderness, or use kalbi marinade	199
beef, hanger	51	124	54	129	**58**	**136**	60	140		
beef loin (rib eye)	54	129	**56**	**133**	58	136	60	140		5·5
beef, strip steak	52	126	**54**	**129**	58	136	62	144	dry aged is ideal	4·180
lamb, leg	54	129	57	135	**60**	**140**	65	149		
lamb loin (rack)	54	129	**57**	**135**	**59**	**138**	62	144		5·25
veal loin	**52**	**126**	**54**	**129**	56	133	60	140		
venison loin	**50**	**122**	**53**	**127**	58	136	60	140	high enzymatic activity can cause mushiness; cooking to a hotter-than-core temperature is recommended; use the same temperatures for similar game	98
pork loin	n/a		58	136	**60**	**140**	62	144		5·17
pork tenderloin	n/a		56	133	**59**	**138**	61	142		5·35
pork, shoulder blade	n/a		58	136	**60**	**140**	64	147	see page 48 for specific cuts	5·78
rabbit loin	n/a		56	133	**59**	**138**	62	144	cook in 72 °C / 162 °F bath to core temperatures to prevent mushiness	5·239
suckling pig loin	n/a		56	133	**58**	**136**	60	140		

(temperatures in orange are those that we prefer)

EXAMPLE RECIPE

RIB EYE WITH CHERRY MUSTARD MARMALADE AND PORCINI

ADAPTED FROM ALAIN DUCASSE

Yields 1 kg (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beef rib eye, bone in, 5 cm / 2 in thick	800 g	100%	① Vacuum seal together. ② Cook sous vide in 54 °C / 129 °F bath to core temperature of 53 °C / 127 °F, about 1¼ h.
Unsalted butter	40 g	5%	③ Sear surfaces with blowtorch.
Shallots, finely minced	50 g	6%	④ Sweat until shallots are tender but not browned.
Fennel, finely minced	25 g	3%	
Neutral oil	12.5 g	1.5%	
Pickled cherry brine see page 5·267	150 g	19%	⑤ Add to shallot mixture. ⑥ Reduce to 100 g to form cherry marmalade.
Red wine vinegar	50 g	6%	
Red wine (Pinot Noir)	40 g	5%	
Quatre épices see page 2·403	0.5 g	0.05%	
Black peppercorns, crushed	0.4 g	0.05%	
Juniper berries, finely ground	0.4 g	0.05%	
Coriander seeds, finely ground	0.15 g	0.02%	
Pickled cherries, finely minced see page 5·267	100 g	12.5%	⑦ Whisk into marmalade.
Grain mustard	40 g	5%	
Morello cherry puree	35 g	4.5%	
Pressure-cooked mustard seeds see page 303	8 g	1%	
Porcini (fresh)	100 g	12.5%	⑧ Slice porcini very thinly, and quickly sauté until golden and cooked through.
Neutral oil	as needed		
Salt	to taste		⑨ Slice meat to desired thickness. ⑩ Season meat, marmalade, and mushrooms, and arrange on plates.

(published 2001, adapted 2010)

Flaky sea salt is a great way to finish a cooked piece of meat or fish. It adds crunchy bursts of saltiness. The only problem is that the salt tends to dissolve into the natural juices by the time the dish reaches the table. Hervé This came up with a solution: toss the salt crystals with oil or fat. A thin layer of oil then separates the flakes from the cooking juices and prevents the salt from dissolving.

VENISON LOIN ROSSINI ADAPTED FROM YANNICK ALLÉNO

Yields 1.1 kg (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Venison rack (first four ribs only), bones frenched	600 g	100%	① Vacuum seal together.
			② Cook sous vide in 65 °C / 149 °F bath to core temperature of 56 °C / 133 °F, about 25 min.
Olive oil	45 g	7.5%	③ Let rest at room temperature for 10 min.
			④ Reserve.
Duck foie gras, sliced 2.5 cm / 1 in thick	200 g	33%	⑤ Vacuum seal.
			⑥ Cook sous vide in 55 °C / 131 °F bath to core temperature of 54 °C / 129 °F, about 20 min.
			⑦ Hold for further 20 min at temperature to pasteurize (optional).
Truffle jus see page 4·53	150 g	25%	⑧ Heat jus until just warmed.
Game broth or brown chicken stock see page 2·304 or page 2·296	100 g	16.5%	⑨ Simmer pasta shells in game broth and mushroom jus until al dente.
Semolina pasta shells	50 g	8.5%	
Mushroom jus see page 2·348	30 g	5%	
Heavy cream, warmed and whipped	25 g	4%	⑩ Fold into pasta.
Salt	to taste		⑪ Slice venison into individual rib chops.
Summer truffle, peeled, thinly sliced and ring cut into 1.25 cm / ½ in circles (optional)	as desired		⑫ Cover top of each loin portion with truffle slices, if using.
			⑬ Slice foie gras into sections 1 cm / ⅜ in thick.
			⑭ Season venison, foie gras, and pasta.
			⑮ Arrange evenly among plates, and garnish with truffle jus.

(published 2006, adapted 2010)

PARAMETRIC RECIPE

TENDER POULTRY SOUS VIDE

As we discuss in chapter 3 on page 1·174, poultry is often singled out for special concern with respect to food safety. One reason is that it is usually sold whole with the skin on, which increases the likelihood of contamination. Another reason is that farmed poultry can harbor *Salmonella* without showing symptoms. In wild birds, surface contamination can be propelled inside the meat by gunshot. Many of the recipes on this page and the following pages will pasteurize meat to the 6.5D level (see page 1·193) if the meat is held for the pasteurization time specified after it reaches the core temperature.

Some of the temperatures indicated are too low to achieve pasteurization, however; in these cases, the space provided for the pasteurization time in the table contains the designation "n/a" for not applicable. These low temperatures are provided for cooking certain red-meat poultry, which has been cooked in this way for generations in Europe. But note that this cooking technique is not as safe as cooking to pasteurization.

COOKING TENDER POULTRY SOUS VIDE

1. **Select an ingredient and target temperature.** The table below provides final core temperatures for many kinds of poultry, both red (top table) and white (bottom table). We prefer the temperatures in orange.
2. **Set sous vide bath to 1 °C / 1.8 °F above the target core temperature.**
3. **Vacuum seal the poultry with any flavorings, fats, or liquids.**
4. **Cook sous vide until the core temperature of the meat reaches the target.** Use a digital probe thermometer, as described on pages 2·202 and 2·243.
5. **Pasteurize (optional).** Hold at cooking temperature for the amount of time indicated in the table to achieve full pasteurization.
6. **Optionally, sear the meat.** See page 2·270 for searing methods.
7. **Season as desired.**

Best Bets for Cooking Tender Red Poultry Sous Vide

	Core temperature for doneness									
	Rare		Hold to pasteurize	Medium rare		Hold to pasteurize	Pink		Hold to pasteurize	
Ingredient	(°C)	(°F)	(h)	(°C)	(°F)	(h)	(°C)	(°F)	(min)	See page
duck breast	52	126	5 h 15 min	54	129	2 h 17 min	58	136	30	5·121
goose breast	50	122	n/a	52	126	5 h 15 min	55	151	40	
grouse breast	50	122	n/a	52	126	5 h 15 min	58	136	30	
ostrich fillet	50	122	n/a	54	129	2 h 17 min	58	136	30	
pigeon breast	52	126	5 h 15 min	54	129	2 h 17 min	58	136	30	5·125

(*temperatures in orange are those that we prefer*)

"Time to pasteurize" is the amount of time to hold *after* the core reaches the specified temperature, if the bath is 1 °C / 1.8 °F above core temperature.

Best Bets for Cooking Tender White Poultry Sous Vide

	Core temperature for doneness										
	Medium rare (slightly pink)		Hold to pasteurize	Medium		Hold to pasteurize	Medium well		Hold to pasteurize		
Ingredient	(°C)	(°F)	(min)	(°C)	(°F)	(min)	(°C)	(°F)	(min)	Note	See page
chicken breast	58	136	30	61	142	13	65	149	2		5·113
chicken "oyster"	61	142	15	65	149	2	68	154	½		
guinea hen breast	52	126	5 h 15 min	54	129	2 h 17 min	58	136	30	best tenderized with a yoghurt- or enzyme-enriched marinade	5·135
pheasant breast	56	133	35	54	129	2 h 17 min	58	136	30		
quail breast	50	122	12 h	52	126	5 h 15 min	54	129	2 h 17 min		101
turkey breast	54	129	2 h 17 min	56	133	35	58	136	30	brine	168

(*temperatures in orange are those that we prefer*)

EXAMPLE RECIPE

POULET AU FEU D'ENFER ADAPTED FROM FERNAND POINT

Yields 1.1 kg (four to eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chicken breasts, skin on	500 g	100%	① Season chicken pieces.
Chicken thighs, bone in and skin on	500 g	100%	② Vacuum seal individually.
Salt	to taste		③ Cook breasts sous vide in **60 °C / 140 °F** bath to core temperature of **59 °C / 138 °F**, about 35 min.
			④ Hold for additional 20 min to pasteurize (optional).
			⑤ Cook thighs sous vide in **65 °C / 149 °F** bath for 1½ h.
Chicken wings, whole, finely chopped	250 g	50%	⑥ Sauté until golden, about 12 min.
Shallots, thinly sliced	100 g	20%	
Unsalted butter	30 g	6%	
Garlic, thinly sliced	20 g	4%	
Brown chicken stock see page 2·296	200 g	40%	⑦ Deglaze wings.
			⑧ Reduce liquid by two-thirds until syrupy, about 10 min.
White wine (dry)	90 g	18%	⑨ Strain sauce.
Red wine vinegar	80 g	16%	
Heavy cream	50 g	10%	
Black pepper, coarsely ground	to taste		⑩ Season vinegar sauce.
Salt	to taste		
Clarified unsalted butter	as needed		⑪ Heat thin film of butter over high heat in two separate pans.
Chanterelles, washed thoroughly	200 g	40%	⑫ Sauté chanterelles until just cooked through, and season with salt.
			⑬ Sear cooked chicken pieces, skin side down only, until skin is just crisped, about 2 min.
			⑭ Slice, and divide evenly among plates.
Chives, finely minced (or chive blossoms)	30 g	6%	⑮ Garnish with vinegar sauce, chanterelles, and chives.

(original ~1930, adapted 2010)

EXAMPLE RECIPE

PIGEON WITH SHELLFISH BUTTER ADAPTED FROM ALAIN CHAPEL

Yields 550 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pigeon breast roulade see page 254	240 g (two roulades)	100%	① Vacuum seal together.
			② Cook sous vide in **55 °C / 131 °F** bath to core temperature of **54 °C / 129 °F**, about 25 min.
Shellfish butter see page 2·329	80 g	33%	③ Hold for additional 2½ h to pasteurize (optional).
			④ Remove roulades from bag, and let rest for 5 min.
			⑤ Reserve infused shellfish butter in warm place.
Spot prawn tails, peeled	180 g (12 tails, 15 g each)	75%	⑥ Vacuum seal tails.
			⑦ Cook sous vide in **50 °C / 122 °F** bath to core temperature of **49 °C / 120 °F**, about 12 min.
Oyster mushrooms, small	80 g	33%	⑧ Sauté mushrooms until just cooked through.
Unsalted butter	12 g	5%	
Salt	to taste		⑨ Season mushrooms, pigeon, and prawns.
Crystallized ginger, small dice	10 g	4%	⑩ Slice each roulade into six pieces, discard ends, and divide among four plates.
			⑪ Garnish evenly with prawn tails, shellfish butter, mushrooms, and candied ginger.

(published 1980, adapted 2010)

EXAMPLE RECIPE

QUAIL WITH APPLE-VINEGAR EMULSION AND WATER CHESTNUTS

Yields 350 g

ADAPTED FROM CHARLIE TROTTER

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Quail, whole, semi-boneless	400 g (four whole)	100%	① Pack cure evenly onto quails. ② Vacuum seal together. ③ Refrigerate for 2 h. ④ Rinse off cure, and vacuum seal quails individually. ⑤ Cook sous vide in 55 °C / 131 °F bath to core temperature of 54 °C / 129 °F, about 25 min. ⑥ Hold at 54 °C / 129 °F for another 2 h 17 min to pasteurize (optional). ⑦ Remove from bags, and allow to rest for 15 min.
Confit cure mix see page 179	60 g	15%	
Brown chicken stock see page 2·296	200 g	50%	⑧ Reduce over high heat to 100 g, and strain.
Apple cider (fresh)	125 g	31%	
Apple cider vinegar	50 g	12.5%	
Shallots, thinly sliced	50 g	12.5%	
Unsalted butter	30 g	7.5%	⑨ Blend into reduction until fully emulsified.
Salt	to taste		⑩ Season.
Chervil	5 g	1.25%	⑪ Whisk into apple-vinegar emulsion, and reserve warm.
Unsalted butter, cubed	40 g	10%	⑫ Sauté water chestnuts and pickled apples in butter until just warmed through, about 2 min, to make topping.
Water chestnuts, peeled, finely diced, and blanched in boiling water for 2 min	40 g	10%	
Sweet pickled apples, brunoise see page 348	30 g	7.5%	
Salt	to taste		⑬ Season topping.
Tarragon, thinly sliced	2 g	0.5%	⑭ Fold into pickled apple and water chestnut topping, and reserve.
Crisp Coat UC or potato starch (National Starch brand)	100 g	25%	⑮ Dry blend powders. ⑯ Dredge cooked quails, and shake off excess coating.
Quatre épices see page 2·403	20 g	5%	
Frying oil	as needed		⑰ Deep-fry quails in 230 °C / 450 °F oil for 35 s. ⑱ Place in center of plates. ⑲ Garnish with apple and water chestnut topping, and apple-vinegar emulsion. ⑳ Dust with additional quatre épices, if desired.
Quatre épices see page 2·403	as needed		

(published 2001, adapted 2010)

PARAMETRIC RECIPE

FISH AND SHELLFISH SOUS VIDE

The cooking temperature for flesh from fish and shellfish is lower than that for meat from mammals and birds—about 10 °C / 18 °F lower. That is because fish and other aquatic creatures live in the comparatively cool comfort of water. Most fish is best cooked at 45–50 °C / 113–122 °F, at least to suit our tastes. But some fish, including many cuts of tuna, should be cooked at 38 °C / 100 °F. Note that none of the temperatures suggested below will pasteurize the fish—neither, however, will cooking at temperatures that the U.S. Food and Drug Administration recommends for fish (see page 1·184).

COOKING TENDER FISH SOUS VIDE

1. **Select an ingredient and target temperature.** The table below provides final core temperatures for many kinds of fish. We prefer the temperatures in orange.
2. **Vacuum seal the fish or shellfish with any flavorings, fats, or liquids.**
3. **Cook sous vide until the core temperature of the food reaches the target.** Use a digital probe thermometer, as described on page 2·243.
4. **Optionally, sear the food by using whichever method you prefer.** See page 2·270 for searing options.
5. **Season as desired.**

The times and temperatures given for "barely cooked" and "tender," and some of the those for "firm," will not pasteurize the fish. See page 1·190 for more food safety information.

Best Bets for Cooking Fish Sous Vide

Core temperature for doneness

Ingredient	Barely cooked (°C)	Barely cooked (°F)	Tender (°C)	Tender (°F)	Firm (°C)	Firm (°F)	Flaky (°C)	Flaky (°F)	Note	See page
black cod	40	104	45	113	48	118	52	126		5·170
cod*	38	100	41	112	45	114	49	122	use same temperatures for cooking ling cod	next
eel	n/a		n/a		54	129	59	138		
escolar	38	100	41	112	46	115	50	122		104
hake*	n/a		44	111	50	122	54	129		
halibut	40	104	42	108	45	113	50	122		187
halibut cheek	n/a		45	113	48	118	52	126	use same temperatures for monkfish and cod cheeks	5·143
hamachi	34	93	38	100	40	108	46	115		5·147
John Dory	n/a		45	113	48	118	50	122		
mackerel	40	104	42	108	46	115	48	118	if cooking to less than 46 °C / 115 °F, brine before cooking	168, 172
monkfish*	42	108	45	113	48	118	50	122		5·151
rockfish	n/a		44	111	48	118	52	126		
salmon*	38	100	41	112	43	109	46	115		
sardine	34	93	38	100	42	108	46	115		
sea bass	n/a		45	113	48	118	50	124		5·175
skate	n/a		48	118	52	126	54	129		5·157
snapper	n/a		48	118	50	122	52	126		
sole	n/a		42	108	45	113	50	122		4·274
sturgeon*	n/a		46	115	50	122	54	129		
trout	37	99	40	104	46	115	48	118		
tuna loin*	38	100	42	108	45	113	48 54	118 129	if cooking to 54 °C / 129 °F, brine in 4% saline solution, refrigerated, for 3 h before cooking	
tuna belly*	38	100	43	109	48	118	50	122		
turbot	n/a		44	111	49	120	52	126		105

(Many stocks of these species are considered overharvested and are protected in several parts of the world. We recommend always checking the status of fish before purchasing. For updates and more details, see the Monterey Bay Aquarium Seafood Watch web site at www.montereybayaquarium.org/cr/seafoodwatch.aspx. Temperatures in orange are those that we prefer.)

VARIATION: COOKING SHELLFISH SOUS VIDE

1 **Select an ingredient and target temperature from the table below.**

2 **Prep as indicated, then vacuum seal as in step 2 at left.** Blanch cockles, clams, mussels, and razor clams by vacuum sealing them while in the shell and immersing the bag in boiling water for 2 min, then shucking. Use a clean bag when vacuum sealing the shellfish again for cooking.

3 **Follow steps 3–5 on the previous page.**

Best Bets for Cooking Tender Shellfish Sous Vide

		Core temperature for doneness										
		Barely cooked			Tender			Firm				
Ingredient	Prep	(°C)	(°F)	(min)	(°C)	(°F)	(min)	(°C)	(°F)	(min)	Note	See page
cockles or clams	blanched and shucked*	48	118	10	56	133	8	65	149	5	cook in its own juice	5·229
langoustine	shelled	48	118	15	56	133	12	70	158	6	sear quickly after cooking	
lobster claws	shelled	54	129	to core	60	140	to core	65	149	to core	best cooked in butter	
lobster tails	shelled	46	115	to core	54	129	to core	59	138	to core	best cooked in butter	5·184, 4·219
					50	122	to core					
mussels	blanched and shucked*	62	144	10	65	149	10	68	154	7	cook in its own juice	5·154
oysters	shucked	45	113	10	48	118	10	52	126	7	cook in its own juice	5·205
razor clams	blanched and shucked*	45	113	10	60	140	10	65	149	5	siphon only	112
scallops	whole	42	108	to core	50	122	to core	54	129	to core		
shrimp (prawns)	peeled	48	118	to core	60	140	7	80	176	4		5·180
					54	129	to core					

(temperatures in orange are those that we prefer)

EXAMPLE RECIPE

LING COD WITH BERGAMOT-INFUSED MILK

ADAPTED FROM MARTÍN BERASATEGUI

Yields 700 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Verjuice (store-bought)	50 g	12.5%	① Vacuum seal together.
Golden raisins	30 g	7.5%	② Cook sous vide in 80 °C / 176 °F bath for 20 min.
			③ Cool completely.
			④ Drain plumped raisins, and reserve for garnish.
Milk	525 g	130%	⑤ Combine.
Heavy cream	25 g	6.25%	⑥ Bring to boil, and then remove from heat.
Bergamot zest, thinly sliced	60 g	15%	⑦ Add to hot milk.
			⑧ Steep, covered, for 10 min, and then strain.
Salt	to taste		⑨ Season infused milk, and reserve.
Ling cod fillet, skin on	400 g	100%	⑩ Divide evenly into four 100 g portions.
Extra-virgin olive oil	80 g	20%	⑪ Vacuum seal individually, with 20 g of oil each.
			⑫ Cook sous vide in 41 °C / 106 °F bath to core temperature of 40 °C / 104 °F, about 25 min.
Salt	to taste		⑬ Season fish.
			⑭ Arrange one portion in each of four bowls.
			⑮ Garnish with plumped raisins and infused milk.

(published 2005, adapted 2010)

If fresh bergamot is unavailable, use bergamot essential oil, page 2·310.

ESCOLAR WITH RED WINE BUTTER ADAPTED FROM ERIC RIPERT

Yields 500 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Yukon Gold potatoes, peeled and sliced 1 mm / ⅓₂ in thick	150 g (one potato)	50%	① Deep-fry in 150 °C / 300 °F oil until crisp and golden brown. ② Drain on paper towels.
Neutral oil	as needed		③ Season chips.
Salt	to taste		④ Reserve.
Red wine (dry)	100 g	33%	⑤ Combine.
Red wine vinegar	45 g	15%	⑥ Reduce to 30 g.
Shallot, minced	10 g	3.3%	
Tarragon	2 g	0.7%	
Black peppercorns	1 g	0.3%	
Thyme	0.5 g	0.17%	
Red wine reduction, from above	30 g	10%	⑦ Blend into reduction until fully emulsified.
Xanthan gum (Keltrol T, CP Kelco brand)	0.5 g	0.17% *(1.7%)**	
Unsalted butter	40 g	13.3%	⑧ Blend into reduction.
Brown butter see page 2·331	30 g	10%	⑨ Strain red wine butter through fine sieve into small saucepan.
Salt	to taste		⑩ Season red wine butter. ⑪ Reserve, keeping warm.
Escolar fillet	300 g	100%	⑫ Cut fillet into four 75 g portions.
Extra-virgin olive oil	80 g	27%	⑬ Vacuum seal individually with 20 g of olive oil each. ⑭ Cook sous vide in 39 °C / 102 °F bath to core temperature of 38 °C / 100 °F, about 20 min.
Salt	to taste		⑮ Season fillets. ⑯ Slice, and arrange in center of serving plates.
Shallot, minced	3 g	1%	⑰ Combine.
Tarragon leaves, thinly sliced	1 g	0.3%	⑱ Garnish center of fish slices.
Black pepper, coarsely ground	to taste		⑲ Drizzle warm red wine butter around plates.
Sea beans, cut into 5 cm / 2 in lengths	4–5 beans		⑳ Top fish slices with potato crisps and sea beans.

(original 2009, adapted 2010)

**(% of total weight of red wine reduction)*

EXAMPLE RECIPE

TURBOT WITH ONION AND MARROW BROTH ADAPTED FROM DAVID KINCH

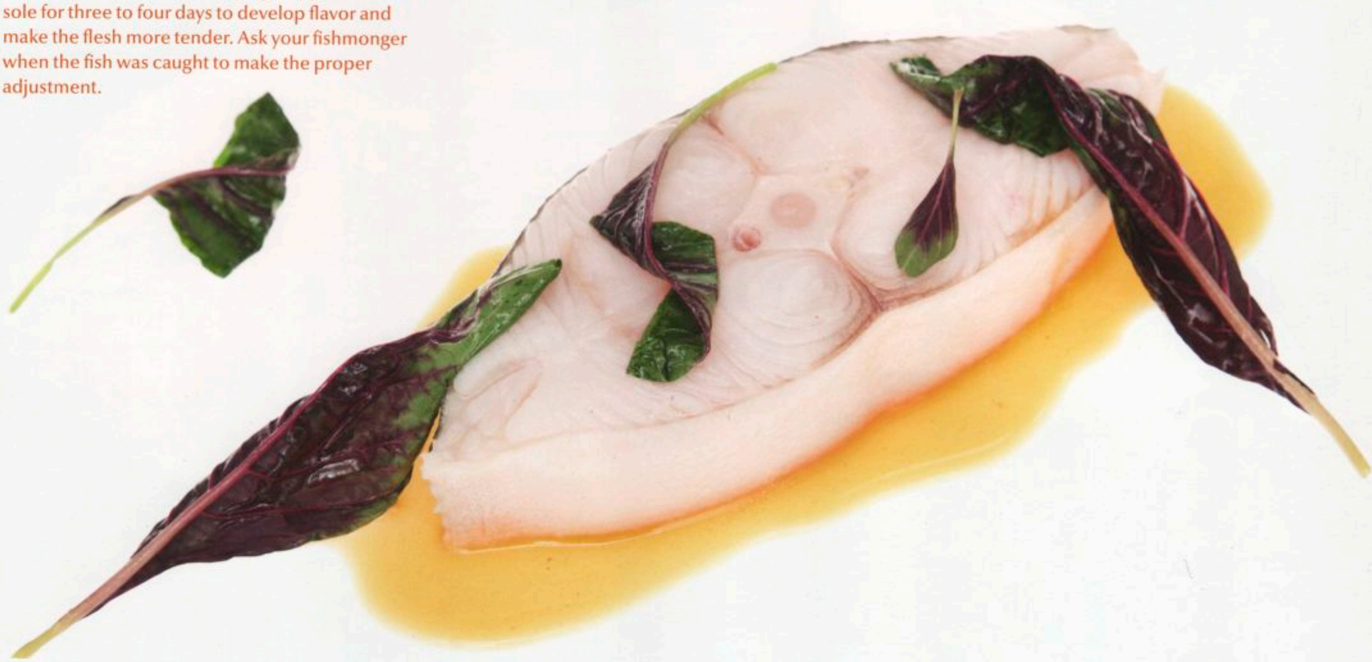
Yields 800 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White onions, peeled and halved widthwise	1.5 kg	250%	① Place in bottom of deep rectangular baking pan, and cover with foil. ② Bake in **230** °C / **450** °F oven for 1 h. ③ Lower oven temperature to **90** °C / **200** °F, and bake for 8 h until most of juice has rendered and collected in bottom of pan. ④ Pass roasted onion juice through fine sieve. ⑤ Measure 250 g. ⑥ Reserve cold.
Veal marrowbones, cut into 7.5 cm / 3 in lengths	1.5 kg	250%	⑦ Bake in **175** °C / **350** °F oven for 30 min to render fat, or render another way (see page 145). ⑧ Strain through fine sieve, and measure 50 g of rendered marrow fat.
Turbot, on bone	600 g	100%	⑨ Cut into four equal portions.
Unsalted butter	40 g	6.5%	⑩ Vacuum seal individually with 10 g of butter each. ⑪ Cook sous vide in **50** °C / **122** °F bath to core temperature of **49** °C / **120** °F, about 25 min.
Roasted onion juice, from above	250 g	42%	⑫ Blend gums into onion jus until fully dispersed. ⑬ Bring to simmer.
Propylene glycol alginate (FMC BioPolymer brand)	0.2 g	0.03% *(0.08%)**	
Xanthan gum (Keltrol T, CP Kelco brand)	0.2 g	0.03% *(0.08%)**	
Rendered veal marrow fat, from above	50 g	8.5%	⑭ Blend into warm onion jus until emulsified. ⑮ Reserve warm.
Amaranth leaves	100 g	17%	⑯ Sauté leaves until just wilted.
Olive oil	10 g	1.5%	
Salt	to taste		⑰ Season jus, amaranth leaves, and turbot. ⑱ Arrange equally in four shallow bowls.

(original 2007, adapted 2010)

(% of total weight of onion jus*)

David Kinch recommends aging very fresh turbot or sole for three to four days to develop flavor and make the flesh more tender. Ask your fishmonger when the fish was caught to make the proper adjustment.



EXAMPLE RECIPE

STEELHEAD TROUT CONFIT WITH FENNEL SALAD

Yields 560 g (four portions)

ADAPTED FROM TETSUYA WAKUDA

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Steelhead trout fillet	400 g	100%	① Remove skin. ② Divide fillet into four 100 g portions, and reserve.
Garlic-infused olive oil see page 2·328	100 g	25%	③ Whisk together. ④ Vacuum seal each fish portion individually with 15 g of oil. ⑤ Reserve remaining 40 g of garlic oil for garnish. ⑥ Refrigerate portions for 2 h to marinate. ⑦ Cook sous vide in 43 °C / 109 °F bath to core temperature of 42 °C / 108 °F, about 25 min.
Thyme essential oil	0.1 g	0.025%	
Rosemary essential oil	0.05 g	0.013%	
Fennel bulb	80 g	20%	⑧ Shave very thin on mandoline.
Black pepper, finely crushed	to taste		⑨ Season fennel shavings.
Lemon juice	to taste		
Lemon-scented olive oil see page 2·328	to taste		
Salt	to taste		
Kombu chips, finely chopped (store bought)	8 g	2%	⑩ Place a portion of fish on each plate. ⑪ Dress each portion with fennel salad and kombu chips.
Flaky salt	to taste		⑫ Season with flaky salt, and drizzle garlic oil around plates.
Steelhead trout caviar	30 g	7.5%	⑬ Garnish fish evenly, and serve.

(published 2001, adapted 2010)

EXAMPLE RECIPE

19TH-CENTURY-STYLE LOBSTER WITH SHERRY AND COCOA

ADAPTED FROM OLIVIER ROELLINGER

Yields 450 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lobster shells and trimmings	50 g	17%	① Sauté together until golden, about 7 min.
Shallot, minced	50 g	17%	
Neutral oil	25 g	8.5%	
Shellfish stock see page 2·296	150 g	50%	② Deglaze pan with shells. ③ Reduce stock mixture to 90 g, and remove from heat.
Amontillado sherry	75 g	25%	
Chervil tips	1 g	0.3%	④ Whisk into stock reduction. ⑤ Cover, and steep for 10 min. ⑥ Strain.
Coriander seeds, toasted	0.8 g	0.25%	
Annatto powder	0.5 g	0.15%	
Tarragon leaves	0.3 g	0.1%	
Vanilla seeds and pulp	0.2 g	0.05%	
Unsweetened cocoa powder	0.1 g	0.03%	
Unsalted butter, cubed	20 g	6.7%	⑦ Warm infused reduction, and blend butter in until fully emulsified.
Lime juice	to taste		⑧ Season sauce, and reserve warm.
Lime zest	to taste		
Salt	to taste		
Sherry vinegar	to taste		
Lobster tails, shelled	300 g (four 75 g tails)	100%	⑨ Vacuum seal individually with 20 g of butter each. ⑩ Cook sous vide in 51 °C / 124 °F bath to core temperature of 50 °C / 122 °F, about 20 min.
Unsalted butter	80 g	27%	
Salt	to taste		⑪ Season.
Green mango, brunoise	80 g	27%	⑫ Garnish with mango and sauce.

(original 2003, adapted 2010)

EXAMPLE RECIPE

SHRIMP COCKTAIL INSPIRED BY GRANT ACHATZ

Yields 280 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Raspberry gazpacho see page 5·277	300 g	100%	① Disperse gelatin into 75 g of gazpacho. ② Bring to boil to fully hydrate, and whisk into remainder of gazpacho base. ③ Cast onto nonstick baking sheet, 2 mm / 1⁄16 in thick. ④ Freeze completely, and cut into 3.75 cm / 1½ in rectangles. Reserve frozen until use.
160 Bloom gelatin	6 g	2%	
Spot prawn tails, peeled	200 g (about 8)	67%	⑤ Vacuum seal together, and cook in 60 °C / 140 °F bath for 7 min. ⑥ Cool completely and remove from bag. ⑦ Reserve refrigerated until use.
Extra-virgin olive oil	30 g	10%	
Garlic clove, crushed	3 g	1%	
Tarragon sprigs	2 g	0.7%	
Celery, peeled, brunoise	6 g	2%	⑧ Align two prawns down center of each plate. ⑨ Season with salt, and garnish with celery, piquillo, olives, and horseradish as desired. ⑩ Lay frozen sheet over prawns and garnish, and allow to thaw and drape over other components of dish, about 5 min, before serving.
Piquillo pepper, brunoise	6 g	2%	
Green olives, thinly sliced	6 g	2%	
Horseradish, finely grated	to taste		
Salt	to taste		

(original 2006, adapted 2010)

PARAMETRIC RECIPE

TOUGH MEATS, POULTRY, AND SHELLFISH

We recommend cooking tough cuts of meat sous vide. The result is a degree of tenderness that traditional cooking methods simply cannot achieve. Select from the temperatures and times listed below to get optimal texture and appearance.

Tough cuts do not magically become tender when a certain temperature is reached. They need to be held for an extended time to fully soften and break down the collagen. Because cooking sous vide does not offer the traditional sensory clues that traditional stewing and braising do, it is a good idea to start with the times and temperatures established by chefs experienced with sous vide methods. Keep a log of your results so that you can chart your preferences. You may also add flavorings or liquids to the bag before sealing and cooking.

Cooking sous vide requires patience. We have also had some good results with pressure-cooking certain meats; times for such cases are given in the table below and are calibrated to sea level—longer cooking times may be necessary at a high altitude. For tips on pressure-cooking, see page 114.

Best Bets for Cooking Tough Poultry

	Cook sous vide						Pressure-cook at 1 bar / 15 psi (gauge)		
	Tender and juicy			Flaky					
Ingredient	(°C)	(°F)	(h)	(°C)	(°F)	(h)	(min)	Note	See page
chicken leg and thigh	**64**	**147**	**1½**	68	154	3	15		100, 5·113
	62	**144**	**15**						
chicken wing	**62**	**144**	**12**	72	162	8			
duck leg	60	140	48	**62**	**144**	**18**	35	best cured before cooking	178, 5·121
	62	144	12	68	154	8			
duck tongue	**88**	**190**	**5**		n/a		25	make sure to debone while still hot	5·81
guinea hen leg	**60**	**140**	**4**		n/a			best marinated in yogurt or other tenderizing solution before cooking	5·135
pigeon leg	**65**	**149**	**3**	68	154	7		cure with confit mix 2 h before cooking	5·125, 179
quail leg	**60**	**140**	**12**	68	154	3			
turkey leg	**62**	**144**	**8**	65	149	2		inject with 10% by weight of 7% brine	174
turkey wing	**58**	**136**	**12**	62	144	18		brine before cooking	4·33, 172

(temperatures in orange are those that we prefer)

The times and temperatures given for "barely cooked" will not pasteurize the food; other time-temperature combinations indicated will. See page 1·190 for more food safety information.

Best Bets for Cooking Tough Shellfish

	Cook sous vide									Pressure-cook at 1 bar / 15 psi (gauge)		
	Barely cooked			Firm			Tender braised					
Ingredient	(°C)	(°F)	(min)	(°C)	(°F)	(min)	(°C)	(°F)	(h)	(min)	Note	See page
abalone	45	113	15	88	190	8 h	**100**	**212**	**12**	35		5·197
octopus		n/a		80	176	3 h	**85**	**185**	**4**	25	freezing and thawing before cooking can increase tenderness	5·193
geoduck	**50**	**122**	**30**	65	149	7	65	190	1½	15	the siphon is quite firm; the belly meat is far more tender	
snail		n/a		65	149	15	**68**	**154**	**5**	20		5·239
squid and cuttlefish	50	122	10	**65**	**149**	**5**	65	149	4	30	apply same temperatures for cooking sea cucumbers	113

(temperatures in orange are those that we prefer)

COOKING TOUGH CUTS

1. **Select an ingredient and target temperature from the tables below.**
2. **If cooking sous vide, set a water bath to the temperature indicated for the desired texture.** If pressure cooking, set the gauge pressure to 1 bar / 15 psi, and cook for the time indicated, and then skip to step 5.
3. **Vacuum seal the food together with any flavorings, fats, or liquids.**
4. **Cook sous vide for the time indicated.**
5. **Serve immediately, or chill and then refrigerate until needed.** Reheat in a bath set to the cooking temperature.
6. **Optionally, sear the food.** See see page 2·270 for searing methods.
7. **Season as desired.**

Best Bets for Cooking Tough Cuts

	Cook sous vide												Pressure-cook at 1 bar / 15 psi (gauge)		
	Firm, steak-like			Tender, yielding			Tender, flaky			Very flaky					
Ingredient	(°C)	(°F)	(h)	(°C)	(°F)	(h)	(°C)	(°F)	(h)	(°C)	(°F)	(h)	(min)	Note	See page
beef cheek	58	136	72	**62**	**144**	**72**	68	154	36	80	176	12	60	remove connective tissue	5·55
beef short rib, bone in	56	133	72	58	136	72	**60**	**140**	**72**	88	190	7	50	texture is best when carved just before serving	5·42
beef brisket	58	136	72	60	140	72	**63**	**145**	**72**	70	158	72		use the fattier, thick end of the brisket called the nose	5·79
beef flatiron	52	126	24	**55**	**131**	**12**	62	144	48	88	190	5		remove central muscle sheath, then apply Activa	5·49
							55	131	48						
flank steak	50	122	3	**55**	**131**	**12**	62	144	36	88	190	7			
beef hanger steak	**50**	**122**	**2**	55	131	12	62	144	36	88	190	6			
							55	131	48						
oxtail	n/a			**60**	**140**	**100**	65	149	48	70	158	24	70		5·49
lamb shank	58	136	48	**62**	**144**	**48**	85	185	5	88	190	5	**60**		5·89
lamb shoulder	**56**	**133**	**48**	62	144	48	**65**	**149**	**24**	85	185	5	40	coat meat with 5.0% olive oil and 0.1% thyme to prevent stronger lamb notes from developing	5·83
pork belly	**60**	**140**	**72**	**65**	**149**	**36**	70	158	18	88	190	8	50	for firm texture, cure with pink brine before cooking	5·101
pork shoulder or fresh ham	54	129	48	60	140	72	**65**	**149**	**36**	84	183	4	60	many individual muscles can be treated like tender cuts	5·78
pork cheek, fat cap on	n/a			**65**	**149**	**38**	68	154	48	85	185	5	35		5·38
pork ribs	n/a			**60**	**140**	**48**	65	149	48	75	167	7			5·78
pork trotter and hock	n/a			n/a			n/a			85	185	12	**120**		5·38
suckling pig shoulder and leg	n/a			60	140	36	**65**	**149**	**24**	80	176	8	60		
rabbit shoulder	n/a			60	140	4	**66**	**151**	**1**	85	185	1		hotter-than-core cooking may be required for younger animals	
veal breast	**54**	**129**	**to core**	62	144	5	68	154	24	85	185	6	**75**	for steak-like texture, use individual breast muscles; remove fat and sinew	111
veal shank	n/a			60	140	72	**62**	**144**	**72**	85	185	8	90	cook veal shanks whole	5·60

(temperatures in orange are those that we prefer)

SUCKLING PIG SHOULDER WITH SHALLOT AND ORANGE SAUCE

Yields 750 g (four portions)

ADAPTED FROM JOAN ROCA

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Suckling pig shoulders	500 g (one shoulder)	100%	① Vacuum seal individually. ② Cook sous vide in 65 °C / 149 °F bath for 24 h.
Extra-virgin olive oil	60 g	12%	
Sugar	20 g	4%	③ Cook in small pot until dark caramel forms.
Brown pork stock see page 2·296	150 g	30%	④ Deglaze caramel. ⑤ Reduce to 150 g.
Orange juice, freshly squeezed and strained	150 g	30%	
Shallots, peeled and halved	400 g (about eight small halves)	80%	⑥ Add to orange sauce. ⑦ Simmer until tender, about 30 min.
Red wine vinegar	10 g	2%	⑧ Season orange sauce and shallots.
Cloves, finely ground	to taste		
Salt	to taste		
Frying oil	as needed		⑨ Debone warm pork shoulders, leaving skins on and keeping structures intact. ⑩ Fry, skin side down only, in thin film of oil, until skin is crisp, about 4 min.
Elderflowers	eight small tufts		⑪ Cut each shoulder in half. ⑫ Distribute among four plates. ⑬ Garnish with shallots, orange sauce, and elderflower tufts.
Flaky sea salt	to taste		⑭ Season pork shoulder and shallots.

(published 2005)

EXAMPLE RECIPE

SOUS VIDE AND PRESSURE-COOKED VEAL BREAST WITH BULBOUS VEGETABLES

Yields 1 kg

INSPIRED BY GRAY KUNZ

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Veal breast, sinew and excess fat trimmed	1 kg	100 %	① Rub veal with oil, and sear both sides in nonstick pan until golden.
Neutral oil	as needed		
White wine (dry)	475 g	47.5%	② Deglaze, and then transfer to pressure cooker.
Apple cider (fresh)	300 g	30%	
White peppercorns, crushed	9 g	0.9%	③ Add to veal-wine mixture.
Bay leaf	0.2 g	0.02%	④ Pressure-cook at gauge pressure of 1 bar / 15 psi for 1¼ h.
Clove	0.2 g	0.02%	⑤ Drain veal, and reserve in warm place with 50 g of cooking liquid.
Cumin seeds	0.1 g	0.01%	⑥ Reserve remaining cooking liquid for vegetables.
Veal breast, central muscle, fat and sinew removed	500 g	50%	⑦ Meanwhile, cook sous vide in 55 °C / 131 °F bath to core temperature of 54 °C / 129 °F, about 1½ h.
			⑧ Allow to rest for 10 min at room temperature.
White cabbage, quartered	475 g	47.5%	⑨ Cook vegetables in oil in bottom of pressure cooker until golden.
Sweet onions, quartered	275 g	27.5%	⑩ Deglaze with reserved cooking liquid.
Leeks, greens removed and halved	175 g	17.5%	⑪ Pressure-cook for 7 min.
			⑫ Remove vegetables, and strain cooking liquid to form sauce.
Shallots, skin on	135 g	13.5%	⑬ Peel skins from cooked vegetables, and reserve warm.
Garlic cloves, with skin	65 g	6.5%	⑭ Reduce strained sauce to glaze.
Vegetable oil	as needed		⑮ Season, and reserve warm.
Unsalted butter	20 g	2%	⑯ Briefly heat cooked vegetables with butter until glazed, about 2 min.
Neutral oil	as needed		⑰ Brown both pieces of veal over high heat for 30 s on each side.
Black pepper, finely ground	to taste		⑱ Season meat and vegetables.
Salt	to taste		⑲ Slice meats as desired, and divide among plates.
			⑳ Pour sauce around.

(published 2001, adapted 2010)

RAZOR CLAM WITH SAUCE VERTE INSPIRED BY ALICE WATERS

Yields 550 g (eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Ramp bulbs (or scallion whites)	100 g	20%	① Vacuum seal. ② Cook in boiling water until tender, about 5 min. ③ Cool in sous vide bag placed in ice-water bath. ④ Drain and reserve.
Ramp greens (or scallion greens)	150 g	30%	⑤ Blanch greens individually in boiling water until tender. ⑥ Shock in ice water. ⑦ Pat dry, and reserve.
Chives	5 g	1%	
Chervil	4 g	0.8%	
Basil	3.5 g	0.7%	
Mint	2.2 g	0.4%	
Caper berries	28 g	5.5%	⑧ Puree with bulbs and blanched greens until smooth, to make sauce verte.
Olive oil	25 g	5%	
Dijon mustard	10 g	2%	
White wine vinegar	10 g	2%	
Salt	to taste		⑨ Season sauce verte, and reserve in refrigerator.
Marcona almonds, toasted	50 g	10%	⑩ Pulse in food processor to crumb-size particles, and reserve.
Razor clams	500 g	100%	⑪ Vacuum seal together. ⑫ Steam or boil at 100 °C / 212 °F for 3 min. ⑬ Chill, in bag, in ice-water bath. ⑭ Remove from bag, and strain clam cooking juices through fine sieve lined with coffee filter, reserving juices. ⑮ Remove clams from shells. ⑯ Clean meat, and vacuum seal with reserved juices. ⑰ Cook sous vide in 60 °C / 140 °F bath for 10 min. ⑱ Chill sous vide bag in ice-water bath. ⑲ To serve, drain, reserving clams and juice separately. ⑳ Slice clams thinly. ㉑ Whisk some reserved juice into sauce verte, to taste. ㉒ Garnish clams with sauce verte and almond crumbs.
White wine (dry)	40 g	8%	
Borage blossoms (optional)	as needed		

(2010)

EXAMPLE RECIPE

SQUID SICILIAN LIFEGUARD-STYLE INSPIRED BY MARIO BATALI

Yields 550 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Garlic, thinly sliced	10 g	5%	① Combine to make cure.
Salt	4 g	2%	
Lemon zest	3 g	1.5%	
Squid tubes, cut vertically to make sheets and surface membranes peeled	200 g	100%	② Spread cure over surface of squid sheets. ③ Vacuum seal, and refrigerate for 15 min. ④ Brush off cure, and cut sheets into thin strips.
Extra-virgin olive oil	10 g	5%	⑤ Vacuum seal strips with oil, and reserve.
Tomato confit, pureed see page 5·62	75 g	37.5%	⑥ Combine, and heat until just warmed through. ⑦ Reserve tomato confit mixture.
Israeli couscous, boiled in 2% brine until al dente, and then cooled	60 g	30%	⑧ Cook squid strips sous vide in 65 °C / 149 °F bath for 4 min.
Pine nuts, toasted	18 g	9%	
Dry currants	15 g	7.5%	
Caper berries, thinly sliced	10 g	5%	
Tomato water see page 2·366	150 g	75%	⑨ Season tomato water generously.
Red wine vinegar	to taste		
Salt	to taste		
Scallions, whites only, fine julienne	30 g	15%	⑩ Spoon reserved warm tomato confit mixture into bottom of bowls. ⑪ Top with squid strips, and garnish with scallions and chili oil.
Chili oil see page 2·330	20 g	10%	⑫ Pour seasoned tomato water around each portion.

(published 2002, adapted 2010)

HOW TO Pressure-Cook Tough Cuts for Quick Results

Although the sous vide technique makes it possible to cook tough cuts of meat to a temperature that maintains the maximum possible juiciness for long enough to gain the perfect degree of tenderness, the time needed to achieve that perfection is sometimes impractical.

Our own 100 hour sous vide oxtail recipe proves this point (see page 5·50). The result is amazing, but it requires you to start cooking more than four days before you want to eat! Pressure-cooking tough cuts of meat can achieve melting tenderness in as little as an hour. The meat won't have the same initial burst of juiciness it would have, had it been cooked low and slow in a water bath. But the gelatin that forms keeps tough cuts such as oxtail, pork shoulder, and duck legs succulent.

For speed, cooking tough cuts of meat in a pressure cooker is unmatched. No busy—and hungry—cook should be without one. So don't let perfection get in the way of completion. Note that the pressure-cooking times given are for sea level; more time may be necessary at a high altitude.

1. **Add 0.5–1 cm / ¼–½ in of water to the pressure cooker.**
2. **Add the meat and any seasonings.**
3. **Heat to a gauge pressure of 1 bar / 15 psi, and then lower heat slowly until hissing steam no longer leaves the pot.**
4. **Vent steam for 1–2 min.**
5. **Cook for 20 min to make the meat firm but tender; for as long as 60 min to make it flaky.** Whole muscles or large portions will take longer to cook.
6. **Cool the pressure cooker under cold running water.**
7. **Lift the meat from the jus.** Reduce the cooking juices to serve alongside the meat or for later use.

EXAMPLE RECIPE

PRESSURE-COOKED CARNITAS

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pork shoulder, boneless, cut into 2 cm / ¾ in cubes	1 kg	100%	① Remove all tendons and sinew. ② Fill pressure cooker with 6 mm / ¼ in water. Add meat. ③ Bring to pressure. When steam emerges, depress valve stem for 2 min to vent fully. ④ Cook at a gauge pressure of 1 bar / 15 psi for 20 min, for tender but firm texture; or 40 min, for flaky texture. Allow pressure cooker to cool for 10 min before lifting meat from cooking juices. ⑤ Coarsely shred meat, if desired; set aside.
Pork cooking juices, from above	200 g	20%	⑥ Reduce cooking juices until slightly syrupy.
Achiote paste	15 g	1.5%	⑦ Combine, and stir into reduced juices to make sauce.
Ancho chili powder	5 g	0.5%	
Chipotle chili powder	5 g	0.5%	
Neutral frying oil	as needed		⑧ Deep-fry shredded meat in 180 °C / 355 °F oil until golden brown, about 1 min. ⑨ Remove three-quarters of meat, straining out oil. Reserve. ⑩ Continue to fry remaining meat until very dark and crisp, about 5 min. ⑪ Combine all meat with sauce.
Lime Juice	to taste		⑫ Season.
Salt	to taste		

(2010)

EXAMPLE RECIPE

MICROWAVED TILAPIA WITH SCALLIONS AND GINGER ADAPTED FROM MRS. ZHU

Yields 550 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Tilapia, cleaned and gutted	800 g (one whole)	100%	① Combine on microwave-safe plate. ② Cover tightly with plastic wrap. ③ Microwave at 600 W for 6 min. ④ Remove scallions and ginger.
Scallion whites, thinly sliced	150 g	19%	
Shaoxing rice wine	5 g	0.6%	
Ginger, peeled and thinly sliced	2.5 g	0.3%	
Scallion greens, julienne	10 g	1.3%	⑤ Mound on top of cooked fish to garnish.
Ginger, peeled and julienne	3 g	0.38%	
Cilantro leaves	1 g	0.1%	
Peanut oil	50 g	6.3%	⑥ Heat to 190 °C / 375 °F. ⑦ Drizzle hot oil over garnished fish.
Soy sauce	25 g	3%	⑧ Combine. ⑨ Pour over fish evenly. ⑩ Lift fillets from bones, and serve with sauce and garnish.
Toasted sesame oil	2 g	0.25%	

(2010)

COOKING SKIN AND INNARDS

Crispy, golden skin is a glorious thing. Almost every cuisine has its own example. In Beijing, it is the skin on Peking Duck. The British love their pork crackling; Spain's equivalent is the *chicharrón*. And for many, the best part of roast chicken is the skin. But cooks face a conundrum: how can you crisp the skin perfectly and, even more challenging, accomplish that without overcooking the flesh beneath it?

It's a dilemma because skin needs to be cooked until dry, whereas the meat should remain juicy. Exactly how much water and fat are removed from skin through cooking, and how quickly, determines whether that skin ends up delicate and crispy, brittle and crunchy, or soft and chewy. With some extra effort, it's possible to achieve the first result rather than the latter two.

Although the science and technique of meat cookery is well-covered territory, food authorities tend to omit any mention of skin or to treat it as an afterthought. They shouldn't. From a biological perspective, skin is a vital organ. This complex material has myriad roles in life—among them protecting, sensing, regulating, sweating, and absorbing. But when cooking it, you can ignore most of these biological nuances and focus on three of skin's most important components.

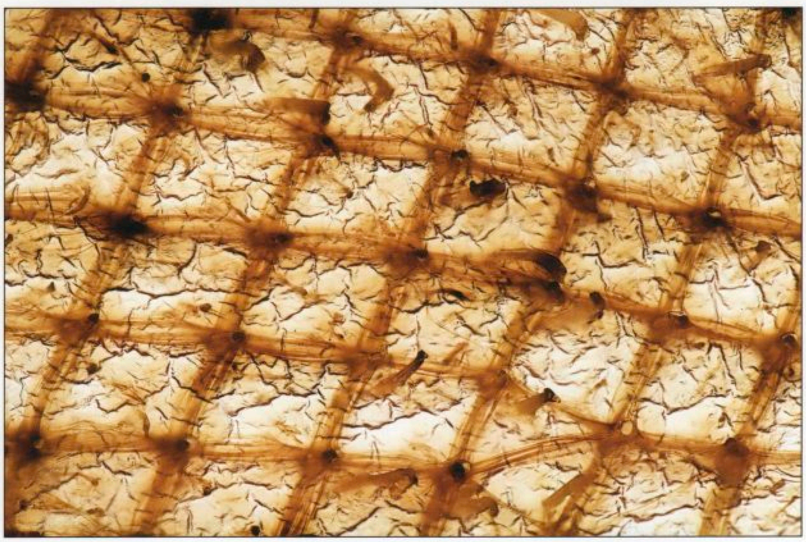
The first is the mesh of connective tissue, woven mostly from collagen, that gives skin its strength and elasticity. Skin is tough because of the long, helical collagen fibers that give it structure. As we discussed earlier in this chapter, collagen fibers are strong and unyielding, but nature weaves individual fibers together for greater strength and to allow some stretch. You can think of skin as a softer and more pliable version of fiberglass cloth.

The second component is water. Skin is surprisingly wet: about 70%–80% water by weight. It often doesn't seem so because the water is trapped within skin's third key constituent: elastic gel.

The gel itself is delicate and would be torn easily were it not for the fabric of collagen fibers woven within it. This collagen gives skin the strength to survive the rigors of daily life. Indeed, biologists believe that the collagen strands actually rearrange their weave at the edges of a cut to stop the mesh from fraying and prevent the tear from growing longer.

The enormous quantity of water bound within skin is essential for the overall health and functioning of a living animal, but from the cook's perspective, this water is a nuisance that must disappear. What many cooks may not realize is that the water is actually needed in order to cook skin in a way that makes it pleasant to eat.

A close-up of duck skin shows a diagonal pattern of fibers. The fibers act much like the threads in woven fabric to give the skin strength. Salmon skin is shown on the next page.



Softening Skin

Because collagen makes skin tough, tenderizing it requires heating to temperatures high enough to unravel helical collagen fibers. But before this happens, the collagen fibers contract, shrinking the skin. If you pay careful attention, you'll notice that skin shrinks more in one direction than the other. This effect occurs because the woven mesh of collagen fibers is oriented in a particular direction. As a result, skin is more elastic in one direction: usually, it can stretch more widthwise than lengthwise, relative to the direction in which the muscle fibers elongate. During cooking, skin contracts more in this stretchy direction.

This detail is worth keeping in mind if you want to ensure that a cooked duck breast, for example, ends up fully covered with a crispy skin. You

should leave extra skin everywhere around the breast during butchery, but leave more on the left and right sides because the skin will contract the most this way.

As the skin cooks, the mesh of corkscrew-shaped collagen fibers contracts, visibly shrinking the skin. Continue cooking for long enough in a very moist environment, and the collagen molecules unwind and split into shorter fragments. Scientifically, this transformation is known as hydrolysis—literally, "water splitting"—although it is sometimes incorrectly called gelatinization because gelatin is the end result. As we discussed in the previous section, this change occurs ever more slowly as the cooking temperature falls below 70 °C / 158 °F and more rapidly as the cooking temperature rises. To soften skin, you must thus convert tough collagen into tender gelatin by applying moderate heat and a lot of moisture for a long enough time.

Skin naturally contains more than enough water for hydrolysis, and it softens quickly in a hot frying pan. But the process can take a long time to complete at the low temperatures favored by many chefs for cooking sous vide. Indeed, the temperatures considered ideal for cooking tender cuts of meat like duck, chicken breast, and pork loin sous vide are often so low that the skin never becomes tender enough. This, along with the desire for crispiness and browning, is why when cooking meat sous vide you typically use a searing or finishing step that cooks the skin further.

The skin of most animals has a layer of subcutaneous (under skin) fatty tissue attached to it. This layer is there to provide cushioning for the animal's internal tissues and, even more important, thermal insulation. Waterfowl like ducks and geese tend to have much thicker subcutaneous fat than do land dwelling birds like chickens. Without this insulating layer, they would lose too much heat when they are in the water.

Thickness also varies from place to place on the body. The belly, for example, tends to be generously endowed with fat. This tendency seems to be the result of a set of genes common to all vertebrates. In pigs this gives us pork belly. In tuna it gives us toro, and it can be seen clearly in our own species by visiting a crowded beach.

Subcutaneous fatty tissue poses its own cooking problems. Fatty tissue is a lot more than just fat—it, too, is full of collagen and connective tissue, and thus qualifies as a tough cut. This composition gives fat its rubbery texture. People don't like to eat rubbery fat, particularly if it lies between crispy skin and tender meat. A second issue is richness—many people prefer to have at least some of the fat content drained.

There are several approaches to cooking skin and fat to the ideal consistency, but none of them are simple, particularly for meat with thick skin and fat, like duck or pork. Peking Duck (see next page) is an elaborate traditional method that works well for skin but less so for meat. Cryosearing (see page 124) uses extreme cold to keep the meat from overcooking as the skin and fat are seared. Other approaches include separate cooking and reassembly (see page 134) and turning the skin into a type of breading (see page 126).

As it cooks, this pork skin contracts because its collagen shrinks. The skin's diagonal pattern lets the shrinkage expose the tender layers of fat beneath, which do not shrink as much as the skin because they contain less collagen.

THE TRADITION OF

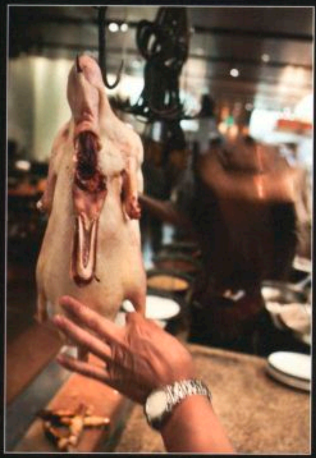
Peking Duck

Peking Duck is one of the great culinary delicacies of the world. A properly cooked Peking Duck has overcooked meat by the usual standards of Western cuisine, but the meat is almost an afterthought; the skin is what makes this dish famous.

The preparation of traditional Peking Duck is an elaborate ritual—as complicated as any Modernist technique in this book. The dish is now made with Pekin ducks, which are force-fed. The birds are specially slaughtered and cleaned, and a small slit is made under one wing so that the body cavity can be emptied and filled with water to cool the meat during cooking. Air is blown through a tube inserted just under the skin at the neck, inflating the skin like a balloon. Boiling water is poured over the duck to blanch the skin, and a sugar and maltose glaze is applied. The duck is then hung up to dry.

Wood-fired brick ovens are used for roasting the birds; intense radiant heat from the walls of the oven cooks the duck from all sides simultaneously. The fruitwood fire also imparts a slightly smoky aroma. The hot, mahogany-brown birds are rushed to the table, where they are carefully carved by a skilled server into, ideally, 108 slices. The slices consist mainly of the crisp skin, with only a small amount of meat attached. The skin is accompanied by various garnishes applied by the diner: small bowls of sugar, thin pancakes, hoisin sauce, and finely sliced scallions and cucumber or carrot sticks.

The result is glorious—a dish containing sweet (from the sugar and hoisin) and sharp (from the scallion) accents that serve as a counterpoint to the crisp skin and unctuous duck fat underneath.



FINGER-LICKIN' CHICKEN

Chicken skin is one of the best parts of cooked chicken, and cooks have evolved many techniques for preparing it. We have covered many of these approaches in this book, but we can't claim to have them all. In addition to the methods pictured here, the techniques used for duck skin (see pages 82 and 124) or pork skin (see page 126) can also be employed, although chicken skin does not have the very thick layer of subcutaneous fat that these meats have, so it is easier to deal with. As with fish skin, chicken skin can also be removed from the meat, cooked sous vide, and then crisped separately between two silicone mats, like a *tuile* (see page 330).

Pressure-Fried Chicken, page 2·120

Beer Can Chicken, page 2·109

Modernist Fried Chicken, page 337

Combi Oven-Roasted Chicken, page 2·178

Ultracrisp Chicken Crown, page 134

Puffed Chicken Feet, page 133

Cockscombs, the flashy top skin that proud chickens show off in display, are often included in descriptions of elaborate French banquets. The original *Larousse Gastronomique* has seemingly endless recipes pairing cockscombs with sweetbreads, truffles, or morels in rich stews and creamy *vol-au-vent* pastries. Like wattles, the fleshy caruncles that hang from the throats of some chickens and turkeys, cockscombs can be prepared the same way as other skin. They should be washed thoroughly inside and out. Parboiling and rubbing will turn them white or gray. They can then be stuffed, braised, or cooked sous vide. Cockscombs and wattles can also be dried, and then puffed.

For more on cryosearing, see the step-by-step procedure on page 124.

For more on the physics of melting, see page 1·304.

Puffed skin (right) is a foam created by residual water in the skin flashing into steam, much as it does in prawn crackers and other puffed fried starches (see page 4·302). Puffing occurs when partially dried skin is subjected to high heat. Without the drying step, you get a very different effect (left).

Cooks often refer to the process of cooking the subcutaneous layer as "rendering" the fat, but true rendering requires a great deal of cooking—even more than tenderizing skin does. Indeed, it is best done in a pressure cooker (see page 145). The temperature and time required for true rendering can't be done while the skin is attached without overcooking the meat. At best, you can achieve partial rendering of subcutaneous fat this way.

Each solution to this problem has advantages and disadvantages. The traditional approach is to sear skin with high heat to make it crispy, heating it for long enough to tenderize and partially render the subcutaneous fat. This can work, but it is a delicate tradeoff between cooking the fat enough and cooking the meat underneath too much.

A surprising solution to that problem is to partially freeze the meat near the skin, in techniques we call cryorendering and cryosearing. First, cook the meat sous vide to the proper doneness. Next, freeze the outer layers. The quick way to do this is to use dry ice or liquid nitrogen to freeze the skin and fat as well as a thin layer of meat beneath them. Finally, sear the surface with high heat in a hot pan, on a *plancha*, with a blowtorch, or in a deep fryer.

It takes a surprisingly large amount of heat to melt the frozen meat, and until it melts, the meat temperature can never climb above freezing. The relatively slow rate of heat conduction ensures that you can cook the fat quite thoroughly without overcooking the meat. We describe these techniques as they apply to cooking duck breast and pork skin in the new few pages, but the general strategy can be applied to other meats and seafood.

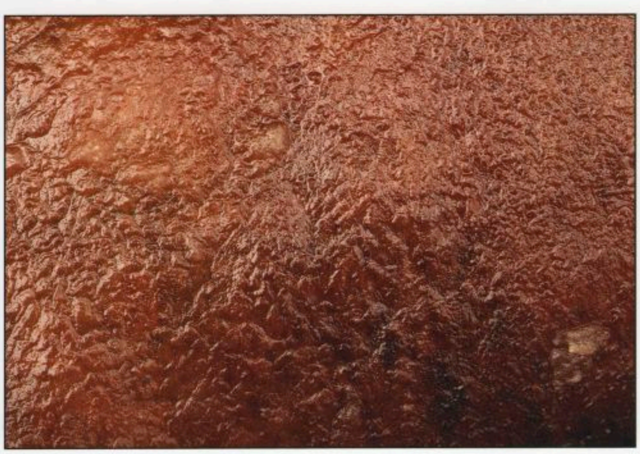
The slow way to cryosear is to freeze the meat solid in a freezer, at which point you can then sear the skin as much as you like. If you are using a *plancha* or pan to sear, then freeze the meat pressed against something flat—vacuum sealing against a flat plate works well. After searing, put the meat into a convection oven to thaw and reheat at low temperature.

Traditional Peking Duck achieves a similar end by different means. The duck's entrails are removed via a hole under one wing. The duck is then filled with cold water before being put in the oven. The water cools the interior of the duck, both directly and through evaporation. This is less effective than freezing but has a similar goal: to cool the meat while the skin cooks.

To drain any rendered fat, cooks traditionally slash or score the skin. That technique works, but we find that it is better to use the bristles of a stiff wire brush (such as the kind used to comb a dog's fur) to poke holes through the skin and into the fat (see page 124). This simple maneuver provides lots of channels for oil to escape. Because the holes are so tiny, it leaves the skin largely intact.

A different solution to the problem is to cook the skin separately from the meat. We have explored several variations on this theme. After the fat and skin have been removed and cooked separately, you can reattach them to the meat with Activa (see page 134). In the case of duck breast, you can either leave the fat on the skin (the cooking step makes it tender) or scrape it off.

With pork skin that is very thick, we reattach



the skin only after grinding it into chunks that puff up to create a kind of pork-rind breading. Subcutaneous fat is much less of a problem with chicken. We actually want a bit more of a layer between the skin and the meat of the chicken, so we make a layer with a ground skin forcemeat.

Of course, you can choose not to reattach the skin and instead serve it as a garnish. This approach is described on page 131 for fish skin, but the same process works with chicken, duck, and other meats. Pork skin or rinds have long been served this way.

Crisping and Puffing Skin

Sometimes, rather than tenderizing skin, you instead want to make it crispy. Doing that means taking most of the water out of it. The simplest way to dehydrate skin is to sear it with high heat. Very thin skin sears well this way. If you find that the meat underneath is overheating, use the methods discussed above to prevent that.

Beyond a certain thickness, skin doesn't respond well to high heat alone. Not enough of the water from the interior of the skin evaporates before the surface starts to burn. The solution is to add a drying step *before* cooking, and to use a relatively low temperature to dehydrate the skin. A subsequent high-heat step can then tackle the crisping.

One approach is to let the skin sit uncovered in a refrigerator to dry, as is traditionally done when making Peking Duck; this also works with chicken and other meats. A more elaborate approach is to use a fan to accelerate the drying. A commercial blast chiller has a powerful built-in fan that makes it a good tool for this.

Another approach is to incorporate a drying step in the cooking, which is done at a low enough temperature that it doesn't overcook the meat. Using a combi-oven is ideal, as our recipe for combi-oven roast chicken on page 2·178 shows.

When drying skin, the moist meat below the skin can serve as a source of moisture that retards the process. A solution is to remove the skin from the meat, dry it partially or completely, and then replace it.

And you don't necessarily need to remove the skin completely; the usual approach in Peking Duck is simply to loosen the skin, for example. We recommend this method for chicken as well (see the recipe on page 2·109). Loosening the skin helps separate it from the meat during the drying and keeps moisture from softening the skin during cooking and searing.

No matter how dry the skin seems, it always contains a little water trapped within it, bound tightly to the proteins that compose the skin. That bound water, also called **vicinal water,** is difficult to vaporize. Never mind; holding a little water inside the skin is a good thing. Indeed, it's crucial for getting the skin to puff up.

When you apply intense heat to the skin, the tiny liquid water droplets in it transform into expanding bubbles of steam, and—poof—the skin puffs. A very hot oven will do, but a deep fryer or a pan with a generous layer of oil serves much better. The heat of the hot oil makes the glassy skin soften and become rubbery, just as heating hard caramel makes it pliable. The heating has to happen fast, however, because in only a few moments, the droplets of trapped water begin to vaporize.

For more on puffing skin, see the step-by-step procedure on page 126. For a recipe that illustrates using ground skin as a subcutaneous layer, see page 134.

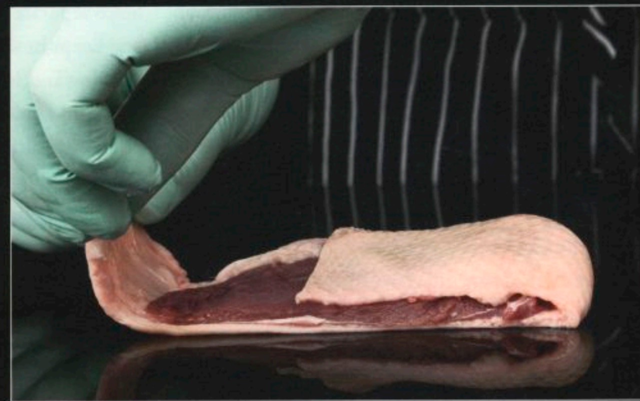
If the dried skin is hot enough to become soft, which requires heating it to 180–200 °C / 355–390 °F, the expanding steam-filled bubbles will stretch the skin into a delicate cellular structure. If it isn't heated enough, or wasn't heated quickly enough, to become soft and elastic when these water droplets vaporize, the steam simply fractures the skin and escapes without puffing up anything.

Whether or not the skin puffs also depends on the number of water droplets present. Too many will prevent the skin from getting hot enough, fast enough. That's because you need to do more than just boil away the water; you also need to superheat the steam to temperatures above 100 °C / 212 °F. And that won't happen if there's a lot of water around. This is the main reason that skin must be dried before frying. But if there are too few droplets, there will be nothing to make steam from. Both in its properties and in how it is made, puffed skin closely resembles puffed starch snacks, which are discussed on page 4·302.

In practice, drying the skin until it is just moist enough to puff takes a bit of trial and error. If everything goes right, the skin will be riddled with fragile bubbles that easily shatter in your mouth, providing a distinctly crisp sensation.

HOW TO Cryosear a Duck Breast

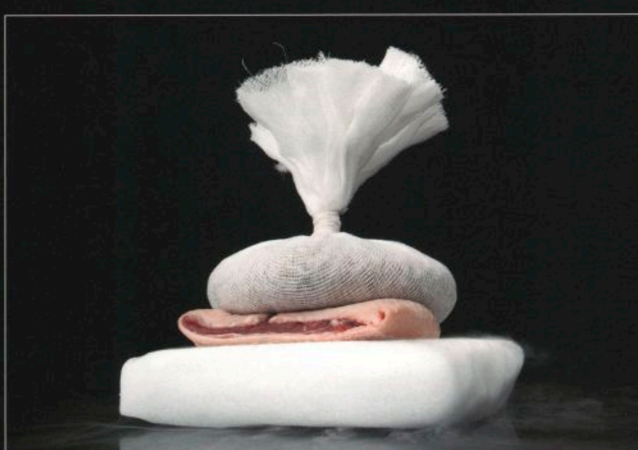
When cooked perfectly, duck is moist but not dripping in fat; its skin is full-flavored yet very crisp. A two-step technique that renders the fat in advance and later sears the skin just before serving can achieve this perfect combination of textures consistently. The trick is to put the duck on dry ice both before and after it is cooked. The same approach can be used for any meat, as long as the layer of subcutaneous fat is not too thick. If dry ice is not available, you can dip the duck breast in liquid nitrogen instead.



1 **Butcher the duck breast, leaving extra skin, and fold the loose skin back over the breast.** Covering the breast with skin helps to keep escaping steam and splattering oil from cooking the flesh as the front is seared. Because skin shrinks during searing, wrapping excess skin around the sides prevents the breast meat from being exposed.

2 **Perforate the skin.** A wire brush is a good tool for making pricks in the skin and underlying fatty tissue with holes so small that they become invisible after cooking. The many points of a Jaccarding (tenderizing) tool also work.

3 **Let the meat rest, skin side down, on a bed of salt for 1 h to begin dehydrating it.** Do not linger too long on this step, or the salt will penetrate the skin and begin curing the meat.



4 **Place the breast, skin side down, on a block of dry ice for 25 min.** About a quarter of the flesh will freeze. Put a weight on top to flatten the breast against the ice (and later the pan or griddle). We use a muslin satchel filled with loose pieces of metal, which conforms to the contours of the meat.

5 **Sear the breast in a pan or on a griddle for 5 min, with the weight resting on top.** The exact time needed to parcook the skin varies with the thickness of the fatty layer under the skin surface. The duck can be refrigerated after this step until you are ready to cook and serve it.

6 Cook to a core temperature of 58 °C / 136 °F. For the best results, cook in a water-vapor oven or combi oven. If using a combi oven, set the temperature to **65 °C / 149 °F** and the humidity to **50%**. If using a CVap water-vapor oven, set the Doneness to **55 °C / 131 °F** and the Browning to **10 °C / 18 °F** higher. We do not recommend cooking the duck sous vide because the humid environment in a vacuum-sealed package keeps the skin too wet, which prevents it from puffing during the crisping step. While cooking, keep the weight warm in the oven.

7 Chill the duck again, skin side down, on dry ice for 5 min. Place the warmed satchel on top to prevent the meat from cooling too much while the skin side refreezes.

8 Resear the breast for 3–5 min in a hot pan with enough oil to cover the skin. Keep the warmed weight on top. The skin will lightly puff and turn golden brown. Trim the excess skin, and then season and serve.

Cryoseared

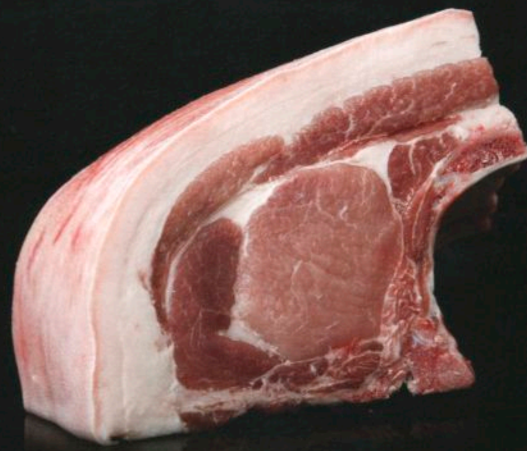
Note that much of the fat under the skin has been rendered. Moreover, heat has not shrunk the meat, which is rarer than that in the conventionally seared breast on the right.

Conventionally seared

Note the shrinkage of meat and thicker layer of fat compared with the cryoseared breast on the left.

HOW TO Puff the Skin on a Pork Roast

A great pork roast is sublime, but too often the skin is less than desirable—or even forgotten altogether. When roasted, pork skin can turn unpleasantly soggy and chewy, hard and crunchy, or both. We prefer pork skin with a delicate, crispy consistency. To engineer that texture, we cook the skin separately from the rest of the roast. Then we chop it to the consistency of a crumble and sieve it to get pieces of just the right size. Finally, we coat the roast with the prepared skin and deep-fry it. Under the intense heat, the small amount of water remaining in the pork skin particles expands to steam, puffing the fragments into something like popcorn. The product is a light, brittle coating that shatters in the mouth, releasing a shower of flavor. For a complete plated-dish recipe, see Autumn Harvest Roast Pork, page 5·17.



Yields 800 g

INGREDIENT	QUANTITY	SCALING
Pork skin, from roast	1 kg	100%
Water	250 g	25%
Rack of pork, skinless, frenched	1 four-rib roast	
Ultra-Sperse M (or tapioca starch)	as needed	
Water	100 g	10%
Methocel K100M (Dow brand)	0.5 g	0.05%
Frying oil	as needed	
Salt	to taste	

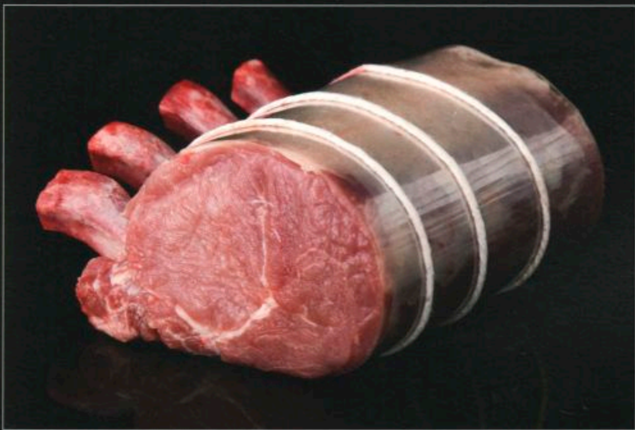
1 **Remove the pork skin from the roast by cutting close to the meat (not shown).**

2 **Cook the pork skin.** Vacuum seal skin with water, and cook sous vide in 95 °C / 203 °F bath for 12 h or pressure-cook for 60 min at a gauge pressure of 1.4 bar / 20.3 psi to complete the transition to a gelatin.

3 **Lay the skin flat with the side toward the meat facing up, and gently scrape away the fat.**

4 **Dehydrate the prepared skin on a baking sheet in a 115 °C / 240 °F oven until the skin becomes rigid.**

5 **Use a food processor to chop the dried skin into small pieces.** Use sieves to remove fragments much larger or smaller than 3 mm / ⅛ in across. Store the crumbled skin in an airtight container with a silica gel desiccant. Use the too-big or too-small pieces for other purposes.



6 **Truss the meat, and cook it.** Bind the frenched and trimmed pork loin with acetate to form a tight cylinder. Cook the roast sous vide to the preferred doneness; we recommend a core temperature of **60** °C / **140** °F.

7 **Plunge the cooked meat in liquid nitrogen for 30 s to freeze a thin surface layer (optional).** You can also ladle nitrogen over the meat. This step helps prevent the pork flesh from overcooking in the fryer.

8 **Dip the meat in warm water for 3 s.** The surface will become tacky.

9 **Coat the meat with a pregelatinized starch such as Ultrasperse M (piece on left in photo below).** Shake off any excess.

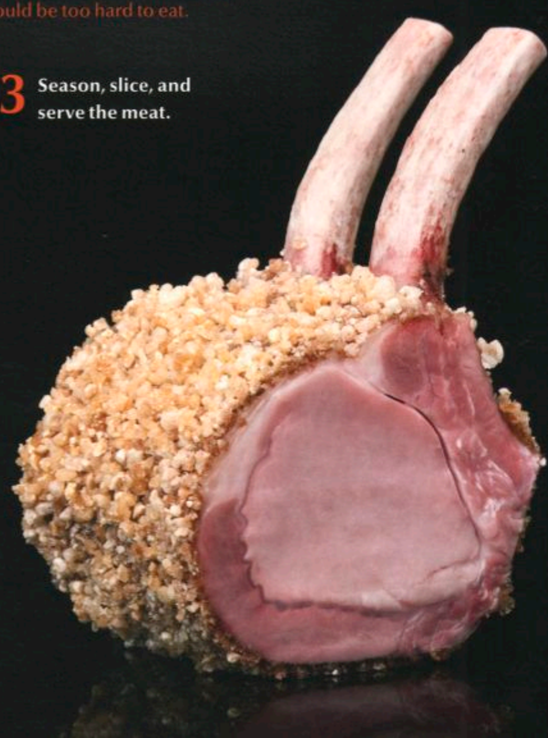
10 **Disperse the Methocel into boiling water.** Cool Methocel solution completely, and whip to stiff peaks. Dip the roast in foam to evenly coat entire surface (middle piece in photo below). For more on making this foam, see page 5·17.

11 **Roll the roast in the crumbled, dried skin to form an even coating (at right in photo below).** Allow 1 min before frying to ensure the skin pieces stay adhered to surface of meat during frying.

12 **Deep-fry the roast in 200 °C / 390 °F oil.** Cook just long enough for the crumbled pork skin to puff into a golden, crispy crust, about 30 s.

This approach works best for meats with a thick skin that otherwise would be too hard to eat.

13 **Season, slice, and serve the meat.**



THE PHYSIOLOGY OF

Slime, the Key to Crispy Skin

Experienced cooks who work with many kinds of fish are familiar with just how much the skin varies from fish to fish. Some species have skin with large scales (tarpon and mahseer have scales measured in centimeters); some have very fine scales (tunas and sharks, for example); and some have no scales (adult swordfish and some catfish). By the same token, all have certain features in common. In particular, all fish skin is flexible enough to sustain the compression and stretching that goes on as the fish swims. The skin must also be strong enough to withstand the force of the muscle contractions that propel the fish.

Whereas the layer of dead cells on the surface of mammalian skin makes it essentially impermeable, fish skin is alive, functional, and permeable throughout. This is why most fish have scales: to protect the living surface of their skin.

Although sweat glands are unique to mammals, fish skin does contain mucus-secreting cells, which provide insulation and protection (some species even secrete poison from their skin to deter predators). The mucus also helps to prevent bacterial infection and makes fish skin less permeable, allowing the animal to maintain its internal salt balance.

The reason cooks should care about the mucus is that it's filled with large polysaccharide molecules that can be dehydrated, by cooking, into a crisp glass. So don't scrape away the somewhat off-putting slime. We learned this from the noted Spanish chef Carme Ruscalleda, who has perfected the art of creating crispy fish skin. It's easy. The heat of the pan serves to slowly dehydrate the skin while transforming the complex sugar molecules within the skin's mucus to give it a glass-like consistency. So if you want crispy fish skin, keep the slime.

One way to ensure that fish skin crisps nicely is to use a trick we learned from Carme Ruscalleda at Restaurant Sant Pau near Barcelona. She found that if you leave the abundant slime on fish skin and then carefully sear it, the complex sugars in the skin transform to make it crispy and fragile.

THE MAKING OF

Puffed Pork Rinds

Our work on puffing skin was inspired by the tradition of puffed pork rinds, a popular snack in the American South. Pork rinds are nothing more than pork skin that has been cooked and then deep-fried so that it puffs into a light, crispy foam.

Successful puffing depends on how you cook and treat the skin. Traditionally, raw or smoked pork skin is dipped in a boiling vat of sweetened brine (1.5% glucose, 1.5% sucrose, and 9% salt in water) for a little less than a minute. This gives the rind some sweetness and saltiness, and the sugar helps the puffed skin develop a golden color rather than remaining pale white.

After a dip in hot brine, the skin is drained, cooled, and cut into small pieces. The next step is heating the bits of skin to 110–120 °C / 230–250 °F to render the contained fat and soften the skin. This is usually accomplished with hot oil, but it can also be done in an oven or even a pressure cooker. Once cool, the pieces of dry skin can be stored frozen for several months if you don't want to eat them right away. (They don't keep as long if they are stored after being puffed.)

To puff them, first dip the pieces of skin in a solution of acetic acid or vinegar, which, for reasons that are not entirely clear, increases the fraction of the pieces that will puff. Then plunge the bits of skin into 200 °C / 390 °F oil. The oil quickly imparts enough heat that the tiny amount of water still remaining trapped in the skin flashes to superheated steam, expanding and puffing the skin. Season and serve the delightfully airy bits of skin.

HOW TO Cook Crispy Fish Skin

Chef Martin Berasategui of his eponymous restaurant in San Sebastián, Spain, has mastered the art of frying small fish with delicious, crispy scales intact, a technique founded in Chinese cooking. He uses sweet red mullet and ladles hot oil down the length of the fish, against the direction in which the scales lie flush. This treatment causes each scale to separate and spike, making the fish look a bit like a spiny hedgehog. The interior of the fish is just cooked through when the scales become crisp and fragile, which makes for a delicious, dramatic presentation. Only small fish with tender scales—such as mullets, small snappers, and sea bream—are appropriate for this technique.

1. **Loosen the scales of a small fish gently by brushing them against the direction in which they lie flush.** Do not detach the scales.

2. **Insert a meat hook through the tail and hang the fish or put it on a cooling rack at a 60° incline.** Place a large pan underneath to catch excess oil.

3. **Ladle hot frying oil at 200 °C / 390 °F down the length of the fish, against the grain of the scales.** Continue ladling until the fish flesh is cooked through and the scales stand up and become crispy, about 2 min.

4. **If using a cooling rack, carefully flip the fish over and repeat on the other side.** The cooling rack method results in less splashing compared to simply hanging the fish, so it is slightly safer.

VARIATION: Crispy Fish Skin Sous Vide

1 **Scale and skin a fresh fish.**

2 **Vacuum seal, and cook the skin sous vide in a 85 °C / 185 °F bath for 3 h.** The collagen will break down, tenderizing the skin and preventing it from shrinking or curling. Cool the skin completely.

3 **To make flat skin chips, brush the skin with oil, season it, and then sandwich it between two baking sheets lined with silicone mats.** Bake in 165 °C / 330 °F oven until perfectly flat and crisp (20–45 min).

4 **To make puffed skin chips, deep fry in 185 °C / 365 °F oil for 1–2 min until very crispy.** Drain on paper towels, and season. Alternatively, brush the skin with oil, and place it between two nonstick silicone mats in a 185 °C / 365 °F oven until it is browned and crispy, about 20 min.

5 **To make skin *tuiles* (right), make a slurry of two parts egg white to one part maltodextrin DE 19, and brush over the surface of the skin.** Lay on a nonstick dehydrator tray, and dehydrate at 50 °C / 122 °F until completely dry and crisp, about 5 h.

This approach also can be used for chicken skin or the skin of other animals, provided that there isn't a thick fat layer (as there is in duck skin). Alternatively, you can scrape the fat layer away after cooking sous vide.

VARIATION: Fish Skin Pillows

H. Alexander Talbot and Aki Kamozawa, the authors of the blog Ideas in Food, make crispy fish-skin pillows by applying a little Activa to the edges of two pieces of fish skin and then sandwiching them together. The deep-fried assemblage swells and crisps like *pommes soufflées* into a delicate, savory textural element. For the recipe, see page 5·161.

MONKFISH WITH CONSTRUCTED SKIN ADAPTED FROM ANDONI LUIS ADURIZ

Yields 420 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cod skins, washed and desalted	1 kg	250%	① Cover with water, and bring to boil. ② Simmer until reduced to one-quarter of original volume. ③ Strain. ④ Reduce broth by half, until it is very thick. ⑤ Measure 150 g of reduction, and reserve.
Water	1.5 kg	375%	⑥ Hydrate gelatin in cold water for 5 min.
160 Bloom gelatin	2 g	0.5%	⑦ Squeeze out excess moisture in gelatin, and then mix into warm reduction until fully dissolved. ⑧ Spread on nonstick surface in layer 1 mm / 1⁄32 in thick. ⑨ Dry at room temperature until dry film has formed, about 1 d.
Vodka	2.5 g	0.63%	⑩ Mix together.
Edible silver powder	0.5 g	0.13%	⑪ Paint onto film with brush. ⑫ Dry film at room temperature for 3 h. ⑬ Cut into 5 cm / 2 in squares. ⑭ Reserve in airtight container.
Monkfish fillet, trimmed and cut into 5 cm / 2 in cubes	400 g	100%	⑮ Vacuum seal together. ⑯ Cook sous vide in 48 °C / 118 °F bath to core temperature of 47 °C / 117 °F, about 20 min.
Extra-virgin olive oil	30 g	7.5%	
Salt	15 g	4%	⑰ Season monkfish. ⑱ Lay piece of film "skin" on top of each monkfish cube.

(original 2007)

For more on making edible films, see page 4·60.

Photo courtesy of José Luis López de Zubiría—Mugaritz

EXAMPLE RECIPE

PUFFED COCKSCOMB

Yields 100 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cockscombs	100 g	100%	① Vacuum seal together.
White chicken stock see page 2·301	50 g	50%	② Cook in 85 °C / 185 °F bath for 2 h to gelatinize skins. ③ Cool. ④ Remove from bag. ⑤ Dehydrate at 50 °C / 120 °F until cockscombs are half their original weight, about 2 h.
Frying oil	as needed		⑥ Deep-fry cockscombs in 190 °C / 375 °F oil until slightly puffed, very crispy, and no longer bubbling, about 5 min. ⑦ Drain on paper towels.
Salt	to taste		⑧ Season.

(2010)

EXAMPLE RECIPE

PUFFED CHICKEN FEET

Yields 80 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chicken feet	500 g	100%	① Vacuum seal together.
Water	100 g	20%	② Cook sous vide in 90 °C / 194 °F bath for 12 h.
Salt	2 g	0.4%	③ Drain. ④ Remove bones using scalpel and tweezers. ⑤ Dehydrate at 115 °C / 240 °F for 3 h.
Frying oil	as needed		⑥ Deep-fry chicken feet in 190 °C / 375 °F oil until puffed, 30–45 s. ⑦ Drain on paper towels.

(2009)

Puffed chicken feet are the chicken equivalent of a puffed pork skin or puffed snack (see page 4·302). Feet work well because of their high gelatin content.

ULTRACRISP CHICKEN CROWN

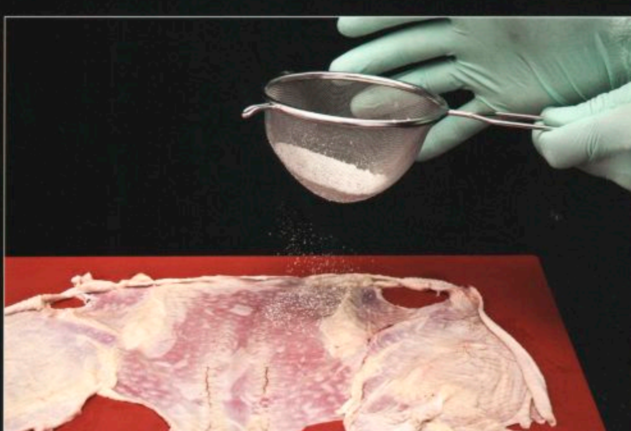
Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whole chicken skin, removed in one piece	200 g	20%	① Lay flat, feather side down, on silicone mat.
Salt	2 g	0.2%	② Dust evenly over skin. ③ Refrigerate uncovered for 12 h to dehydrate.
Chicken skin pieces, chopped	250 g	25%	④ Combine, pack tightly into Pacojet, and freeze.
Activa GS	5 g	0.5%	⑤ Process three times; pack firmly and freeze thoroughly after each cycle.
Salt	2.5 g	0.25%	⑥ Alternatively, puree in food processor, and pass through fine sieve. ⑦ Spread onto dehydrated chicken skin in even layer 2.5 mm / ⅛ in thick.
Skin, from above	280 g	28%	⑧ Dust Activa GS around perimeter of skin.
Activa GS	3 g	0.3%	
Chicken crown	1 kg	100%	⑨ Place skin over chicken crown, and tuck in all edges. Vacuum seal. ⑩ Refrigerate for 30 min to ensure all air pockets between skin and meat are removed. ⑪ Refrigerate uncovered for at least 5 h before assembly.
Liquid nitrogen	as needed		⑫ Cook chicken crown in convection oven at 65 °C / 149 °F to core temperature of 60 °C / 140 °F, about 40 min.
Neutral frying oil	as needed		⑬ Lower temperature to 60 °C / 140 °F, and hold for 1 h. ⑭ Heat oil to 200 °C / 390 °F. ⑮ Dip cooked chicken crown in liquid nitrogen for 30 s, preferably with wire hook. ⑯ Deep-fry in hot oil for 45 s. ⑰ Repeat dipping in liquid nitrogen and deep-frying until crown is golden and very crispy, about three cycles.
Salt	to taste		⑱ Carve chicken from crown, and season with salt.

(2010)

The same cryofrying process can be applied to an unadulterated chicken crown or whole chicken. Here, we've added the pureed skin layer to keep the skin crisper for longer. The pureed skin layer prevents the moisture in the meat from permeating the skin as readily as it does with a traditionally roasted chicken.

The pureed skin with Activa is essentially a skin forcemeat or sausage.



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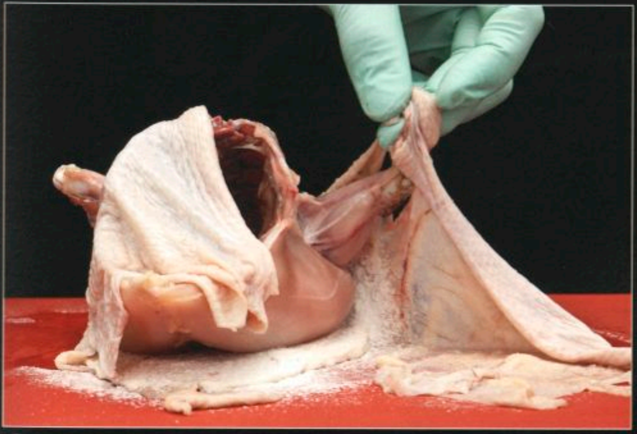
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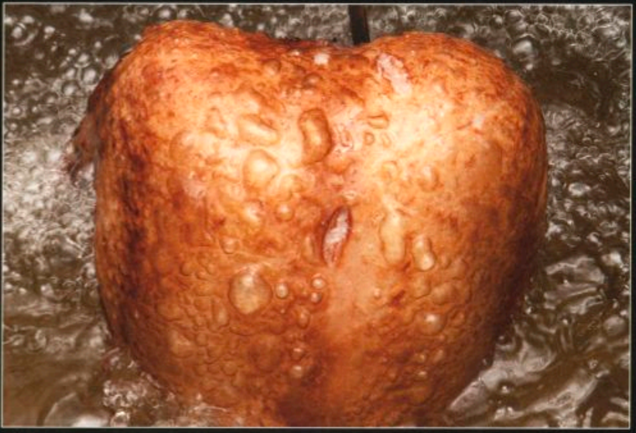
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Cooking Innards

Of all the foods eaten today in the world, none is inherently revolting; their status is entirely based on cultural expectations and conventions. As a result, many people who are perfectly content to be carnivorous are uncomfortable with—even squeamish about—the notion of eating the guts of an animal. Few things reflect cultural bias and taboo as much as the consumption of innards.

Many organ meats are often soaked in water or milk as an initial cooking step. For specific recommendations, see page 146.

From the beginning of time, obtaining an entire animal for slaughter was a prized event; it was unthinkable to let any part of the beast go to waste, from the snout to the intestines to the brain. But to the increasingly urbanized population in westernized countries, the process of rearing, slaughtering, butchering, cooking, and ultimately eating an animal is alien. These days, meat is sold in convenient portions, neatly packaged and divorced as much as possible from any resemblance to an animal. Indeed, the more we ascribe humanlike traits to a species, the more this is true.

Eating an organ reminds many people that they are, after all, eating a food that was once a vital part of a living animal. That is a discomforting reality for a lot of diners.

In our opinion, this is unfortunate. Both the biological and the culinary differences among various innards is far greater than the difference among cuts of meat taken from various skeletal muscles. A liver is entirely different from a sweetbread, and a kidney has nothing in common with bone marrow; but a rib steak is not vastly different from a rump steak.

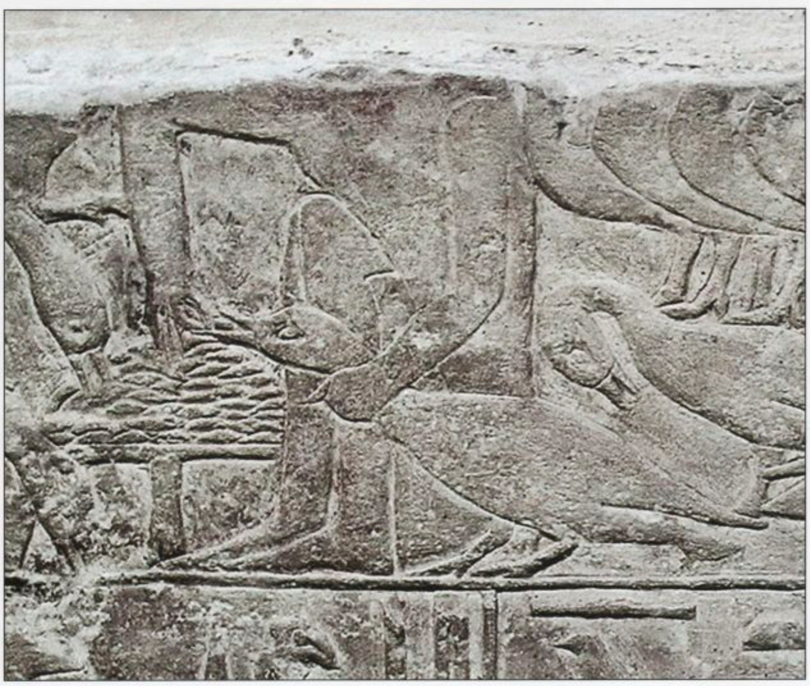
Cuisines around the world are resplendent with recipes that celebrate these differences. Across Asia, Eastern Europe, Africa, the Middle East, and Latin America, myriad regional dishes use every part of an animal to delicious ends. Once upon a time, cooked offal dishes were equally popular in Europe and North America. They are less so in those regions today, in no small part because affluence and the economies of scale of industrialized agriculture afford the opportunity to eat only premium muscle cuts of meat—or as the idiom has it, "high on the hog."

But a handful of Western chefs, most famously London-based Fergus Henderson, have become devotees of cooking offal and promoting the pleasure of "nose to tail" eating. This style of cooking now holds sway among culinary aficionados in the West and, as a result, more and more chefs have begun to offer various parts of animals on their menus. In the process, they are learning—or relearning—some principles and practices related to preparing offal of all kinds.

Case in point: when it comes to innards, freshness is everything. Unlike skeletal muscles, the tenderness and flavor of which can improve with some aging, old innards are simply unpleasant. But what constitutes fresh can be deceptive. Many people, cooks and chefs included, do not equate fresh with frozen. But for most organ meats, it so happens that frozen is almost always freshest.

Freezing preserves freshness in this case by halting the action of enzymes. In skeletal muscles, the enzymatic reactions responsible for aging meat work at near-freezing temperatures. Enzymes are no different in an organ; indeed, organ tissues often have even greater numbers of especially active enzymes, as a result of their biological functions in life. The changes wrought by these enzymes in the minutes and hours after an animal is slaughtered quickly degrade freshness. Only freezing halts these changes, and any damage caused by freezing is, in our opinion, a reasonable tradeoff.

A bas-relief from an Egyptian tomb shows a worker force-feeding a goose to produce foie gras, a delicacy that appears to date to 2500 B.C.



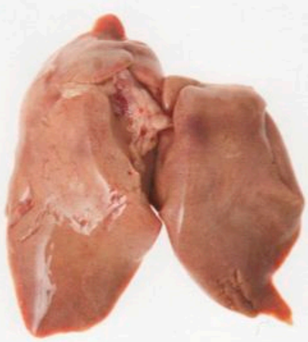
Tripe, made from the lining of the stomach, has a distinctive, geometric texture unlike that of any other part of the animal.

Liver and Foie Gras

The liver is the janitor of the body: the organ that (along with the kidneys) cleans up the blood by capturing and neutralizing toxins in it. The liver is also the chemical refinery that performs many of the functions of metabolism, such as breaking complex carbohydrates into simpler sugars, building amino acids and proteins from basic nutrients, and converting fats from one form to another. One of the liver's products is bile, that bitter, dark, alkaline fluid that flows into the small intestine to aid in the chemical digestion of food. Bile is what gives liver its slightly bitter taste.

Because the liver plays so many roles in the physiology of animals, many of the nutrients that the body absorbs from digested food are processed there or stored in the organ for later use. In other words, the liver is the end of the meal! The liver consumes a lot of energy in its work, so it is highly perfused with blood and myoglobin and thus takes on a dark-red color. These iron-bearing compounds also impart a slight metallic taste.

Lightly cooked liver has a mild aroma. Cooking at too high a temperature, however, creates potent sulfur compounds, which strongly affect the flavor. As is true of most organ meats, neither the taste nor the texture of liver improves with age—with one important exception, which we discuss below. Although the liver of many animals is a routine ingredient in many cuisines, one particular form of liver has long commanded special interest from chefs. That form, of course, is foie gras, the fattened liver of a duck or goose.



The dark liver of a calf (top) hardly resembles the pale liver of a fattened Moulard duck (foie gras, left), and the much smaller liver of a fattened chicken (foie blonde, above).

As a delicacy, foie gras dates back at least as far as ancient Egypt and was popular in ancient Greece and Rome as well. Some historians credit its introduction into Europe to the Jews of the Diaspora.

Not just any animal can yield foie gras: the secret lies in the biology of a select few varieties of ducks and geese that store huge quantities of fat in their livers as an energy reserve for migration. Overfeeding stimulates this natural process and produces foie gras in several breeds. Among the most popular are the domesticated Toulouse goose and the Moulard duck, or "mule duck," the sterile hybrid offspring of a female Pekin duck (*Anas peking*) and a male Muscovy duck (*Cairina moschata*).

Not surprisingly, because the liver is the center of detoxification, it's filled with enzymes. These chemicals cause havoc if freed from their cellular confines, which usually occurs after slaughter through a process known as autolysis—literally meaning "self-splitting" but perhaps best thought of as "self-destruction." The damage done by autolysis eventually ruins the cellular structure of the organ, yielding foie gras with an unpleasant, grainy, and greasy texture when cooked.

To avoid this problem, a few producers freeze their foie gras. Unfortunately, the process is somewhat tricky: if not done just right, freezing can cause as much damage as it prevents. The wrong way to freeze foie gras is simply to put it into a freezer at −20 °C / −4 °F. The liver freezes so slowly at this temperature that ice crystals have time to grow quite large. The crystals tend to grow *between* the cells of the liver rather than within the cells, and as they do so, they draw unfrozen water out of the cell through the process of **osmosis**, dehydrating and rupturing the cells in the process (see Freezing and Melting, page 1·304).

When you cook a liver frozen this way, the melting ice crystals release a gush of water that percolates toward the surface of the organ, leaving the foie gras riddled with holes and tunnels once occupied by ice. At the same time, molten fat leaks from the ruptured cells. As a result, the texture of such foie gras will be rubbery, dry, and greasy.

The correct way to freeze foie gras is thus fast—quickly enough that ice crystals don't have time to grow very large. Foie gras producers like Rougié in France use liquid nitrogen to chill the

THE PATHOLOGY OF

Hepatic Steatosis and Foie Gras

The liver not only cleans toxins from the blood but also stores a mixture of fat and glycogen within itself. In birds (and in some fish), these stores provide a ready source of energy for long migrations. As they prepare for migration, some bird species increase the fat content of their livers to 40% or more of the organ's weight. This process is known to pathologists as hepatic steatosis or (when it occurs in certain ducks or geese) *foie gras*—French for "fat liver."

In hepatic steatosis, storage sacs known as vesicles inside liver cells swell up with fat. The number, size, and way in which these vesicles are distributed inside the cells all have important effects on the quality and texture of foie gras.

Two distinct patterns of distribution are common. In the first pattern, called microvesicular steatosis, numerous small, fat-filled vesicles are distributed fairly evenly inside the liver cells (technically known as hepatocytes).

The second pattern, macrovesicular steatosis, usually involves one very large vesicle swelling inside a liver cell. This fat-filled vesicle tends to become so large, in fact, that it pushes the other contents of the cell to the periphery. The Spanish chef Andoni Aduriz, working with Raimundo García del Moral, professor of medicine at the University of Granada, has gathered evidence that the average size and distribution of these vesicles may be the dominant factor in explaining the final texture of cooked foie gras.

If the foie gras liver is primarily composed of cells that have macrovesicular steatosis, then cooking causes the cell membranes and the large, fat-filled vesicles to rupture and fuse together, creating large pools of oil. This guarantees a greasy eating experience.

Livers with mostly microvesicular steatosis, in contrast, tend to have fewer fused fatty vesicles and thus do not ooze with oil. In reality, even the best foie gras falls short of perfection and contains both large vesicles of fat and small ones. This explains, in part, why one lobe of foie gras can have some wonderful sections and other sections that are best thrown away.

Unfortunately, without a great deal of time and a good microscope, there is no ready way for a cook to judge the distribution of fat types in foie gras.

The natural process of hepatic steatosis causes vesicles in the livers of migratory birds to fill with fat. In the macrovesicular pattern (left), a few vesicles grow very large. When the foie gras is cooked, these giant vacuoles fuse and rupture, thereby making it greasy.

In the microvesicular pattern (right), many smaller, fat-filled vesicles are found throughout the organ. This pattern makes it better able to retain its fat when cooked.

For a recipe for fried sweet-and-sour sweetbreads, see page 201.

liver from body temperature to −55 °C / −67 °F within 20 minutes of harvesting it from the bird. As long as the liver remains deeply frozen, the enzymes cannot degrade the texture. When combined with the best artisanal methods of rearing and feeding the ducks or geese, cryogenic freezing produces a foie gras of the highest quality.

But preserving a lobe of foie gras at peak freshness will have been for naught if it isn't also prepared well in the kitchen. Although the number of preparations chefs have devised for foie gras is virtually uncountable, the very best approach—at least for any cooked foie gras dish—is sous vide. Indeed, cooking foie gras was the original gastronomic use of sous vide cooking (see page 1·42). We provide numerous examples of foie gras dishes prepared using sous vide techniques throughout this chapter, and our best bets for cooking temperatures and times can be found on page 2·276.

Sweetbreads

Tagged with a delicious-sounding (if slightly misleading) name, sweetbreads are actually two different glands: the thymus and the pancreas. The thymus is cylindrical and comes from the throat of the animal, whereas the pancreas is more spherical and is located in the chest near the heart. All mammals have both glands when they are young, but as the animal grows, the thymus shrinks in size, with most of its mass being replaced by fat.

As glands, the thymus and pancreas are involved in a variety of roles in life, including supporting the immune system, regulating metabolic hormones, and aiding in digestion. Although they differ in shape, size, and purpose, these two organs—as well as all other glands—share the same basic organization: a collection of specialized cells forms the bulk of the organ, and a thin sheath of connective tissue holds the tissue together. Often the glands have the appearance of several smaller lobes bunched together. A network of blood vessels throughout the tissue supplies cells with oxygen and nutrients, and ferries off molecules synthesized by the gland.

Given their commonalities, sweetbreads and all other glands are prepared and cooked in similar ways. Usually, you must cut away an insulating and protective layer of surrounding fat, and then soak the organ in acidulated water—usually nothing more than cold water with a slug of vinegar. The acidic solution helps loosen the collagen fibers that make up the surrounding membrane so that it is easily peeled away. Soaking also helps to remove blood left in the vessels.

Freshness is paramount; a sweetbread should have only a mild odor and should be pale pink to light gray in color. As with the liver, the cells that compose sweetbreads are filled with large amounts of enzymes that can quickly spoil the texture and flavor. Refrigeration, or even freezing, will slow or halt the destructive work of these enzymes. When cooking sweetbreads, heat them to the desired core temperature relatively quickly, and serve them promptly: the cooking temperatures that achieve the ideal soft and creamy texture are not high enough to destroy the enzymes that will ultimately turn them to a chalky mush. The traditional techniques of quickly sautéing, breading, and frying sweetbreads, or simply grilling them, all work well. But cooking them sous vide is ideal. The steady temperature of a water bath makes it easy to achieve a perfect rich, silky consistency from the surface to the core.

Tongue

The tongue is technically a skeletal muscle, just like tenderloin. Unlike the tenderloin, however, the tongue is not a single muscle but rather an intricately organized network of muscles; each muscle runs in a different direction to give the tongue the dexterity it needs to push food around during chewing. In humans, the assortment of muscles also make it possible for the tongue to contort itself to form speech.

A tough tissue, closely related to skin, also covers the tongue, the upper surface of which is dotted with various receptors that sense everything from tastes like saltiness and sweetness to the painful sensation of capsaicin, as well as the temperature and texture of food.

In ruminants (animals that chew their cud) like cattle, the tongue is an extremely hard-working set of muscles that is almost constantly in motion. As a result, it is both flavorful and very tough.

But none of this matters when cooking tongue, because the skin-like cover is peeled away and discarded. The underlying muscle itself is fairly tough and generally benefits from cooking slowly at low temperatures, making it meltingly tender due to its high collagen content, which is converted into gelatin. Hot-pickling is another popular approach that can be combined with low-temperature cooking and slow-cooking; in this method, the pickling acid helps soften the muscle's connective tissue. Because tongue muscles run this way and that, a large tongue is often sliced thinly to maximize its tenderness by minimizing the strength of the crisscrossed muscle fibers. Duck tongues, however, are so small that they are cooked whole, either by braising or by deep-frying. Be aware that duck tongues contain a supporting bone down the center, which is best removed before serving.

Kidney

The kidneys are, in mammals, bean-shaped organs that are surrounded by generous layers of fat, which provides both insulation and protective padding. The pair of kidneys in an animal together help regulate the composition of blood by filtering it—effectively acting as a **reverse osmosis** filter for the body. Crucially, the kidneys also keep the volume of water in the body constant by removing excess water from the blood as they remove waste in the form of urine. Because of their role in life, kidneys spoil quickly, and they must be absolutely fresh to be palatable.

The layer of fat surrounding a kidney has a pronounced flavor prized by some (and strongly disliked by others). Beneath this fat, the kidney itself is sheathed in a thin membrane of tough connective tissue that should be peeled away. At the center of a kidney is a hardened core that should be carved out before cooking.

Quickly searing kidneys over a grill and serving them rare to medium rare is one popular approach. In England, broiled kidneys were once a common breakfast dish, but these days, braised kidneys in a steak-and-kidney pie are more popular. The type of kidney is not particularly crucial in our opinion; some say calves' kidneys are the best, others prefer lambs', and we really like pigs' kidneys. We also recommend small, delicate rabbit kidneys. No matter what type you use, it bears repeating that freshness is paramount.

Gizzard

The word "gizzard" derives from the Latin *gigeria*, meaning "giblets." The gizzard is a muscular organ found in the digestive tract of birds and some other animals, including many reptiles. It is essentially a powerful involuntary muscle, and like other involuntary muscles, it is made from smooth muscle tissue, which has a very different structure from that of skeletal muscle. Strong and elastic, smooth muscle contains a relatively high proportion of elastin, a stretchy, fibrous protein woven through the connective tissue to give it more elasticity and strength. The muscle fibers themselves are organized into layered sheets that, together with the elastic connective tissue, allow the muscle to stretch and shrink. Elastin does not break down with cooking, and gizzards will thus always have a slightly chewy texture.

This chewiness is exacerbated in gizzards by nearly indestructible fibers of keratin (the same fibrous structural proteins that make up hair and nails), which binds the muscles to the inner grain sac. The tough keratin fibers also don't soften with cooking. It is thus important to cut away these fibers and some of the tissue beneath the membrane to ensure that they have all been removed. Do this by slitting the gizzard open and removing the bag full of grit at the center, and then laying the butterflied muscle flat and slicing away the membrane lining between the muscle and the sac.

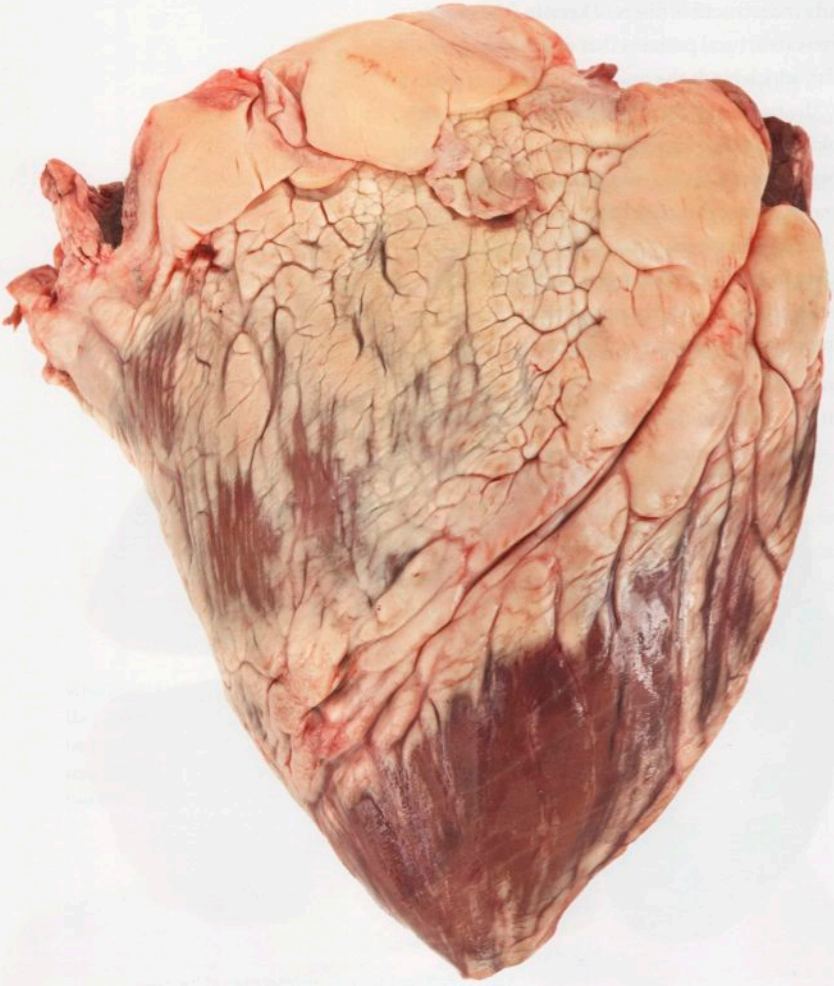
Kidneys (left) and gizzards (right) are two of the many organ meats that are delicious when properly prepared.

At St. John restaurant in London, the very popular heart kebab is made from diced heart threaded on a skewer, and then quickly grilled with a little salt and pepper. Armandino Batali of Salumi in Seattle serves rich, braised ox heart sandwiches on Valentine's Day. In some cultures, cooks stuff and then slowly bake smaller hearts.

Chicken gizzards are the most popular kind of this organ used as food, and turkey gizzards add an unmistakable touch to Thanksgiving gravy. A briefly seared gizzard is quite firm and chewy, a texture appreciated by some. Long, slow cooking will, however, give the muscle a texture reminiscent of a braised pig's ear, a more yielding texture that is pleasant but not exactly tender.

In general, a gizzard can be prepared in two ways. It can be seared quickly but left mostly raw for a chewy texture like that of the heart. Or it can be slow-cooked sous vide or pressure-cooked for a more tender texture. Gizzards are excellent breaded and fried like Southern-fried chicken. Chinese chefs like to cut the flesh into small cubes, marinate them briefly in a mildly alkaline slurry with baking soda, and then stir-fry them.

Because the heart is constantly in motion, its tissue is very tough and has a texture that is quite different from that of skeletal muscle.



Heart

The heart is the one muscle in an animal that moves incessantly as long as the animal is alive. It is thus unsurprising that this organ is unlike any other muscle. Although obviously an involuntary muscle, the tissue of the heart differs from smooth muscles, such as those in the gizzard and the stomach. It is more closely related to skeletal muscles, such as the tongue, but has adapted to be highly resistant to fatigue.

The sheaths of connective tissue that cover cardiac muscle fibers are much stronger than those in skeletal muscles, and they contain a large fraction of elastin, which helps the heart rebound from each contraction to refill with blood. The high elastin content is the source of the distinctive, resilient texture of cooked heart meat. Heart is a very lean meat and is edible in virtually all animals. Always peel away membranes, veins, and arteries on the surface, and when preparing larger hearts, such as those from ox, remove the lower pumping chambers. The organs from older animals tend to be tougher because of extended use and are improved with tenderizing marinades.

When braising heart, the meat will never become truly tender as a brisket might, although it will soften slowly with moist, low-temperature cooking or more quickly with pressure-cooking. Another strategy, popular in many parts of the world, is to simply grill thinly sliced or diced heart meat. It should be charred but still rare so that the meat is pleasantly chewy but not extremely tough.

Stomach and Intestines

The stomach and intestines of mammals have always been prized as containers: the intestines for sausages and the stomach for Scottish haggis and Icelandic blóðmör (technically, a type of sausage), in which the stomach of a sheep is stuffed with blood, oats, and fat. In the culinary world, intestines are often referred to as chitterlings or chitlins, whereas the stomach is called tripe or maw.

Tripe is found in many classic Mediterranean stews. It is a common sight in Vietnamese pho soup and on Chinese dim sum carts. Menudo, a Mexican tripe and hominy soup, is considered a world-class hangover remedy and is often served on Sundays. Hog maw and chitlins, stewed and then deep-fried, make up a classic dish from the American South. Fish maw—the air or gas bladder of fish—is sometimes used in Asian stews, most notably Chinese fish maw soup.

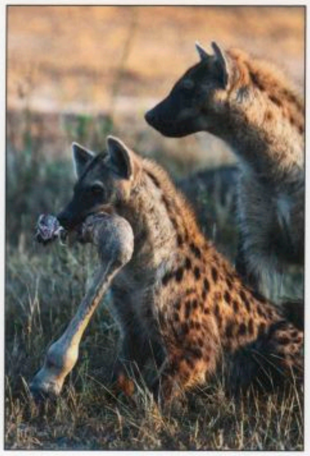
Tripe can be found in several varieties, even from a single animal, because ruminants, such as goats and cows, have multiple stomachs. Each stomach performs a different function and thus has a lining of slightly different composition. The most commonly seen are the rumen, or smooth tripe, and the reticulum, or honeycomb tripe.

Because they are directly connected to the exterior of the animal, the intestines and stomach are not sterile at the time of harvest—far from it. So they must be meticulously cleaned before they are brought into a kitchen. The interior of the organs is often scraped and then thoroughly rinsed. We recommended soaking them, followed by long, slow, moist cooking. Tenderizing marinades can be particularly useful when soaking these kinds of offal. Although use of acidic marinades is a common strategy, a potent alkaline marinade prepared from a 2% solution of sodium tripolyphosphate is exceptionally good for tenderizing these cuts. Be sure, however, to soak the stomach or intestines in fresh water to remove excess amounts of the phosphate salts before cooking.

Steamed and then grilled or fried, these tissues can have an amazing texture: crispy, chewy, and tender all at once. When cooked sous vide for long enough or pressure-cooked briefly, they can also be transformed from tough and chewy to soft and tender, with a unique texture revered in many parts of the world.

Bones and Marrow

Although people rarely think of them as such, bones are an organ, too. Anatomically speaking, the skeleton is a cartilaginous substance impregnated with calcareous salts—in other words, mineralized tissue that is porous and slightly flexible but still very strong. Besides supporting the body, the bones also supply blood: the soft marrow at the center of bones creates both red and white blood cells. Joints, which are complex assemblies of cartilage, tendons, and ligaments, are crucial ingredients in many stocks and sauces. Although bones themselves have little flavor, these connective tissues and the pieces of flesh attached



Bones are an important animal tissue, although we don't tend to think of them in that way. Bones are about 40% collagen and other protein by weight, and a few animals, like the hyena and the lammergeier (also called the bearded vulture), have specialized digestive tracts that can digest bones. Bones also protect another key tissue: bone marrow, the soft, fatty, sponge-like network that makes blood cells. Bone marrow is a delicious but well-protected treat.

to them make ribs, oxtails, shanks, and other bones very flavorful indeed.

The red marrow inside smaller bones has little flavor, but the fatty white marrow in large bones such as the femur (thighbone) is delicious. You can collect the marrow by cutting the bone into shorter lengths and soaking these in cold water for several hours until the marrow is loose enough to pry it free, or you can simmer or roast the bone to soften the marrow so that it can be gently pushed out or even eaten straight from the bone. We like to cook marrow bones sous vide at 60 °C / 140 °F for 40 minutes to preserve the delicate, custard-like texture of bone marrow. For example uses of marrow, see our plated-dish recipes for osso buco, page 5·60, and Suet Mousseline, page 5·8.

Special elongated silver spoons were historically served at formal meals for collecting the marrow from osso buco or roasted marrow bones.

Blood

Blood is perhaps the most divisive of ingredients. Some embrace it as a healthful and inherently natural food, whereas others abhor blood-eating as an abomination. As a food, it is rich in vitamins and protein and is the best available source of iron. In fact, it is the iron-bearing hemoglobin molecule that gives blood its characteristic metallic taste.

For a recipe for blood sausage, see page 238.

The thickening and gelling properties of blood make it a popular ingredient worldwide. Many classic sauces are thickened *au sang*, "with blood." Civet, jugged hare, and traditionally made coq au vin include blood as an ingredient, both for its flavor and to add texture to the sauce. Blood is sometimes combined with bland starches, such as oatmeal and rice, and packed in casings to make the ubiquitous blood sausages found throughout Europe. Blood soup is a somewhat less common Scandinavian dish, and tofu-like blood cakes are often served in Asia.

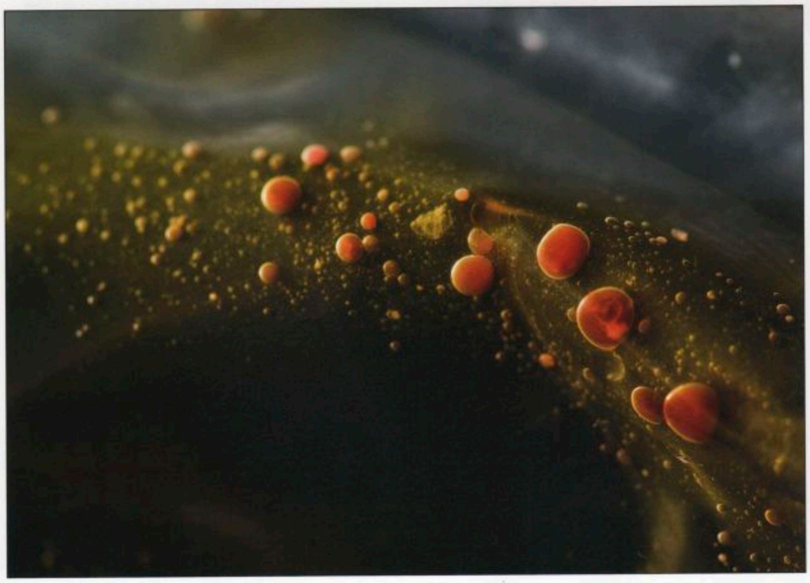
All of these preparations take advantage of blood's clotting ability. Sometimes, however, a cook may want to keep the blood from clotting because it can lend a distinct, slightly gritty texture to a preparation. The easiest way to prevent clotting when cooking with blood is to keep the temperature below 70 °C / 158 °F. An example of a rich and thick blood pudding made without coagulation of the blood can be found on page 4·221.

Fat

Fat may be the only type of offal considered a culinary staple. Kitchen fats are primarily adipose tissue, whose principal functions include serving as insulation and padding beneath the skin. Sections that contain a lot of fat, like the fatty areas around organs and in the backs of pigs, are the most prized.

These fats may seem accessible and ready to use, but the fat still needs to be removed from the cellular structure—that is, rendered—before it will combine with other ingredients. Fats can be rendered wet, by simmering, pressure-cooking, or cooking sous vide, or dry, by roasting, searing, or grilling (see next page). Dry-rendering is probably a more common approach in most kitchens, but wet-rendering preserves the integrity of the fat so that it stays fresher for longer. Wet-rendered fat also performs better than dry-rendered fat as a frying or deep-frying medium.

Animal fat is primarily used as a cooking medium or ingredient, rather than as a food in its own right. Some fats, such as the web-like caul fat that surrounds the abdominal organs in some animals, are strong enough that they are used as natural casings for sausages or pâtés.



Fat and meat juices emerge from a lamb shank cooked sous vide.

STRATEGIES FOR RENDERING FATS

Fat in meat is locked into specialized cells that need to be ruptured before it can be collected and used. The process of collecting pure fat from fatty tissue is called rendering. Rendering must do more than melt the fat; it must also break down the nonfat part of the tissue, and that takes both time and heat. In general, the yield from rendering is improved by finely dicing or grinding the fat before you start. One common source of fatty tissue for rendering is skin; another is fat and connective tissue trimmed from meat. Once the fat is cut or ground, you must apply heat—either wet or dry—via one of several different approaches. The time required for rendering depends entirely on the type of fat and what animal that fat is from, but typically it takes 2–4 hours to do a good job of rendering.

Dry-Rendering

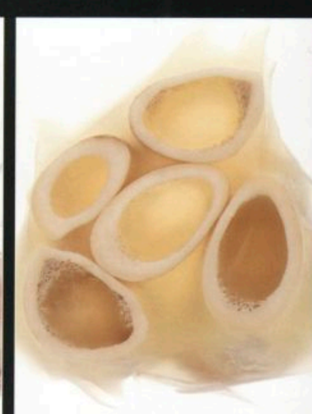
Dry-rendering is as simple as sautéing chopped or ground fat in a pan at low heat, as when frying bacon. A convection oven at 160 °C / 320 °F is better than a frying pan because it is less likely to burn the fat. Dry-rendered fat tends to be flavorful, but the high temperature affects the fat molecules, making the fat go rancid sooner and giving it a lower smoke point.

Wet-Rendering

In wet-rendering, the meat is covered with water and either boiled or, better yet, pressure-cooked for 2–4 h. Pressure cookers have two advantages for rendering: they work at a higher temperature than a regular pot, and they are not plagued by the rapid water movement that occurs during boiling, which can emulsify some of the fat. Wet-rendered fat does not have the roasted flavor of dry-rendered fat, but it keeps longer and has a higher smoke point, so it is better suited for frying or sautéing than dry-rendered fat is. Putting some bromelain in the water will help clarify the fat.

Pressure-Rendering

Our favorite technique for rendering is to wet-render in a pressure cooker with the addition of 0.4% (of the weight of the fat) of baking soda. Pressure-cook in a canning jar for 4 h, and decant off the fat. The aroma will be very strong at first, so leave the jar open to cool. The result is unbelievable—a better flavor than dry-rendered meat, with the other qualities of wet-rendered meat, and a remarkably clear appearance.



Rendering Sous Vide

Rendering fat sous vide is a variation of wet-rendering. It is tidy and offers full temperature control and minimal oxidation, so the fat stays fresh longer and can be used for frying. Vacuum seal ground fat or bone marrow and cook it in a 88 °C / 190 °F bath for 3–4 hours. By packaging the food in a retort pouch or canning jar, you can render fat this way in a pressure cooker.

PARAMETRIC RECIPE

OFFAL SOUS VIDE

Organ meats are ideal for cooking sous vide: the tender varieties benefit from precise temperature control, and the tough ones require slow-cooking to tenderize them. As with other sous vide recipes, any of the times and temperatures given below may be used to cook the meat without vacuum packing if the low-temperature steam mode of a combi oven or water-vapor oven is used (see page 2·154).

COOKING OFFAL SOUS VIDE

1. **Prepare the meat.** Many organ meats require an initial preparation step, such as blanching or soaking in water or a marinade.
2. **Vacuum seal.** Most offal recipes require no other ingredients.
3. **Cook sous vide to the desired doneness.** The tables below list recommended temperatures; those printed in orange are our favorites. Estimated cooking times are given in some cases; in others, "to core" indicates that cooking should continue until the core temperature of the food reaches the recommended temperature.
4. **Sear (optional).**
5. **Chill and set (for meat served cold).**

Best Bets for Cooking Tough Offal Sous Vide

	Tender, juicy			Braised texture				
	(°C)	(°F)	(h)	(°C)	(°F)	(h)	Note	See page
beef and veal tongue	68	154	12	67	153	48		5·49
duck tongue	70	158	8	88	190	5	remove central bone while still hot	5·81
chicken gizzard		n/a		60	140	12	cure before cooking	5·125
veal heart		n/a		80	176	5		
honeycomb tripe		n/a		88	190	2		
cockscomb		n/a		85	185	2	blanch and peel before cooking	133

(times in orange are those we prefer)

Best Bets for Cooking Tender Organ Meats Sous Vide

	Medium rare			Pink			Medium				
	(°C)	(°F)	(h)	(°C)	(°F)	(h)	(°C)	(°F)	(h)	Note	See page
duck foie gras	50	122	to core*	54	129	to core*	60	140	to core*		5·109
				56	133	to core*					
poultry liver	52	126	to core*	56	133	to core*	60	140	to core*		
veal liver	58	136	to core*	62	144	to core*	65	149	to core*	soak in milk or water for at least 8 h before serving	
lamb sweetbreads		n/a		55	131	2	65	149	1	soak in water for at least 5 h before serving	
veal sweetbreads		n/a		60	140	1	67	153	1		5·31
cock's kidney		n/a		70	158	20 min		n/a		panfry briefly after cooking for best texture	5·125
kidney (mammal)		n/a		56	133	to core*	60	140	1	pork kidney is ideal because it is often milder tasting than other types of kidneys	

**(If cooked just to these core temperatures, these meats may not meet food safety guidelines. To pasteurize, hold at the cooking temperature for the period of time given by the table on page 1·184. Times in orange are those we prefer.)*

EXAMPLE RECIPE

ANKIMO TORCHON

Yields 450 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Monkfish liver (ankimo-quality)	500 g	100%	① Remove main veins. ② Cover in water, and soak refrigerated for 3 h, changing water every 30 min. ③ Drain and reserve.
Water	200 g	40%	④ Whisk together to make brine.
Sake	50 g	10%	⑤ Vacuum seal monkfish livers with brine, and refrigerate for 24 h.
Salt	8.75 g	1.75% (*3.5%*)*	⑥ Drain. ⑦ Roll livers together into tight cylinder by using plastic wrap.
Sugar	6.25 g	1.25% (*2.5%*)*	⑧ Vacuum seal. ⑨ Cook sous vide in 63 °C / 145 °F bath to core temperature of 62 °C / 144 °F, about 35 min. ⑩ Cool, and refrigerate overnight to allow flavors to mature.
Daikon, julienne	as desired		⑪ Slice monkfish liver, garnish with daikon, and serve with ponzu.
Sous vide ponzu see page 2·313	as desired		

(2010)

(% of total combined weight of water and sake*)

Many recipes for foie gras, liver, sweetbreads, and other offal include a soaking step before cooking. For kidneys, this step serves a very simple purpose: to remove any trace of the animal's bodily fluids. Recipes often call for soaking foie gras, liver, and sweetbreads in milk. It is often said that milk improves the taste, purges blood, lightens the color, or affects some other property of the meat. We were skeptical, so we tried several experiments. With a mild-flavored organ meat like foie gras, we could taste a difference, but, frankly, in our tests, we prefer the taste of water-soaked to milk-soaked foie gras. With stronger-flavored organ meats, there is even less of a difference than with foie gras. So our suggestion is to simply soak the meat in water.

FOIE GRAS AND BUTTON MUSHROOM TART

ADAPTED FROM PASCAL BARBOT

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Verjuice (store-bought)	1 kg	140%	① Marinate foie gras in verjuice for 3 h.
Duck foie gras, Grade A	700 g	100%	② Cut carefully into slices 5 mm / 3⁄16 in thick, and reserve.
Button mushrooms	450 g (12 large mushrooms)	65%	③ Peel, and rub with lemon juice to prevent discoloration. ④ Slice very thinly on mandoline, and reserve about 20 slices for garnish.
Lemon juice	16 g	2%	
Roasted-hazelnut oil	10 g	1.5%	⑤ Season remaining mushroom slices, and reserve.
Orange zest, finely grated	3 g	0.4%	
Black pepper	to taste		
Salt	to taste		
Maple syrup	40 g	5.5%	⑥ Whisk together to make maple butter.
Unsalted butter, melted	20 g	3%	
Brik pastry sheets	three pieces		⑦ Lay one sheet of pâte à brick on silicone mat. ⑧ Brush carefully with maple butter. ⑨ Repeat with other two sheets until three-layer pastry stack is formed. ⑩ Punch out 12 cm / 4¾ in circles from stack, using pastry cutter; makes about 20 rounds. ⑪ Place rounds on baking sheet between two silicone mats. ⑫ Bake in 160 °C / 320 °F oven for 12 min.
Dried mushrooms, ground to fine powder	as needed		⑬ Arrange seasoned mushrooms on each pâte à brick round. ⑭ Top with slices of marinated foie gras. ⑮ Dust lightly with mushroom powder. ⑯ Top with reserved, unseasoned mushroom slices. ⑰ Dust with more mushroom powder.
Eggless citrus curd see page 4·234	70 g	10%	⑱ Slice rounds (tarts) into quarters. ⑲ Serve with dab of curd on side.

(original 2000)

Raw foie gras is an underutilized ingredient. Traditionally, foie gras is cured and then poached or baked for making cold terrines. But a beautifully fresh foie gras lobe can also be treated like any other meat destined for raw preparations. The texture is unctuous, and the flavor is very clean.

EXAMPLE RECIPE

FOIE GRAS SOUP WITH BOMBA RICE AND SEA LETTUCE

Yields 800 g (four portions)

ADAPTED FROM ANDONI LUIS ADURIZ

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Foie gras lobe (Grade B)	600 g	100%	① Cut into two or three large pieces, depending on size. If three pieces, cut off ends by about 1 cm / ½ in to facilitate removing blood.
Whole milk	1 kg	167%	② Whisk until salt has dissolved, and bring to 30 °C / 86 °F.
Water	1 kg	167%	③ Add foie gras pieces; keep submerged for 3 h.
Table salt	10 g	1.7%	④ Remove foie gras from milk brine, and pat dry.
Sunflower oil	50 g	8.3%	⑤ Sear brined foie gras until golden brown on all sides.
			⑥ Bake in 130 °C / 265 °F oven to core temperature of 58 °C / 136 °F.
			⑦ Remove, and place weighted sheet pan on top of foie gras to press out excess fat and blood.
			⑧ Rest in warm place for 5 min.
Extra-virgin olive oil	10 g	6.7%	⑨ Sweat until lightly golden, about 7 min.
Yellow onion, finely chopped	25 g	4.2%	
Bomba rice	50 g	8.3%	⑩ Add rice to onion, and toast for 5 min.
White vegetable stock, brought to a boil see page 2·303	500 g	83%	⑪ Pour in hot vegetable broth, and simmer for 15 min.
Sea lettuce (fresh)	50 g	8.3%	⑫ Add to rice, simmer for 5 min, and remove from heat.
			⑬ Cover pot, let stand for 15 min, and pass through fine sieve.
Salt	as needed		⑭ Season broth.
			⑮ Slice foie gras into four portions, each 4 cm / 1½ in thick, and place in center of four warm bowls.
			⑯ Finish with rice broth.

(original 2001)

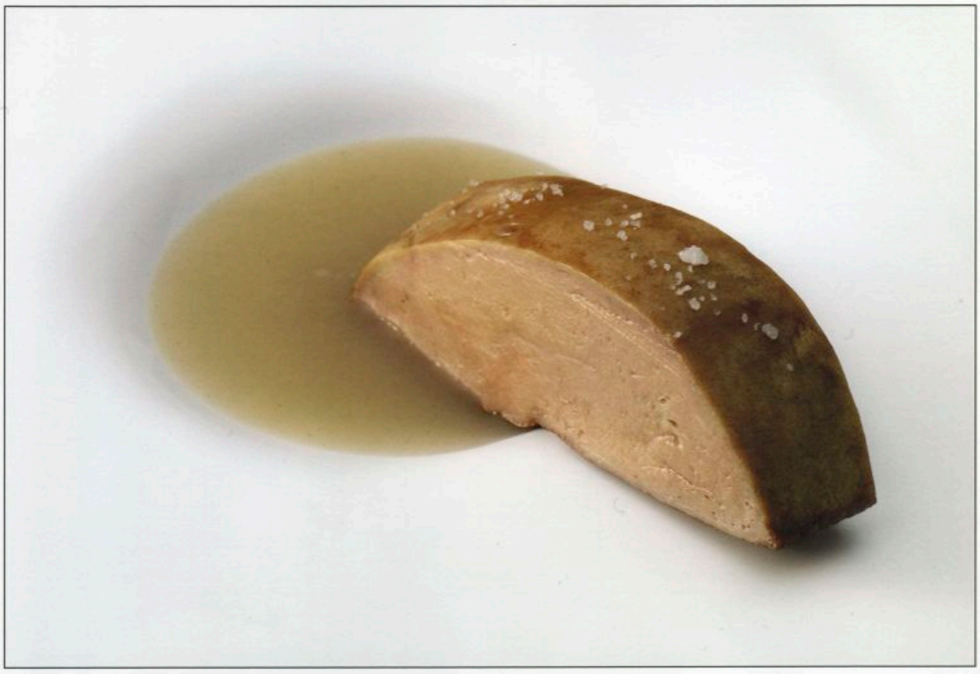


Photo courtesy of José Luis López de Zubiría—Mugaritz

An alternative to baking foie gras in the oven is to seal raw foie gras in a sous vide bag and cook it at 58 °C / 136 °F. Remove the meat from the bag, place a weighted sheet pan on top of the foie gras to press out excess fat and blood, and then sear the meat. This procedure replaces steps 5–7 in the recipe above.

CRISPY SWEETBREADS ADAPTED FROM SCOTT ANDERSON

Yields 1.2 kg (six portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White soy sauce	140 g	23.5%	① Combine, and vacuum seal.
Extra-virgin olive oil	70 g	11.5%	② Cook sous vide in 93 °C / 199 °F bath for 10 min.
Garlic cloves, thinly sliced	60 g	10%	③ Cool, strain, and reserve.
Black pepper, coarsely ground	1.5 g	0.25%	
Veal sweetbreads	600 g	100%	④ Peel off exterior membranes. ⑤ Separate along seams, using a sharp knife, into 2.5 cm / 1 in pieces, and reserve. ⑥ Vacuum seal sweetbreads with cooled infusion. ⑦ Cook sous vide in 60 °C / 140 °F bath for 1 h. ⑧ Cool quickly in ice-water bath.
Wondra flour	20 g	3.5%	⑨ Combine to make dredging powder, and reserve.
Pistachio powder	15 g	2.5%	
Salt	3 g	0.5%	
Dried orange zest powder	2 g	0.3%	
White asparagus stalks, chopped	130 g	22%	⑩ Sweat together until asparagus stalks are tender.
Spanish onion, thinly sliced	90 g	15%	
Extra-virgin olive oil	15 g	2.5%	
Soy milk	300 g	50%	⑪ Add to asparagus mixture, and simmer until very tender, about 15 min.
Macadamia nut butter	35 g	6%	⑫ Puree, and pass through fine sieve.
Salt	to taste		⑬ Season asparagus stalk puree, and reserve warm.
Asparagus tips, blanched and cut lengthwise	90 g	15%	⑭ Warm in small pot. ⑮ Drain cooked sweetbread pieces, and coat with dredging powder. ⑯ Fry in 190 °C / 375 °F oil until golden brown and just warmed through, about 45 s. ⑰ Drain on paper towels.
Chickpeas, cooked and peeled	60 g	10%	⑱ Spoon asparagus puree into bowls. ⑲ Top with crisp sweetbread pieces, asparagus tips, and chickpeas.
Black summer truffle, julienne	12 g	2%	⑳ Garnish plates. ㉑ Dust with additional dredging powder.
Chive flowers	as needed		

(original 2010)

EXAMPLE RECIPE

SWEETBREADS WITH SOUR MANGO POWDER AND SHIITAKE

Yields 650 g (four portions)

ADAPTED FROM JEAN-GEORGES VONGERICHTEN

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Veal sweetbreads	600 g	100%	① Peel off exterior membranes.
White vegetable stock see page 2·303	200 g	33%	② Vacuum seal with stock and salt. ③ Cook sous vide in 67 °C / 153 °F bath for 1 h.
Salt	9 g	1.5%	
Carrot, finely minced	60 g	10%	④ Sweat until carrots and ginger are tender, about 5 min.
Unsalted butter	60 g	10%	
Ginger, finely minced	32 g	5.5%	
Shiitake, thinly sliced	120 g	20%	⑤ Add, and cook until tender, about 5 min.
Shallot, thinly sliced	80 g	13.5%	
Brown chicken stock see page 2·296	110 g	18.5%	⑥ Deglaze sauce base. ⑦ Reduce until syrupy, about 5 min.
White port (dry)	40 g	6.5%	
Manzanilla sherry	25 g	4%	
Amchoor (sour mango powder)	34.5 g	6%	⑧ Whisk 4.5 g of amchoor and 1 g of licorice into sauce, and reserve.
Licorice powder	6 g	1%	
Freeze-dried carrot powder see page 2·450	30 g	5%	⑨ Combine with remaining amchoor and licorice powder. ⑩ Dust powder over surfaces of cooked sweetbreads.
Clarified unsalted butter	70 g	11.5%	⑪ Fry sweetbreads in very hot butter until golden on both sides, about 1 min each.
Salt	to taste		⑫ Season sauce and sweetbreads.
Lemon juice	to taste		⑬ Slice sweetbreads into desired dimensions. ⑭ Divide evenly among four plates, and garnish with sauce.

(original 1997, adapted 2010)

SALTING AND DRYING

Humans have always needed to preserve food. After our distant ancestors learned to hunt, they realized that success in bringing down a large animal created an instant surplus. And without a way to keep the meat from rotting, much of the effort they had expended for it would go to waste. The earliest technique for preserving food was drying—either haphazardly in the sun or more reliably over a low fire, and later in an oven. At some point, somebody figured out a purely chemical means of accomplishing the same thing: salting. The earliest records of this practice go back five thousand years, but salting was almost certainly used long before that.

Over the years, cooks have developed several procedures for modifying flesh with salt. **Brining** is the process of soaking meat or seafood in water with salt and, often, other flavorful ingredients. The goal is to use modest concentrations of salt to cause muscle fibers to swell and absorb water, as well as to better retain water when cooked. The added salt also seasons the flesh, boosting its inherent flavor. Briefly dry-rubbing flesh with salt achieves similar ends more quickly, although no extra water is added this way and, in fact, some moisture is wicked away.

Curing aims to permanently change the texture of the meat or seafood, while also slowing spoilage, preserving color, and enhancing flavor. Nitrate and nitrite curing salts often are added to assist. There are two approaches to curing. **Wet-curing** is similar to brining in that raw meat or seafood is soaked in a strong saltwater solution. Fresh hams, corned beef, and lox are frequently prepared this way. **Dry-curing** uses a covering of salt that steadily dissolves and diffuses into the flesh to create a cured texture and flavor. Country hams and salt cod are commonly dry-cured.

Curing is done to preserve, but by itself it is not enough. Brined and cured meats contain too much water to be considered preserved, and thus they require refrigeration. Cured meats must be dehydrated, often for weeks or months on end, to become fully preserved.

Mistakenly, cooks—and even commercial meat producers—often speak in terms of the **salinity** (or salt concentration) of a brine or cure. This is a flawed way of thinking. We don't care about the salinity of the surrounding liquid; we care about the salinity of the food itself. That is what determines whether the end result is brined or cured. If the salinity of the flesh is less than 2% (relative to the weight of the meat), then the result is brined. Higher salt concentrations accelerate the curing process and yield a firmer texture. So the final salinity for freshly cured foods is typically around 3%; it increases to 5% or more if the food is then dried enough to be considered preserved.

Whether brining or curing, cooks tend to talk about "salt" moving into the food, but strictly speaking, that's incorrect. Only crystalline sodium chloride can properly be called salt.

Salt is one of the great modifiers of meat. It can be used to change the texture and flavor, as with corned beef (next page), or to dry food by osmosis, as with salt halibut (right).

For more on how salt and other substances dissolve in water, see Water as a Solvent, page 1·330. For more on how heat diffuses through food, see How Heat Conducts Itself, page 1·277.

When dissolved, salt dissociates into positively charged sodium **ions** and negatively charged chloride ions, which are what actually diffuse through food. Salinity is a measure of the concentration of these ions that equates to a specific ratio of dissolved salt and water.

The ions diffuse through the meat in essentially the same way that heat diffuses via conduction. Just as heat flows from hot to cold regions, ions flow from concentrated to diluted regions. The main difference is speed: the diffusion of dissolved salt through flesh is 100 to 1,000 times slower than the conduction of heat. This is why you can cook a pork leg in hours, but it can take months to cure a ham.

The diffusive nature of brining and curing has some important consequences. The first is that, like heating food, the time required roughly scales with the square of the food's thickness. So a cut that is twice as thick as another takes four times as long to brine or cure. Second, differences in salt concentration within food equilibrate over time, just as temperature does. Later, we will look at the implications of these two facts on strategies for brining and curing.

In general, we recommend being cautious about the overall salt level used in brining. It is better to be subtle than to have meat that tastes obviously salty and verges on being overbrined. Start at the low end of the range by aiming at a 0.5% final salt content, and see how you like it before moving higher.

Many common notions, and even some authoritative explanations, of how salt transforms meat and seafood are misleading or simply wrong. Osmosis is frequently cited to explain the flow of dissolved salt into—and the flow of water out of—muscle foods, but detailed research by meat scientists has shown that conventional osmosis does not play the role many people think it does. Osmosis alone would draw water out, but brining actually causes water to flow into the flesh. Wet-curing causes water to flow in and then out, whereas dry-curing only draws water out and begins drying flesh immediately.

For more on osmosis, see page 1·335.

What's really going on? Chloride ions, from dissolved salt, diffuse into muscle fibers and accumulate along the surface of protein filaments. As these ions increase in number, they generate a negative charge that loosens and pushes neighboring filaments apart—analogous to the way magnets with the same polarization repel each other. The charged filaments push far enough apart that they cause the muscle fibers to swell—if water is available to fill the space opened up in the process. Brines and wet cures supply excess water, so they actually plump the flesh, at least initially, while dry-cures do not.

But both liquid brines and dry rubs yield juicier meats and seafood. That's because, even if there is no surrounding water to draw in, proteins are modified by the ions in ways that cause them to bind the water in the flesh more tightly—as well as to resist the shrinking of muscle fibers that squeezes juices out during cooking. The flesh continues to swell and bind water more tightly until its salinity increases to 6%, and then it shrinks and begins to lose water.

Wet-curing and dry-curing both expose meat and seafood to much higher concentrations of salt than 6%, so given enough time, both will dry flesh out. But you stop curing well before the flesh reaches equilibrium with the surrounding cure; otherwise the end result would be much too salty to eat. At this point, wet-cured flesh is left with nearly as much water as it had at the outset, whereas dry-cured flesh has lost a substantial amount of water.

However the salt for a cure is applied, flesh begins to cure when the salinity rises above 2%. Above this threshold, charged ions from the salt destabilize and unravel various proteins within muscle fibers. Over time (and faster at higher concentrations), these unfolded proteins become entangled and form a gel that gives cured meats and seafood their characteristic firm and chewy texture. This is not altogether different from what cooking with heat does to proteins.

Brined foods that are cooked have a telltale texture because the combination of salt and heat creates a firmer, more elastic gel than heating does alone. Indeed, part of the secret to getting a good result that isn't too firm and chewy is to avoid overdosing the salt when brining.

Brining

The goal of brining is to apply enough salt to meat or seafood that the food retains more juices during cooking and that flavor is enhanced *without* curing the flesh in process. Thus, the challenge of brining is to disperse dissolved salt evenly throughout a piece of food, while preventing the salinity from becoming too high.

This problem is analogous to cooking to a particular core temperature. You can cook at a temperature higher than the target and try to time the cooking just right so that the core reaches the

Functional Ingredients in Brines, Cures, and Dry Rubs

Many kinds of active compounds are available for use in flavoring, preserving, and altering the texture of meat and seafood. Quantities indicated in the table below are relative to the weight of the meat or seafood. When making a salt cure, for example, use 15–30 g of salt for every 100 g of meat. Some curing salts, such as sodium nitrate, are far more potent and may require only a single gram for every kilogram of meat.

Class	Ingredient	Brine (scaling)	Cure (scaling)	Dry rub (scaling)	Note
flavoring salts	salt (sodium chloride)	3%–10%	15%–30%	2%–15%	usually the most important ingredient; alters protein structure; works as a preservative at high levels
	disodium 5′ guanylate	0%–0.5%			
	disodium 5′ inosinate	0%–0.5%			
curing salts	sodium nitrite	0.001%–0.020%*			preserves and enhances color and flavor; helps prevent growth of harmful bacteria; can be dangerous, even lethal, at levels above those indicated
	sodium nitrate (only for dried sausages and whole muscles); see page 160	0.003%–0.210%			converts into nitrites during long cures, naturally replenishing nitrite levels during the curing process
	potassium nitrate (saltpeter)	n/a			obsolete; works just like sodium nitrate, but not at refrigerator temperatures; forms nitrogen dioxide, a toxic gas, when mixed with solutions of pH ≤ 4.8
sweeteners	sugar (sucrose)	1.5%–20%			adds sweetness and masks saltiness; appropriate concentration varies by kind of sugar
	honey (fructose)	5%–30%			50% sweeter than sugar; has a distinct flavor
	corn syrup (glucose)	5%–30%			less sweet than sugar
phosphates	10:1 blend of sodium tripolyphosphate and sodium hexameta-phosphate	0.05%–0.30%			enhances activity of salt and uptake of water into meat; speeds development of cured texture; never dissolve in hot water; legal limit is 0.5%; above 0.3%, gives brines a distinct metallic or soapy taste
antioxidants	vitamin C (ascorbic acid)	0.1%–0.3%			slows oxidation of fat; works as a preservative; can cause dangerous reactions when used with nitrites and nitrates at pH ≤ 4.8
	rosemary, thyme	0.1%–1.0%			contain antioxidants similar to vitamin C
spices and seasonings	garlic	1%–3%	1%–3%	1%–10%	contains natural antioxidants, nitrites, and nitrates
	paprika	1%–3%	1%–3%	1%–10%	contains natural antioxidants, nitrites, and nitrates
flavor enhancers	monosodium glutamate	0%–1%			

(for dry-cured sausages and whole muscles, the legal limit is extended to 0.06%)

Skin, fat, and bone do not allow salt to migrate through them in the same way that meat does. So in addition to a salt gradient from surface to center, there can also be differences in salt concentration due to the shielding of some part of the meat from salt by a fat cap or other nonmeat tissue. Resting the brined cut until equilibrium is reached eliminates these differences.

If you are going to rinse overbrined food, don't bother to keep the faucet running. This is simply pouring water—and money—down the drain. Unless the soaking water is nearly as salty as the food itself, salt will diffuse outward into it nearly as fast as it would in entirely fresh water.

With any approach to salting food, reaching equilibrium takes a long time. A thin cut may brine fully in a day or two, but a large roast or large bird takes weeks. As a result, most brining recipes never actually finish the job. We discuss several strategies for accelerating brines and cures on page 166.

target temperature as the food rests. But if the center is perfectly done, the part near the surface will inevitably be overcooked. Or you can cook at, or just slightly above, the desired final core temperature and patiently wait for the entire piece of food to equilibrate to the same temperature. This is the approach typically used when cooking sous vide.

You have the same two choices when brining. The conventional approach, used by almost all brining recipes, is to soak the food in a relatively strong salt solution (usually 5%–10%) for just the right amount of time. Inevitably, when the food is removed from the brine, the surface is too salty and the core isn't salty enough—there is a salinity gradient. And if your timing is off, you risk undersalting or, worse, oversalting the meat. It's like cooking with high heat in that respect, except even more challenging because there is no simple tool like a thermometer that can measure the salinity of the meat or seafood at its center. Even if there were, it would be hard to use because salt continues to diffuse through the meat over such a long time.

The best you can do is to follow a recipe—and hope that the inevitable variation in the size, shape, and composition of a piece of meat or seafood doesn't affect the outcome. Once a good combination is found, everything can be kept the same to repeat the results. It helps that cooks tend to err on the side of underbrining, because it isn't a catastrophe if the flesh isn't fully brined. Some people have even argued that it is not necessary to fully brine food because the surface is the part that gets overcooked and benefits the most from being brined.

Still, the surface may be too salty and the core not salty enough when you take the meat out of the brine. You can solve this problem in one of two ways. The first is to rinse the meat briefly, and then rest it outside the brine. After enough time passes (sometimes hours, sometimes days), the salt gradient eventually equilibrates—much as the temperature of resting meat equilibrates after high-heat cooking. This approach gives good results but takes time. Although we provide some guidelines on page 172, finding the optimal time may require some trial and error.

The second method, recommended in many cookbooks, is to soak the meat in fresh water after brining to remove some of the excess salt. Many people do this under running water, but that approach is wasteful. The freshwater soaking method works to some degree because it removes the saltiest part of the concentration gradient, but it cannot even out the rest of the gradient. Neither

THE CHEMISTRY OF

Brining and Curing with Other Salts

Sodium chloride is not the only useful salt for brines and cures. Calcium chloride and some phosphate salts are examples of other salts that can be put to good use in brines and cures.

Calcium chloride has two big benefits over mundane table salt for these purposes: each molecule packs twice the punch of sodium chloride, because it has two chloride ions paired with each calcium ion, whereas each sodium ion pairs with only one chloride ion. Recall that it is the negatively charged chloride ions that do the work of brining; thus, calcium chloride causes more swelling at lower concentrations. There is another potential benefit: calcium ions stimulate the enzymes that are responsible for tenderizing meat during aging and the early stages of cooking—notably the calpain system discussed on page 76. So brining meat with calcium chloride, followed by a long maturing step, can improve the tenderness of meat (although these enzymes do not tenderize tough connective tissue, so inherently tough cuts of meat benefit less than more tender cuts).

The drawback is that calcium chloride doesn't taste salty; instead, it has a bitter and slightly metallic taste. This isn't apparent at low concentrations, so it puts an upper limit on how much calcium chloride can be used. In our experience, about 0.03% calcium chloride in meat is fine. You can put more in brine (around 10 times as much), but it must be followed by a rinsing step or, preferably, a long, refrigerated maturing step so that concentration gradients can even out and the stimulated tenderizing enzymes have time to work.

Because of the limits of good taste, calcium chloride shouldn't be seen as a replacement for regular salt in brine but rather as an adjunct that can boost the effectiveness of salt while also enhancing meat tenderness.

Phosphates are an entire class of salts, with many different kinds for different purposes. For brines and cures, two are particularly useful: **sodium tripolyphosphate** and **sodium hexametaphosphate**. Typically, these are blended together in a 10:1 ratio. The primary way in which these salts work in brines and cures is by shifting the pH of the meat slightly upward. This makes them more akin to acidic or alkaline marinades than to salt brines.

They can dramatically increase the efficacy of brining or curing with salt. Indeed, commercially they are often used as a cure accelerator, because even at low levels (around 0.3% or less), they rapidly dissolve myosin and accelerate the development of a cured texture in meats and seafood.

This is overkill for brining. But at very low levels (less than 0.05%), they have a very high impact on the juiciness of meat and seafood. At such levels, they can enhance the efficacy of any salt brine, even a very dilute one meant to enhance juiciness without creating a telltale brined texture when cooked. For example, when used at levels around 0.02% in a very dilute salt brine (or even no salt at all), a suitable blend of polyphosphate salts doesn't give meat or seafood a brined texture, but when the result is carved in the kitchen or cut up on the plate, the natural juices do not readily leak out. Instead, they are retained in the flesh to give a juicier burst of flavor in the mouth.

When working with phosphates it's good practice to first dissolve them into a small amount of warm water (but never hot, which decomposes the salt) and then add this solution to the brine or cure. These salts are difficult to dissolve in water, and because they're used in such small quantities it's easy to not notice they weren't dissolved in a large volume of brine. This can cause inconsistent results.

The meat on the left has been brined with a 0.05% solution of polyphosphate, and it shows no loss of juice when cut, as the untreated meat to the right does.

Prague Powder No. 1, Insta Cure No. 1, DQ curing salt, ModernCure, and many other brands of curing (or "pink") salts usually have the same composition—93.75% salt and 6.25% sodium nitrite plus a safety coloring. Our recipes are all formulated to work with a curing salt of this composition. Be aware that the Morton brand Tender Quick has a very different composition and cannot be easily used as a substitute in our recipes.

For more on how to measure salinity, see page 2·313.

Prague Powder No. 2, Insta Cure No. 2, and some other brands of curing salts add another 1% sodium nitrate to provide, in effect, a slow-release reserve of nitrites, necessary for a long, slow cure, such as that of a whole ham or fermenting salami. The proper use of these curing salts, coupled with fermentation steps, is essential for producing safe slow-cured foods. But they should not be used in our recipes unless specifically called for.

For more on making infusions, see page 2·310.

can it reverse the effects that result after a strong brine begins curing the outer layers of the meat. And it's awkward to spend the time to create an uneven gradient, only to wash some of it out.

We prefer a different brining strategy altogether, one that does away with all of the guesswork. Instead of making a traditional brine, weigh the meat or seafood together with the water for the brine, and then add the proper amount of salt (and any other ingredients) for the desired final salinity. For example, we prefer a mild final salinity of 0.5%–1.0% for most meats and seafood, hence we would add 0.5%–1.0% salt relative to the *combined* weight of the food and water. (Subtract the weight of any bones. For whole chickens or turkey, bones can be 40% of the total weight.) Dissolve all of the salt into the water, and soak the food until salinity levels inside and outside the flesh are the same.

It's easy to check whether the salinity has reached equilibrium; you just use an inexpensive salinity meter to measure the effective concentration of salt in the brine. It starts out higher than the target salinity, but as dissolved salt diffuses into the flesh, the strength of the brine diminishes. When the salinity of the brine drops to the target value, the salinity in the flesh has risen to be the same as the brine. It thus works in much the same way that cooking sous vide creates an equilibrium temperature.

We call this approach equilibrium brining. It takes longer than other methods do, but about as long as the sum of the brining and resting times required when you use a stronger brine.

Notice that we didn't specify how much water to use. Once you weigh the salt, you can use the smallest amount of water that dissolves the salt. You can even put the salt on the meat without any water and seal the salted meat tightly in a sous vide bag. Dry-packing the meat with no water will not plump the meat slightly as brining does, so it produces a different result. Nevertheless, adding virtually any amount of water ultimately produces the same result—if you're willing to wait long enough for the salt gradient to reach equilibrium. The more water you add, the less extreme the salt gradient that appears early in the process.

A reasonable rule of thumb is to use at least as much water by weight as you have meat. In that case, the starting concentration will be double the final concentration—if you want a brine of 1%, make a 2% starting solution. This helps avoid a cured-meat taste.

This custom-brining approach all but ensures that you will never oversalt the meat; if you let it rest too long, the mixture reaches equilibrium and then stays there. The method also makes it hard to underbrine: you can check the salinity of the brine to see how far along you are, and stopping early just produces a less extreme salt gradient than a conventional brining strategy does.

Equilibrium brining takes a long time, particularly for thick pieces. A thin cut can brine in a day or so, but a large roast or a turkey can take weeks. As a result, most meat-brining recipes never let the meat reach equilibrium and instead subject the meat to a large gradient, letting some parts of it get saltier than other parts.

We recommend accelerating the brining of thick cuts (those more than 5 cm / 2 in at their thickest part) by using a Jaccard tenderizer, injector, or vacuum tumbler—or, ideally, all three, as described on pages 50 and 174. Another way to accelerate brining is to use a very low level of phosphate, which chemically boosts the effects of brining and curing—see the discussion on the previous page.

So far we have focused on salt, but brines often include other functional and flavorful ingredients. Salts such as calcium chloride and polyphosphates are more capable than plain table salt at enhancing juiciness and altering textures. Used with care, these are useful ingredients in the Modernist chef's larder. Sweeteners, herbs, and spices balance and can improve the overall flavor of brined foods. One consideration, however, is that the surface of meat and seafood acts like a very fine filter; only dissolved compounds diffuse into the flesh. Thus, we prefer to infuse our brines with spices and herbs—or simply use essential oils—for the desired strength of flavor, and then strain out the ingredients before using the brine. This technique yields more consistent results.

Curing

Unlike brining, curing is about using salt to transform the texture and flavor of raw meat and seafood in a way that is similar to cooking. Curing is what gives ham, corned beef, and other cured meats their characteristic texture and flavor. The

Traditional French duck confit is cured with salt, herbs, and spices before being cooked in fat. The process was originally meant to preserve the meat ("confit" means preserved).

Monosodium glutamate, or MSG, is a useful addition to brines and cures that imbues the meat with an umami flavor. It generally can be added in an amount that is about 10% of the amount of salt, so a brine with 5% salt would get 0.5% MSG. Two other flavoring salts that are helpful are disodium 5′ inosinate and disodium 5′ guanylate. Add these in an amount that is about 1% of the amount of salt.

For more on making and using brines, cures, and rubs, including recipes, see page 168.

original goal was preservation (especially when combined with drying), but today we cure meat primarily for the changes in flavor and texture.

Accomplishing this transformation requires raising the salinity of the meat above 2% and keeping it there for a while. Above this threshold, charged ions from the salt destabilize proteins in the muscle fibers and cause them to denature and coagulate, which yields the characteristic texture of cured flesh. Over time, curing causes some of the proteins to break up into small, savory peptides and amino acids, which contribute to the cured flavor.

This transformation takes time. Brief exposure to moderately high salt concentration, 10% or so, will not instantly cure meat or seafood. This is why the conventional approach to brining works.

Traditional wet-curing uses a very salty brine, typically 18%–22%. Dry-curing packs the food in crystalline salt, but once moisture is wicked out of the food, the salt immediately starts to dissolve and thus becomes a wet cure with a salinity of 23%–26%. In either case, the high salinity creates a steep concentration gradient. If a cut of meat or seafood were left in a wet cure or a dry cure for long enough, there would be no difference between the two approaches.

Traditional curing, like traditional brining, relies on careful timing to determine when to remove the food from the cure and then let it rest to equilibrate. This is where the difference between wet-curing and dry-curing arises: water initially flows into wet-curing flesh as the salinity rises to 6%, and then flows back out as the salinity continues to

THE CHEMISTRY OF
Nitrates, Nitrites, and Nitrosamines

Today, most curing is done using curing salts that contain sodium nitrite ($NaNO_2$), a highly reactive compound. But that high chemical reactivity means that nitrite tends to become depleted quickly. So for longer cures, like those used to make country hams and slowly dried, fermented forcemeats such as salami, nitrite's more oxygenated cousin, sodium nitrate ($NaNO_3$), is used along with it. Certain kinds of salt-tolerant bacteria, often added as a commercial culture, provide a long-term source of nitrite within the meat by steadily transforming nitrate to nitrite.

Nitrite partakes in many chemical reactions that prevent the growth of some toxic spoilage bacteria, preserve the appealing red color of myoglobin, prevent rancidity and warmed-over flavor, and even enhance flavor. Unfortunately, under certain circumstances nitrites can transform to nitrosamines, which are known to cause cancer in test animals. For this reason, some health experts call for an outright ban on the use of nitrates and nitrites in curing meat. And many consumers are wary of buying products containing nitrate and nitrite preservatives. We think this is an overreaction, however.

The U.S. Department of Agriculture has set limits for the maximum concentration of nitrate and nitrite that can be added to most cured foods. For bacon, which is routinely cooked to a temperature at which nitrosamines form, the USDA has banned nitrates altogether and prescribed a nitrite level of 120 parts per million—about 0.12 g per 1 kg / 0.002 oz per 1 lb of meat. This is not a limit. Rather, it's set at a level that will inhibit the growth of spoilage bacteria without risking the formation of excessive amounts of nitrosamines in foods that are cooked to a high enough temperature to cause the reaction—essentially, a temperature high enough to brown meats and seafood.

In our view, the health benefits that nitrates and nitrites bring to cured meats far outweigh their dangers. As the 16th-century physician Paracelsus noted, "All things are poison and nothing is without poison." Or you might say that the poison is in the dose, and lots of things—including oxygen and pure water—are dangerous at high doses, yet innocuous at low doses.

One fact that should help put concerns about nitrates and nitrites in perspective is that many vegetables, as diverse as paprika, garlic, beet, celery, and lettuce, naturally contain significant amounts of sodium nitrate. That's why only a small percentage of the nitrate we eat comes from cured meat. It's also why some cured meats contain various vegetable powders; these function as preservatives that preserve a "clean label." But just as with conventional meats, it's the nitrate, and the nitrite that it is reduced to, that are the active substances here, although the labeling touts only "natural" ingredients.

Composition of Common Curing Salts

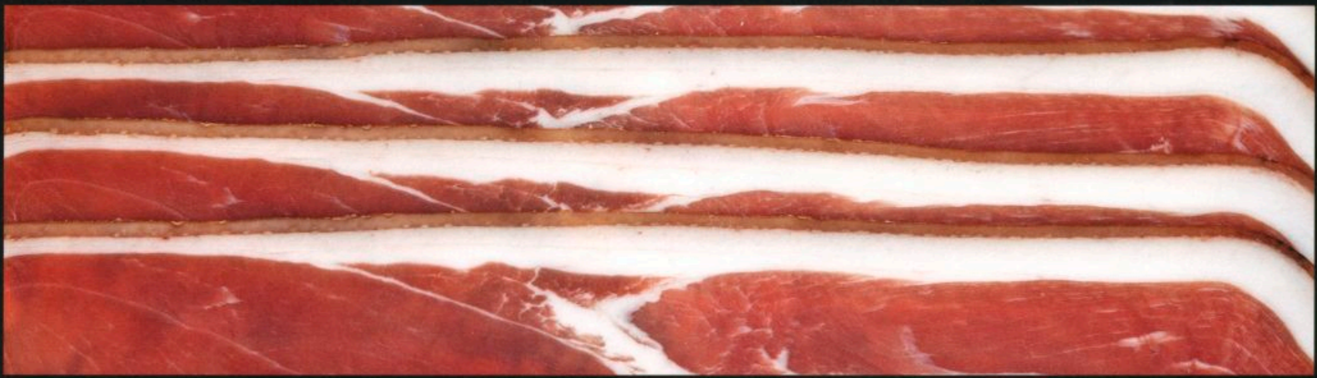
The main ingredient—by far—in curing salts is simply salt. Proportions of minor ingredients such as nitrites and nitrates vary from one preparation to the next, but only slightly. The proportions of salt and minor ingredients found in several popular curing salts are listed below.

Curing salt	Salt	Sodium nitrite	Sodium nitrate	Potassium nitrate	Other ingredients	Note
Insta Cure No. 1 Prague Powder No. 1	93.75%	6.25%			safety coloring	brand names include DQ Curing Salt, DC Curing Salt, and Modern Cure
Insta Cure No. 2 Prague Powder No. 2	92.75%	6.25%	1.0%		safety coloring	use for semicured, fully cured, and fermented meat; never use on meat that will be browned or fried
Morton Tender Quick	99%	0.5%	0.5%		sugar, propylene glycol, safety coloring	a popular brand-name product used for long cures and for making dried, fermented products
sel rose	varies			varies	sugar, MSG, safety coloring, other	not recommended

Maximum Concentrations of Curing Salts Permitted by the U.S. Dept. of Agriculture

The USDA has set upper limits on the amount of nitrites, nitrates, and other curing sales that can be added to certain meats. The values below are given as grams of curing salt per kilogram of meat.

Meat	Nitrite (g/kg)	Nitrate (g/kg)	Insta Cure No. 1 (g/kg)	Insta Cure No. 2 (g/kg)	Tender Quick (g/kg)	Note
immersion-cured meats (excluding bacon)	0.200	n/a	3.2	n/a	n/a	
injection-cured meats (excluding bacon)	0.120	n/a	1.9	n/a	n/a	
immersion-cured bacon	0.120	n/a	1.9	n/a	n/a	USDA rules require 550 ppm of sodium erythorbate to ensure that all nitrites react before cooking
injection-cured bacon	0.100	n/a		n/a	n/a	
dry-cured bacon	0.200	n/a	3.2	n/a	n/a	
uncured forcemeats (sausages, pâtés, reconstructed meats)	0.156	n/a	2.5	n/a	n/a	
dry and semidry sausages	0.625	1.719	10.0	10.0	125.0	
dry-cured whole muscle cuts	0.625	2.187	2.5	2.5	31.2	



For more on the causes and prevention of botulism, see chapter 2 on Microbiology for Cooks, page 1·102, and chapter 3 on Food Safety, page 1·162.

climb. For dry-curing flesh, there is no water to be drawn in, but as soon as the salinity rises above 6%, water begins to flow out of the curing flesh. The net result is that wet-cured meats and seafood lose little or no water, whereas dry-cured meats and seafood lose as much as 20% of their weight in water by the time enough salt has accumulated in the flesh.

Producers who want a fresh-cured product that will be kept refrigerated (and cooked before eating) favor wet-curing because it gives them a higher yield and is less finicky than dry-curing. For dried and fully preserved meats and seafood, such as country hams and salt cod, dry-curing makes more sense because drying starts during the initial curing step.

Our approach to brining also works for curing. For equilibrium wet-curing, weigh the meat and water for the cure together (making an allowance for the weight of bones and gristle if necessary), dissolve 2%–3% of the combined weight in salt into the water, add any other ingredients, and then vacuum seal the cure and flesh together.

As with brining, the amount of water to add is up to you. The minimum is the amount that will dissolve the salt, but you may want to add more so

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Sel Rose, An Obsolete Curing Salt

We do not advocate the use of sel rose-style curing salts, for several reasons. First, every brand of sel rose salt has a different composition. In addition to table salt and saltpeter, sugar and other ingredients such as monosodium glutamate are often added. Thus, it is rarely possible to find out how much potassium nitrate a particular brand actually contains. This makes it very difficult to use sel rose at acceptable levels for curing. Second, sel rose does not contain nitrites, which would act quickly to stabilize the color of curing meat and to inhibit unsafe bacterial growth. Curing with sel rose often yields inconsistent, even dangerous results.

Why did anyone ever use it? Part of the answer is simply historical accident: saltpeter (potassium nitrate) and its close cousin Chile or Peru saltpeter (sodium nitrate) are common impurities in salts from places such as the Dead Sea. It wasn't long before people who preserved meat and seafood with salts from certain places found that it resulted in preserved meat that had better color and flavor.

Second, in an era before refrigeration, nitrate salts worked more reliably than they do now. This is because nitrate is steadily converted into nitrite by certain species of bacteria at a temperature above 8 °C / 46 °F, but this process essentially halts at modern refrigeration temperatures below 4 °C / 39 °F. Thus, until refrigeration became ubiquitous after the Second World War, curing was often done in cellars or caves that tend to have an average temperature of 8–10 °C / 46–50 °F. Nitrate did a pretty good job in those environments because it was quickly converted into the necessary nitrite salt.

Today, the use of sel rose to cure food while refrigerated essentially halts the growth of the necessary bacteria and, thus, the formation of the critical nitrites. The result can be inconsistent and potentially unsafe; in many curing situations, nitrate salts are actually banned from use.

Only in the 20th century did meat scientists work out the complex chemistry of how curing works. Once it was understood that nitrites are the more important salt and that modern refrigeration temperatures can stall the conversion of nitrate into nitrite, sodium nitrite quickly replaced the less reliable nitrates for most curing jobs. Thus, nitrate-containing sel rose has become obsolete.

Miso-Cured Black Cod is cured with sake, soy sauce, and white miso. For the recipe, see page 179.

THE FOOD SAFETY OF

Worrisome Signs When Curing

If you brine meat only occasionally, you probably discard the brine afterward. Butchers and meat processors tend to reuse their brines for a long time, however, and they use salinity meters to measure and adjust the salt content (see page 2·313). When reusing brines in this way, a thin layer of froth or white mold often accumulates on top of a curing brine. Generally this isn't a problem; you can simply skim it off. But if the foam starts to smell foul or to turn bluish, or if the cure becomes thick and slimy, then remove the curing meat. You can wash it off with fresh water and place it into a freshly made curing solution.

Bad brine is often referred to as a "ropy" pickle because the sticky, slick brine oozes off a finger dipped into the cure in syrup-like strands. This stringiness results from unwanted bacterial growth.

Good curing habits include boiling the brine before use, waiting to add seasoning and herbs until the brine is hot enough to pasteurize any bacteria they may be harboring, using impeccably fresh meat, and covering the curing tank. Because salt and water are both inexpensive compared with meat, consider making a fresh batch of curing solution each time you cure meat.

that there is enough to measure with a salinity meter. When the salinity of the surrounding curing solution has fallen to the target level, the flesh will be evenly salted to just the right degree. This entire process takes no longer than the conventional two-step approach that soaks and rests the food in separate steps.

For equilibrium dry-curing, simply rub the desired weight of salt over the flesh, vacuum pack it, and let it rest until all of the salt has dissolved and been absorbed. Remove the flesh from the packaging, and store it in a cool, humid environment (ideally less than 15 °C / 59 °F at 75%–80% relative humidity) so that moisture slowly and steadily evaporates until the food loses 30%–50% of its weight. At that point it can be considered fully preserved, and salt levels at the surface should match those in the core.

Curing salts are frequently used in place of table salt, with sodium nitrite being the preferred curing salt today. In ancient times, people used sea salts containing impurities such as potassium nitrate (saltpeter) or sodium nitrate (Chile or Peru saltpeter). They discovered that nitrate-bearing salts preserved the color and flavor of meats better than pure sodium chloride does.

And, although this wasn't understood until the 20th century, nitrates or nitrites protect against botulism (an illness caused by *Clostridium botulinum*, a bacterial species named, appropriately enough, after the Latin word for sausage). Beneficial bacteria, such as strains of *Kocuria*, convert nitrate to nitrite, the compound that kills spoilage bacteria.

Nitrite has plenty more to recommend it. It is transformed into nitric oxide, which binds with myoglobin, causing cured meat to redden. Nitrite functions as a potent antioxidant that prevents cured meat from going rancid as it matures or from acquiring the warmed-over flavor of a reheated day-old steak. And nitrite reacts with meat, in ways that are not entirely understood, to enhance flavor. Indeed, nitrite is the primary reason bacon tastes like bacon. Just don't eat it. Combinations of table salt with nitrates or nitrites are called Prague powders or "pink salts": they're colored pink to avoid accidental, and possibly lethal, use as table salt.

That's not why nitrate is prohibited or carefully regulated in certain kinds of cured food, such as bacon. Unfortunately, under some conditions, such as when the meat is heated to frying temperatures,

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Cooking Defects with Cured Meats

Although many people think of cured meats as preserved against spoilage bacteria, the truth is more complicated. Very often, cooking meat or seafood that has been cured yields an unpleasant result. Offensive aromas occasionally occur when cooking cured pork belly or brined salmon, for example. Certain bacteria that can tolerate high concentrations of salt and nitrite can survive curing, and during cooking they can thrive long enough to produce some noxious odors. *Brochothrix thermosphacta* confers a distinct cheese-like aroma; *Vibrio* species of bacteria create potent sulfurous aromas; and *Proteus* and *Providencia* bacteria can produce extremely foul fecal-like odors.

Discoloration is another defect that occasionally crops up when cured meats are cooked. "Greening" is by far the most common variation. It happens when lactic acid bacteria produce hydrogen peroxide as a by-product of their growth. During cooking, hydrogen peroxide reacts with the cured myoglobin pigment, changing it from an appealing rosy color to an unattractive green-gray color (or, on rare occasion, yellow or white). Often when cooking sous vide, this defect doesn't even become apparent until the meat is taken from the bag and exposed to oxygen, which drives the reaction.

Regardless of which species causes what defect, it's important to remember that many bacteria can thrive on and in cured foods. The best strategy to keep them at bay is to blanch meats in boiling water before curing. Having thus decontaminated the surface, you can then cook them at a lower temperature. Keep in mind that if the flesh was contaminated, the curing brine probably is, too. Either make a new batch or boil the curing solution before using it again.

any residual nitrates are reduced to nitrites and transformed into nitrosamines, a class of carcinogenic compounds. Nitrite, on the other hand, reacts so quickly that virtually none is left after curing is complete.

A combination of misunderstandings, along with legitimate health concerns, cause some food-safety advocates and health-conscious shoppers to frown on the use of nitrates and nitrites. But botulism isn't particularly healthy either, and there really are no good substitutes for the use of these salts in many cured foods.

Strategies for Speeding Brines and Cures

Salt penetrates flesh very slowly. Not surprisingly, the meat-processing industry has developed a number of strategies for speeding the action of brines and cures.

One tactic frequently used is to inject brine deep into muscle tissue in several spots. A large joint of meat might have as many as 400 individual injections; something smaller, like a chicken, might have a couple dozen. Large operations have motorized injection pumps and use dozens or hundreds of needles. But it is remarkably fast to inject meat with a simple butcher's syringe.

A vacuum tumbler speeds the absorption of brines and wet cures. The partial vacuum frees trapped air, and the tumbling action massages the meat and helps the solution gradient work its way toward equilibrium. Vacuum-tumbling equipment is also useful for marinating, and you can even buy small and inexpensive vacuum tumblers, called marinating tumblers, for home use.

You can inject brine into a large artery or vein instead. Spurts of brine will burst out from ruptured capillaries throughout the meat, so "arterial pumping" needs to be done slowly several times, pausing after each perfusion to allow the pressure to abate as the brine is redistributed. This approach works particularly well for primal cuts, such as shoulders and legs, because it is simple enough to find a large artery or vein.

After injecting, a resting step allows the brine to fully diffuse throughout the meat. During the resting step, cuts of meat or sides of fish should be immersed in the same brine that was injected—called a "covering brine"—for a more consistent result.

A second approach to speeding the absorption of a brine or cure is a Jaccard meat tenderizer. Jaccarding can be done on its own or in addition to injection. Like salt, Jaccarding increases the meat's ability to retain its juice, so if you are going to the trouble of brining or curing it, you may as well Jaccard it, too.

The final approach to speeding up brining or curing is to use a vacuum tumbler. Even some delicatessens and grocery stores have these machines, which are pretty much what the name implies: an apparatus for tumbling a piece of meat under reduced atmospheric pressure. Meat is placed into a stainless steel vessel, brine is poured in, the lid is sealed, and most of the air is removed with a vacuum pump. The vacuum causes air trapped in empty blood vessels and pores in the meat to bubble out, and it allows dissolved salt to penetrate, much as it does in other forms of vacuum infusion (see page 2·310).

The tumbling action helps to speed the diffusion, but it also makes the brining far more effective. The massaging action of tumbling loosens and breaks the sheaths of collagen that surround individual muscle fibers and fiber bundles. The protein filaments inside the muscle fibers are free to be pushed even farther apart under the repelling action of the chloride ions in the brine. Thus, tumbled flesh plumps with even more moisture than it does with immersion or with injection brining and curing alone. Tumbling often is combined with Jaccarding or injection to speed the absorption and even out the distribution of injected brine.

The tumbling action also helps salt to undo and dissolve more of the proteins in muscle fibers. The slightly foamy and sticky juice that builds up on the surface of the meat is caused by extracted protein. This can be good or bad. If your goal is a cured texture, with its characteristic firm and chewy consistency, then tumbling is wonderful for speeding things along.

A cooked terrine is one good example. The sticky myosin-laden juice that coats the pieces of meat gel during cooking serves to hold everything together. In fact, this is how many canned hams and other restructured meat products are made. It is also a useful technique for creating more cohesive sausages.

On the other hand, tumbling can be too much for a delicate meat or seafood, which could fall apart under the strain. And the extra protein extracted by the tumbling could make the cut overly firm and rubbery once cooked. As with nearly any technology, thoughtful and judicious use is always best.

Ripening and Drying

After curing, many meats and seafood are allowed to mature, a step referred to as "ripening." Ripening is essentially a continuation of the resting step beyond what is necessary for the salt levels to even out. Ripening for weeks, months, or even years lets the texture and flavor develop.

The development of a full flavor comes from many complex reactions, but at the most basic level, it comes from the slow breakdown of proteins into taste-enhancing amino acid chains, many of which provide a strong umami component to the overall taste. The longer the ripening period, the more concentrated these potent tastants become.

New aromas also develop during ripening. The slow oxidation of fats, driven largely by a class of enzymes known as lipases, produces numerous potent aromas by degrading fats and oils in the flesh. The species, breed, and diet of the animal all influence the chemistry of the fats and oils, and

Acidic and alkaline marinades also work in part by loosening the sheaths of collagen that encase muscle fibers, so the contractile proteins inside swell with moisture. For more details, see Marinating, page 190.

For more on the role of myosin in forcemeat preparations, see page 250.

Cured, dried, and ripened meats include bacon, pepperoni, and beef jerky.

PARAMETRIC RECIPE

BRINES, CURES, AND DRY RUBS

Brining, curing, and rubbing are all essentially just different ways to apply salt and other seasonings to meat. The tables below and on the next page offer recipes for brines, dry rubs, and wet cures. Our suggestions for brining or curing a variety of common meats are given in the tables on page 172. For a step-by-step guide to the process, see How to Brine and Wet-Cure Meat, page 170.

MIXING A BRINE, CURE, OR RUB

1. **Select a brine, wet cure, or dry rub; the Best Bets tables below and on the next page suggest many good options.**

2. **Combine the ingredients, stir fully to dissolve, and then refrigerate the solution.** Quantities for rubs are given relative to the amount of salt. For example, to make a basic dry rub, use 10 g of sugar and 5 g of spices for every 100 g of salt. For convenience, quantities for brines and wet cures are given using two distinct kinds of baker's percentages. Quantities in the scaling 1 column are relative to the combined weight of the meat and water (excluding the weight of any bones), and are appropriate for the equilibrium brining method described on page 170. Quantities in the scaling 2 column are for use with the more traditional high-concentration approach described on page 171, and are explained there.

Best Bets for Brines

Recipe	Ingredients	(scaling 1)	(scaling 2)	Note	See page
basic brine	meat and water	100%		works well for most applications	210, 5·113
	water	as needed	100%		
	salt	1%	7%		
	sugar	0.4%	3%		
basic seafood brine	meat and water	100%		higher sugar content balances this brine for delicate fish and shellfish	5·161
	water	as needed	100%		
	salt	1%	5%		
	sugar	0.6%	3.5%		
basic pink brine	meat and water	100%		has an effective nitrite concentration of 0.12%; works well with color-sensitive meats, such as pork belly or tongue	5·101
	water	as needed	100%		
	salt	10%	10%		
	Insta Cure No. 1	0.2%	2%		
basic phosphate brine	meat and water	100%		firms meat and maintains moisture; using more sodium tripolyphosphate than indicated here can produce a rubbery texture	
	water	as needed	100%		
	salt	1%	7%		
	sodium tripolyphosphate	0.007%	0.05%		
umami brine	meat and water	100%		saltiness varies with brand and type of soy sauce but is usually about 19%; usukuchi shoyu has an excellent flavor	
	water	as needed	100%		
	usukuchi shoyu	5.3%	100%		
	honey	1%	20%		
cola brine	meat and cola	100%		popular sweet brine in the American South; never add curing salts to cola brines because the mixture will release a lethal gas	
	cola (not diet cola)	as needed	100%		
	salt	1%	8%		
dairy brine	meat & cultured whey	100%		has a mild tenderizing effect; adds characteristic dairy sweetness; especially good with mild meats like chicken and fish	
	cultured whey	as needed	100%		
	salt	1%	6%		

Best Bets for Wet Cures

Recipe	Ingredients*	(scaling 1)	(scaling 2)	Effective salinity	Effective nitrite concentration	Note
basic wet cure	water and meat	100%		17%	0.1%	keep meats and seafoods submerged and refrigerated
	water	as needed	100%			
	salt	2%	20%			
	Insta Cure No. 1**	0.14%	1.40%			
basic sweet cure	water and meat	100%		17%	0.1%	sugar, corn syrup, honey, molasses, and treacle are all commonly used sweeteners
	water	as needed	100%			
	salt	2%	20%			
	sweetener	1.5%	15%			
	Insta Cure No. 1**	0.14%	1.4%			
Wiltshire tank cure	water and meat	100%		19%	0.10% nitrite 0.25% nitrate	traditionally used for bacon
	water	as needed	100%			
	salt	2%	20%			
	sodium nitrite	0.001%	0.01%			
	sodium nitrate	0.003%	0.03%			
corned beef cure	water and meat	100%		10%	0.1%	to make pickling spice mix, combine 10 g coriander seed, 8 g black peppercorns, 5 g yellow mustard seeds, 5 g dill seeds, 5 g star anise, 1 g mace, 1 g clove, and two fresh bay leaves for each 1 kg cure; combine cure ingredients and bring to boil; cool completely to infuse; inject 10% cure to weight of meat; submerge meat in remaining cure; refrigerate for 3–5 d; rinse
	water	as needed	100%			
	salt	2%	8%			
	brown sugar	1.7%	4.5%			
	Insta Cure No. 1	0.14%	1.4%			
	pickling spice mix	see note				

*(*allow sufficient cure to cover meat or seafood*); **(*optional*)

Phosphates in brines or wet cures should be dissolved separately in a small amount of warm water and added to the main mixture only after fully dissolved.

For the herbs and spices in the dry rub recipes, use any spice mix, such as our Indies Spice Blend (page 2·403), Kansas and Memphis Rubs (page 5·68), Pastrami Spice Blend (see page 213), or various curry blends (see page 5·89).

Best Bets for Dry Rubs

Recipe	Ingredients*	(scaling)	Effective nitrite concentration	Note
basic dry rub	salt	100%	none	customizable to your own taste
	sugar (optional)	10%		
	herbs and spices (optional)	5%		
sweet dry rub	salt	100%	none	
	sugar	50%		
	herbs and spices (optional)	5%		
pink salt rub	salt	100%	less than 0.15%	only suitable for brief dry-curing or brining under refrigeration
	Insta Cure No. 1	16%		
	sugar (optional)	20%		
	herbs and spices (optional)	5%		
slow-curing rub	salt	100%	less than 0.15% for both nitrites and nitrates	recipe includes nitrates; must be used only for dry, long cures
	Morton Tender Quick	43%		
	sugar (optional)	30%		
	herbs and spices (optional)	5%		

* (*allow sufficient rub to cover meat or seafood*)

HOW TO Brine or Wet-Cure Meat: Equilibrium Method

Wet-curing and brining are very similar processes. Because both involve soaking meat in salty water, we have combined them here. There are a few key differences that are worth noting, however. Brining is generally done to achieve a final salt concentration of 0.5%–1% in the meat. Curing usually aims for a 2%–3% final salt concentration and sometimes more. Both brining and curing rely on ordinary salt as their primary ingredient, but they may contain other salts (sodium nitrate, calcium chloride) or ingredients like phosphates (see page 155) for tenderness, or sugar and other ingredients for flavor.

Our preferred method of brining and wet-curing is to calculate the amount of salt and other ingredients needed to bring the meat to the correct final value so that you cannot oversalt the meat. You must weigh both the meat and the water, and then calculate the amount of other ingredients. The table on page 168 has scaling numbers in the column "scaling 1" for brines based on the assumption that the final salt concentration should be 1%; to get a 0.5% final concentration, simply divide the ingredient amounts in half. The table on page 169 similarly has a "scaling 1" column for cures based on the assumption that the final salt concentration should be 2%; to get another concentration, multiply or divide the ingredient amounts accordingly.

In either case, set the weight of the meat plus the water to 100%, scale to get the ingredient amounts, and then mix them with the water. The amount of water depends on what you need to cover the meat and what will fit in your refrigerator. Try to use at least twice as much water by weight as meat (a 2:1 ratio) if the container you'll need to hold the brining meat will fit in your refrigerator. The brining or wet-curing can be done in any nonreactive sealed container; plastic tubs work well. You can also vacuum seal the liquid with the meat by using a low vacuum setting.

Brining and curing are diffusion processes that scale roughly with the square of the thickness: a piece of meat twice as thick will take four times as long for the brine or cure to penetrate. Injection, tumbling, and perforation with a Jaccard meat tenderizer can be used to speed these processes (see page 174).

4

6

1 Choose a brining or curing recipe. Good options are listed in the tables on the next page; recipes for brines and cures are given in Best Bets for Brines on page 168 or Best Bets for Wet Cures on page 169. Use the "scaling 1" column for quantities in the recipe tables.

2 Weigh the total amount of meat plus water, and use the resulting weight as the 100% value for scaling. If the meat has a lot of bone, subtract the approximate weight of the bone. In general, use an amount of water equal to at least 10% of the weight of the meat. If you have room in the refrigerator, however, use twice as much water as meat by weight, or more. The greater the amount of water, the more evenly salt will be distributed throughout the meat.

3 Mix the salt and other ingredients in the water, stir to fully dissolve, and then refrigerate the solution. To chill the mixture faster, dissolve the ingredients in part of the water, and then add ice to reach the full amount of water required (be sure to account for the addition of ice in the water weight, however).

4 If the brine or cure recipe includes phosphates, dissolve them fully in a cup of warm water, and then add the phosphate solution to the rest of the brine or cure. Use care; too high a temperature will degrade the phosphates, but water that is too cold will not dissolve them.

5 Optionally, inject the meat with the solution, vacuum tumble the meat, or perforate it with a Jaccard-style device. Each of these steps greatly speeds the process and distributes the salt more evenly; they can all be done consecutively. We recommend using these acceleration steps for any cut of meat thicker than 2 in / 5 cm.

6 Immerse the meat in the brine or the wet cure, and refrigerate for the soaking time plus the resting time given in the appropriate table on the next page. The thinner the meat, the quicker the concentration gradient will reach equilibrium. Use a salinity meter, if available, to check the progress (for instructions, see page 2·313). Alternatively, monitor the weight increase as described in the note at the bottom of this page. The gradient will fully equilibrate by the time that the brine has attained the desired final salt concentration. If you want to brine to a final salt concentration of 1% in the meat, for example, it is done when the salinity of the brine reaches 1%.

7 Rinse the meat quickly with fresh water to remove excess salt from the surface, and pat dry. The meat is now ready to use. Brined meat typically requires cooking before service. Cured meat may require drying, smoking, ripening, or other steps before service.

8 Optionally, ripen and dry the meat. Slowly drying a fully cured piece of meat or seafood is often an essential step for creating the desired texture and flavor, as well as for fully preserving it. Frequently, this stage includes a smoking step. However ripening is done, the humidity should be kept between 75% and 90% so that the exterior and the interior dry at about the same rate.

VARIATION: High-Concentration Method

A different approach to brining or wet-curing is to mix a standard concentration of the brine or cure regardless of the amount of meat used. This method has the advantage that the solution can be made up in advance; it has the disadvantage, however, of creating a salt concentration gradient in the meat. To reduce the gradient, either soak the meat in fresh water for 1–4 h or rest it for the times recommended on the next page. The resting step after brining works very much like that after cooking. Salt, just like heat, continues to diffuse through the meat after it is removed from the source.

The high-concentration method is less precise than the equilibrium method above, but it is traditional and widely used. Use the brining, resting, and soaking times in the tables as guidelines, but expect some trial and error to find times that work well and repeatably for meat of a particular size.

1 Choose a brining or curing recipe. Our recommendations are listed in the tables on the next page, which refer to brine and cure recipes on pages 168 and 169. Use the "scaling 2" column for quantities in the brine and cure recipes.

2 Follow steps 2–5 above.

6 Immerse the meat in the brine or the wet cure, and refrigerate for the soak time or time with cure indicated in the appropriate table on the next page—or monitor the weight increase as described below.

7 Rest the meat, and soak in fresh water for the time indicated in the table on the next page. Brined meat is then ready to cook. For cured meat, continue with step 8 above.

Another way to judge when brining is complete is to calculate the final weight of the meat when it has reached the desired salinity, D (in percent), which typically ranges from lightly brined at 0.7% salinity to an intense cure of 2%. First, determine the salinity S of the brine from the weight of salt and water in grams by using the formula $S = 100 \times \text{salt} \div (\text{salt} + \text{water})$. Next weigh the unbrined meat to obtain the starting weight M in grams. Then calculate the target weight of the meat T by using the formula $T = M + (D \times M \div S)$.

As the meat soaks in the brine in step 6 of the procedure above, remove and weigh it periodically to check whether the weight has increased to the target weight. For example, if brining 1 kg pork chops in the basic brine recipe on page 168, $S = 100 \times 7 \div (7 + 100) = 6.54$. $M = 1{,}000$ g, the starting weight of the pork chops. To achieve a final salinity $D = 0.7\%$, brine to a target weight of $T = 1{,}000 + (0.7 \times 1{,}000 \div 6.54) = 1{,}107$ g. The pork chops will thus weigh about 1.107 kg when they have reached the desired degree of saltiness.

Best Bets for Brining

Meat	Recommended brine	Thickness (cm)	Thickness (in)	Soak* (h)	Rinse (min)	Rest (h)	Note	See page
chicken breast, boneless and skinless	basic brine	3.2	1¼	4	n/a	2	extend soaking time if skin on or bone in	168
chicken legs, skin on, bone in	basic brine	3.8	1½	7	n/a	3		168
duck breast, skin on, boneless	basic phosphate brine	3.2	1¼	10	n/a	5		168
fish fillet, portion, skinless	basic seafood brine	3.8	1½	5	n/a	1		168
lobster tail, whole, shelled	basic seafood brine	3.2	1¼	3	n/a	1		168
shrimp, whole, shelled	basic seafood brine	1.25	½	2	n/a	½		168
pork belly, whole, skin on, bone in	basic pink brine	6.4	2½	72	2 h	24	adjust soaking time for preportioned cuts	168
pork chop, bone in	basic brine	2.5	1		see note		vacuum seal pork with brine until meat absorbs 10% of liquid	168
pork tenderloin, whole	juniper brine	3.8	1½	12	n/a	8		5·35
pork shoulder, whole, skin on	cola brine	23	9	72	2 h	n/a	inject with 7% brine, and immerse in remaining brine**	168
sweetbreads, membrane peeled	umami brine	3.8	1½	10	30	n/a		168
veal tongue	basic phosphate brine	7.6	3	24	2 h	n/a	inject with 14% brine, and	168,
whole chicken	basic brine	2.5 kg		24	n/a	24	immerse in remaining brine**	2·178
whole turkey	basic brine	5 kg		48	n/a	48		

* (*tumbling or injecting the meat reduces the soaking time required*); **(*by weight of meat, which is about 60% of weight of whole poultry*)

Best Bets for Curing

Meat	Recommended rub or cure	Thickness (cm)	Thickness (in)	Cure time* (d)	Rinse (h)	Rest (h)	Example use	Note	See page
beef tenderloin, whole	basic dry rub	8.75	3½	2	n/a	24	cured beef		
brisket, whole	pastrami cure	7.5	3	7.5	n/a	n/a	corned beef pastrami	we prefer the meat from the nose end	213
duck breast, skin on	basic sweet cure, corned beef cure	2.5	1	1	wipe off cure	12	corned duck, duck ham	for corned duck, cook after curing; for duck ham, hang dry in refrigerator for 7 d	
duck leg, skin on	basic dry rub	3.2	1¼	6 h	wipe off cure	n/a	duck confit	can be cured for up to 12 h for a firmer texture	178
fish fillet, whole side, skin on	3% salt, 1% sugar to weight of fish	3.75	1½	24–28 h	wipe off cure	n/a	smoked salmon	vacuum sealing recommended	180, 212
pork belly, whole, skin on, bone in	basic dry rub, Wiltshire tank cure	6.25	2½	5–7	n/a	7 d	bacon	omit resting if using Wiltshire tank cure	
pork leg, skin on, bone in (fresh ham)	basic wet cure, blackstrap molasses cure	17.5	7	12–15	8	8	honey baked ham, prosciutto	injection curing recommended	183
pork jowl, skin on	pink salt cure	3.75	1½	1	2	n/a	guanciale		
pork shank, skinless (ham hock)	sweet dry rub	7	2¾	5	quick rinse	12	smoked ham hock		

*(*cure time is approximate, but varies with the thickness of the meat*)

thus the kind of aromas that will develop in matured cured meats and seafood. Subtle effects from the cure and the process used combine with the inherent qualities of the flesh to create aromas that can range from nutty to fruity to even floral. And the overall aroma isn't static: it changes in quality and intensity over time.

Finally, the ubiquitous Maillard reaction slowly produces additional aromas and color-darkening pigments. Indeed, the Maillard reaction is the reason that some Spanish hams—particularly Ibérico hams—have an intense dark-brown color rather than the rosy color of the more widely known Italian prosciutto hams and American Smithfield hams. Clearly, breed and the diet of the pig are important, but Spanish hams are different in large part because they are matured for much longer than other hams are. The long ripening step creates qualities in these hams that many connoisseurs revere (but that can be off-putting to the uninitiated).

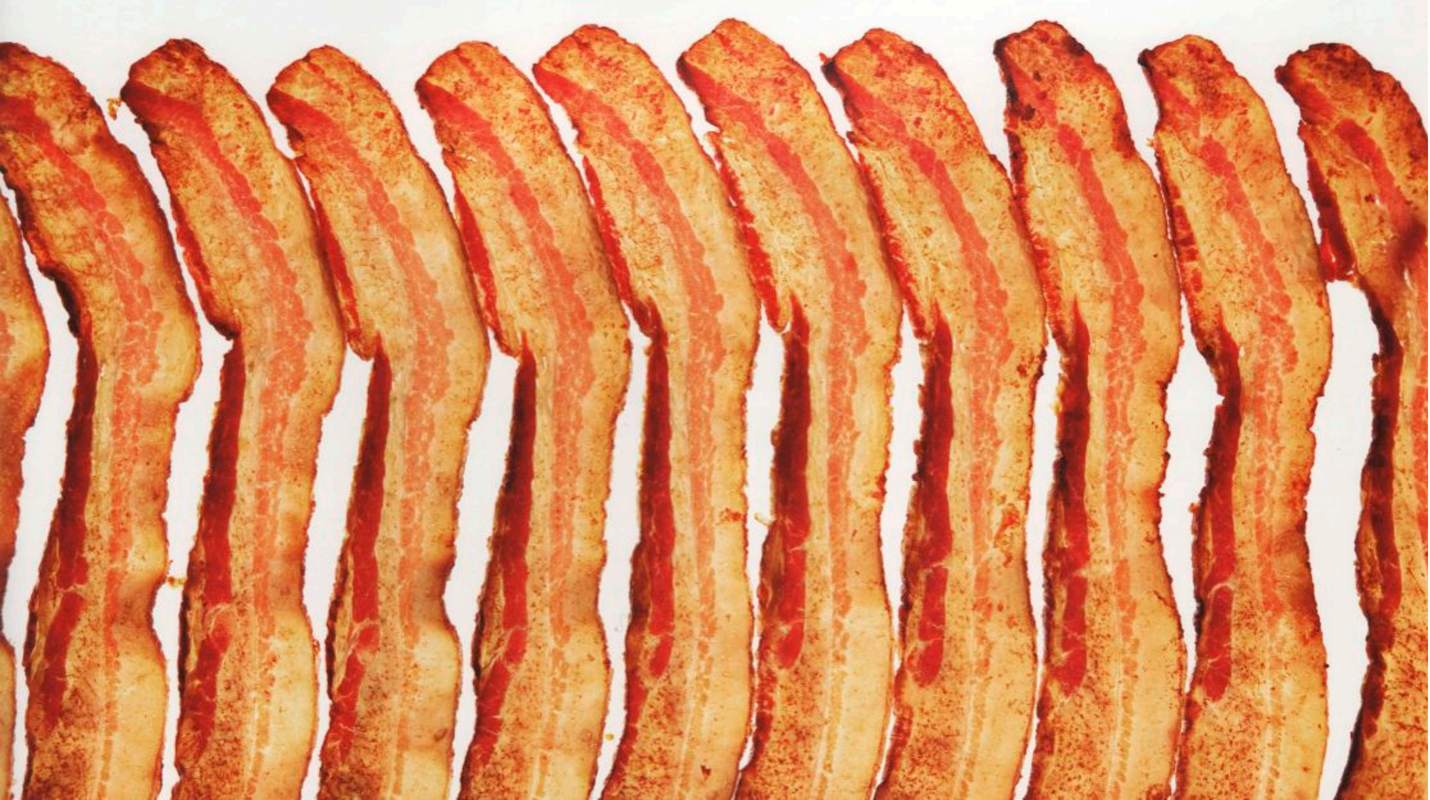
Mold and yeast may be allowed to grow—or even forced to grow via live culture—on the surface of ripening meat. Scientists are still investigating exactly how these organisms influence the flavor of cured meats, but there is no question among artisan producers that these salt-tolerant organisms contribute to the flavor by feeding off the cured flesh and creating new aromas as a by-product. Just as the aroma of sourdough bread is profoundly influenced by the organisms living in the starter, wild yeasts and molds help give a particular cured meat or seafood (like Japanese *katsuobushi*) its distinctive flavor.

Drying is the final change that occurs during a maturing step. Traditionally, this was done to allow salt levels to finish equilibrating and to complete preservation by removing water from the food. The increase in salinity and the decrease in water content together stave off spoilage.

Drying must be carefully controlled so that water evaporates from the surface of the food just as fast as it migrates from the center to the surface—until the food has lost 20%–40% of its weight in water. To make this happen, freshly cured meats or seafood are usually dried at temperatures of 15–20 °C / 59–68 °F and, initially, at a relative humidity of about 90%, which is slowly reduced to 70% as the food dries. This can take from hours to months, depending on the size of the food and how dry you want it to become.

For more on Jaccarding meat, see page 50.

Sometimes cured meats and seafood are also smoked as part of the ripening process. We discuss the details of smoking food in chapter 7 on Traditional Cooking, page 2·2, and in this chapter on page 208. We mention it here to point out that it can be an important step after curing. Sometimes, it is done early, often during the resting step, after the curing is complete. Other times, it's done at the end, after the product is fully mature. The choice to do it early or late comes down to whether or not you want a distinct smoky aroma. Over time, smoke aromas dissipate to the point that you would no longer describe the flavor as smoky.



HOW TO Speed Brine or Wet-Cure by Injection or Vacuum

The time needed to completely brine or cure meats or seafood is substantial. Depending on the size of the food, it can take days, weeks, or even months for enough salt to accumulate in the flesh and then spread out evenly from the surface to the core. Commercial manufacturers have developed some simple techniques to slash those waiting times by using two processes: injection brining and vacuum tumbling. Injection brining works just like it sounds. The brine or wet cure is pumped through needles directly into the meat, with quick and even results.

Vacuum tumbling bounces the meat around inside a clothes-dryer-like device at low pressure. The process accelerates the equalization of salt concentration throughout the meat and also tenderizes muscle fibers and extracts muscle proteins.

1 **Mix and chill a brine or cure.** For recipes, see page 168. Strain any large particles (like spices) out of the portion that will be injected so that they do not clog the syringe. In general, injection works best with equilibrium brining or curing (see page 170) and when the quantity of water in the brine solution weighs at least as much as the meat to be brined.

2 **Optionally, use a Jaccard meat tenderizer to puncture the meat.** This step makes injection more effective. Ideally, Jaccard the meat in a direction perpendicular to the direction in which you will inject the meat.

3 **Fit a butcher's syringe with the side-port or perforated needle, and fill it with brine or wet cure.**

4 **Push the needle into the meat until it hits bone or until it is near the opposite side of the meat.**

5 **Inject the brine or cure by pushing on the syringe plunger while slowly withdrawing the needle.** Stop when the first side-port on the needle reaches the surface. Note that during injection some liquid may leak out of open vessels or Jaccard penetration points; that is normal.

6 **Move the syringe over about 2.5 cm / 1 in, and inject again.** The goal is to inject the brine or cure evenly so that no part of the meat is more than 2.5 cm / 1 in from an injection site. Spacing injection points more closely is usually fine, particularly if the brine contains a large amount of water compared to the weight of the meat.

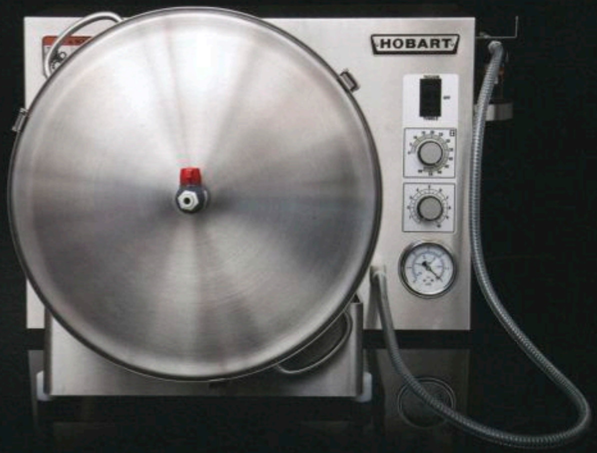
7 **Optionally, vacuum tumble the meat, as described on the next page.**

8 **Following the steps on page 170, cover the meat with the remaining brine or wet cure in a closed container (or vacuum seal the mixture), and refrigerate.** The total time required for brining after injection is much less than is required without injection but is difficult to specify exactly. If you are using the equilibrium method described on page 170, you can use a salinity meter to check whether the brining is done.

If you are injecting a large roast, shoulder, or ham, you can also fit the syringe with a slanted-end needle and insert it into a vein or artery. Inject liquid until you feel the meat expand. Wait a few minutes, and then inject again. The blood vessel method is helpful in injecting a large piece of meat, but the regular injection pattern is actually better in most cases.

For more on using a Jaccard, see page 50.

Variation: Vacuum Tumbling

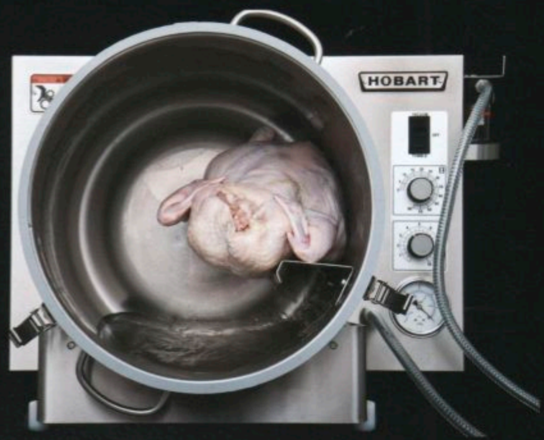


1 **Follow steps 1–6 on the previous page to make a brine or cure and (optionally) Jaccard the meat and/or inject the solution.**

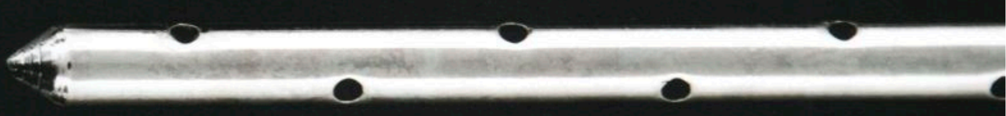
7a **Place the meat and the liquid in the tumbler.** Generally the container will be only about one-quarter to one-third full of liquid. Capacities vary by model, but there should be enough room inside the container that the meat can tumble when the machine turns.

7b **Run the vacuum pump to suck out the air.** Let the machine sit for several minutes at maximum vacuum. On most models, the vacuum hose must be disconnected before tumbling.

7c **Turn on the tumbling motor.** Tumbling times vary, but 30–60 min usually works well. If the tumbler offers a speed control, use low speed for most meats, higher speed for very tough meat.



8 **Follow step 8 on the previous page to complete the brining or curing.** For best results, cover the meat with the remaining brine, and refrigerate until the salt concentration gradient has equilibrated.



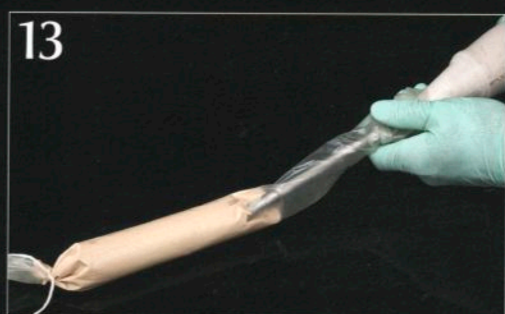
The basic tool for injection is a heavy-duty butcher's syringe (above) with a side-port needle (bottom right). The side ports help distribute the brine in all directions, and this is the most useful needle for most injection tasks. The slant-end needle (middle right) is useful primarily for injecting into a blood vessel in a whole animal or a primal cut. Other injection tools are available, including those that draw brine from a container through a hose, and some that are motorized.

FOIE GRAS TORCHON

Yields 875 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Raw duck foie gras, Grade A	800 g	100%	① Bring lobe of foie gras to room temperature.
Water, cold	as needed		② Butterfly lobe carefully to reveal network of blood vessels.
			③ Remove veins and any remaining blood by scraping away with a spoon.
			④ Set aside foie gras.
White port (sweet)	16 g	2%	⑤ Blend to form cure.
Salt	14 g	1.75%	⑥ Rub onto foie gras; cover completely.
Cognac	4 g	0.5%	⑦ Vacuum seal foie gras.
Sugar	4 g	0.5%	⑧ Refrigerate for 12 h to cure.
Insta Cure No. 1	2 g	0.25%	⑨ Cook cured foie gras sous vide in 56 °C / 133 °F bath to core temperature of 55 °C / 131 °F, about 20 min.
			⑩ Remove from bag, and cool at room temperature for 10 min, or until fat begins to congeal.
			⑪ Reserve 50 g of fat.
Synthetic sausage casing, 5 cm / 2 in diameter, 20 cm / 8 in long	1 piece		⑫ Puree cooked foie gras.
			⑬ Pour into synthetic sausage casing.
			⑭ Tie ends of casing with butcher's twine.
			⑮ Refrigerate for at least 3 d to age.
Brioche loaf	300 g	37.5%	⑯ Cut into slices 2.5 cm / 1 in thick and 75 g each.
Foie gras fat, from above	50 g	6.25%	⑰ Brush brioche slices evenly with reserved foie gras fat.
Salt	3 g	0.4%	⑱ Toast slices in nonstick pan until edges are golden and centers are tender, about 3 min.
Yuzu and kumquat marmalade see page 356	40 g	5%	⑲ Serve slices of aged foie gras with marmalade and hot, toasted brioche.

(2008)



EXAMPLE RECIPE

SHAVED FOIE GRAS ADAPTED FROM DAVID CHANG

Yields 1.2 kg (16 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lychees, drained (canned in syrup)	200 g	50%	① Quarter. ② Refrigerate until use.
For Riesling gelée:			
160 Bloom gelatin	4 g (two sheets)	1%	③ Combine, and bring to simmer. ④ Refrigerate in small mixing bowl for 6–8 h.
Riesling (dry)	250 g	62.5%	⑤ Stir, and thoroughly break up gelée once an hour with long-tined fork. This will give appearance of shattered glass.
Rice vinegar	4 g	1%	⑥ Cover gelée, and store refrigerated for no more than 1 wk.
For pine nut brittle:			
Sugar	100 g	25%	⑦ Cover baking sheet with parchment paper or silicone mat, and set aside for caramel.
Glucose	100 g	25%	⑧ Combine sugar, glucose, and isomalt in heavy-bottom saucepan.
Isomalt	100 g	25%	⑨ Cook over medium heat without disturbing until golden caramel forms, 12–15 min, and remove from heat.
Pine nuts	400 g	100%	⑩ Meanwhile, toast nuts in 150 °C / 300 °F oven until golden and fragrant, 6–7 min. ⑪ Fold into caramel.
Unsalted butter, brought to room temperature	75 g	18.75%	⑫ Stir into caramel until fully incorporated, about 30 s. ⑬ Pour caramel immediately onto prepared baking sheet in thin layer, and cool.
Kosher salt	to taste		⑭ Break brittle into small, bite-size pieces.
Foie gras torchon, frozen see previous page	400 g	100%	⑮ Place two tablespoons of quartered lychees in bottom of each of eight serving bowls. ⑯ Top lychees with tablespoon of Riesling gelée. ⑰ Top gelée with tablespoon of cracked brittle. ⑱ Grate mound of frozen foie gras with Microplane onto each bowl, as generously as desired.

(original 2008)

DUCK LEG CONFIT WITH POMMES SARLADAISES

ADAPTED FROM PAULA WOLFERT

Yields 1.4 kg (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Moulard duck legs	1.6 kg (four legs)	100%	① Pack cure evenly onto duck legs. ② Vacuum seal.
Confit curing mix see next page	288 g	18%	③ Refrigerate for 10 h. ④ Rinse off cure, and blot legs until completely dry.
Rendered duck fat	80 g	5%	⑤ Vacuum seal legs individually with 20 g of fat each. ⑥ Cook sous vide in 82 °C / 180 °F bath for 8 h. ⑦ Cool quickly in ice-water bath, and refrigerate.
Waxy potato, sliced 5 mm / 3⁄16 in thick and cut into 3 cm / 1 3⁄16 in coins	160 g	10%	⑧ Vacuum seal together. ⑨ Cook sous vide in 88 °C / 190 °F bath until just tender, 20–25 min. ⑩ Warm duck legs in 80 °C / 176 °F bath for 12 min. ⑪ Brown legs in skillet, skin side down, until skin is crisp, about 4 min. ⑫ Garnish crisped legs with potatoes.
Water	30 g	1.9%	
Rendered duck fat	20 g	1.25%	
Garlic, thinly sliced	5 g	0.3%	
Salt	1.4 g	0.09%	
Thyme leaves	0.5 g	0.03%	

(published 1983, adapted 2005)

EXAMPLE RECIPE

CONFIT CURE MIX

Yields 1.1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Kosher salt	1 kg	100%	① Combine, vacuum seal, and refrigerate until use.
Coriander seeds, toasted	100 g	10%	② Use to cure poultry and game.
Garlic cloves, mashed	11 g	1.1%	
Star anise, finely crushed	7 g	0.7%	
Orange zest, finely grated	5 g	0.5%	
Thyme leaves	2 g	0.2%	
Black peppercorns, coarsely crushed	0.8 g	0.08%	
Bay leaves, thinly sliced	0.4 g	0.04%	

(2008)

EXAMPLE RECIPE

MISO-CURED BLACK COD INSPIRED BY NOBU MATSUHISA

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White miso	500 g	80%	① Combine to make cure.
Mirin	100 g	25%	
Sake	80 g	20%	
Shoyu	35 g	8.75%	
White soy sauce	25 g	6.25%	
Yuzu zest, finely grated	8 g	2%	
Lime zest, finely grated	5 g	1.25%	
Lemon zest, finely grated	3 g	7.5%	
Black cod fillet, skin on, 3.25 cm / 1¼ in thick	400 g	100%	② Cut into four 100 g portions. ③ Spread cure over all surfaces of fish. ④ Vacuum seal individually. ⑤ Refrigerate for 12 h. ⑥ Remove from bags, and wipe off excess cure.
Unsalted butter	60 g	15%	⑦ Vacuum seal each portion with 15 g of butter. ⑧ Cook sous vide in 49 °C / 120 °F bath to core temperature of 48 °C / 118 °F, about 20 min.
Toasted sesame seeds	15 g	3.75%	⑨ Blend in spice grinder to fine powder.
Ginger powder	4 g	1%	
N-Zorbit M (National Starch brand)	4 g	1%	
Clarified unsalted butter	80 g	20%	⑩ Dust cooked fish generously with sesame powder. ⑪ Brown in very hot butter until just golden, about 45 s.
Daikon, fine julienne	40 g	10%	⑫ Toss together.
Spring onion, fine julienne	40 g	10%	⑬ Garnish each fish portion.
Sesame oil	to taste		
White soy sauce	to taste		
Yuzu juice	to taste		

(published 2001, adapted 2010)

For a photo, see page 164.

GRAPEFRUIT-CURED SALMON

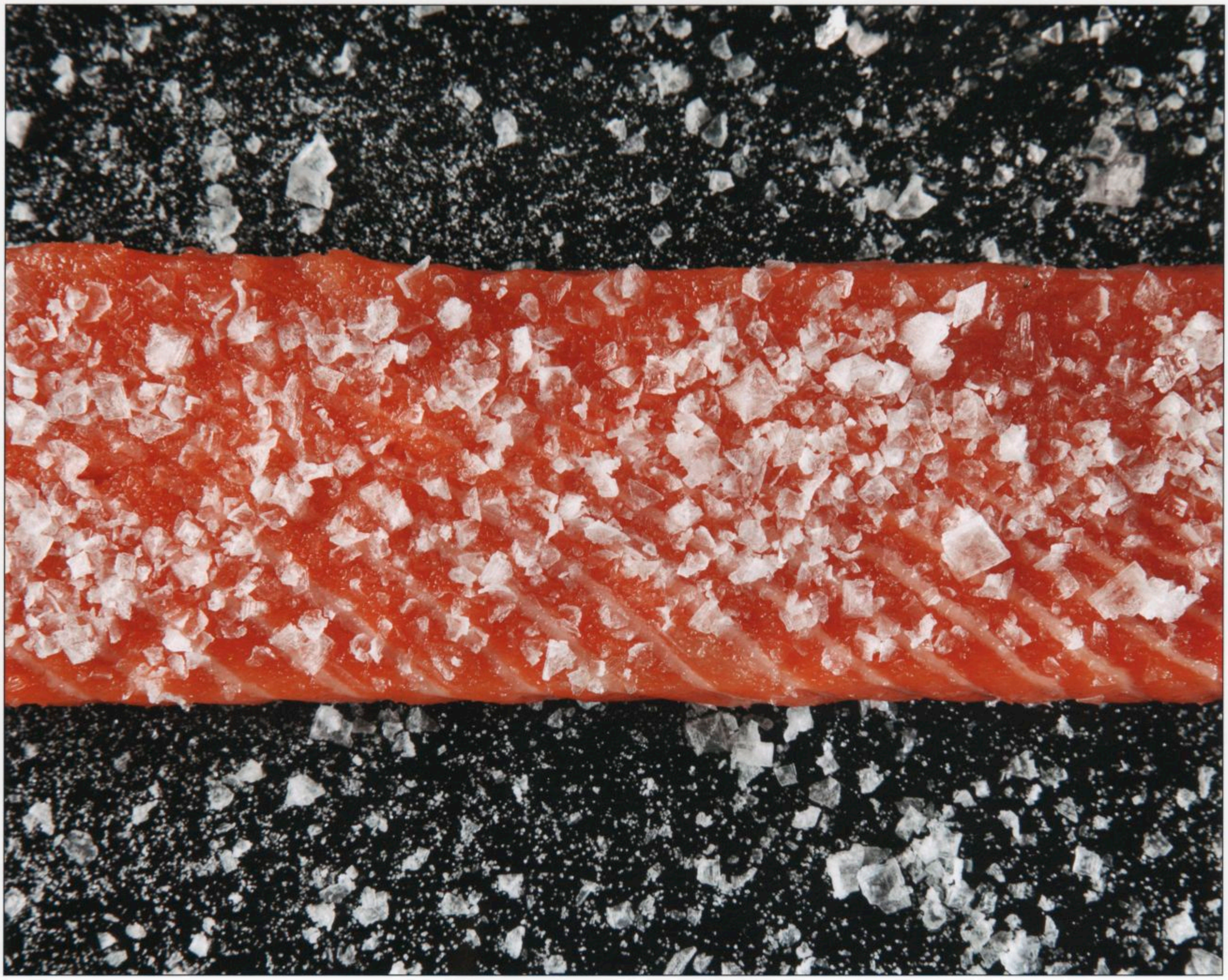
Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Salmon belly, 2.5 cm / 1 in thick	400 g	100%	① Trim, and remove skin. ② Set salmon aside.
Salt	60 g	15%	③ Blend, forming wet cure. ④ Rub cure onto salmon to completely cover. ⑤ Vacuum seal rubbed salmon. ⑥ Refrigerate salmon for 12 h to cure. ⑦ Remove cured salmon from bag. ⑧ Rinse cure off with water, and dry. ⑨ Vacuum seal, and refrigerate salmon to store.
Sugar	40 g	10%	
Young Douglas fir buds	30 g	7.5%	
Vodka	15 g	3.75%	
Pink grapefruit zest, finely grated	5 g	1.25%	
Juniper berries, crushed	4 g	1%	
Black peppercorns, finely ground	2 g	0.5%	
Douglas fir essential oil	0.1 g	0.025%	
Pink grapefruit essential oil	0.1 g	0.025%	

(2008)

Fir tree buds can be picked from early May through mid-June. You can omit them if they are not available—the taste will be subtly different but still good.

For more on working with essential oils, see page 2·325.



EXAMPLE RECIPE

FLUKE CURED IN KOMBU ADAPTED FROM KYLE CONNAUGHTON

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Dry kombu sheets, about 20 cm / 8 in long	eight sheets		① Soak in cold water until fully hydrated, about 20 min.
Fluke fillets, 1.5 cm / ¾ in thick, skinned and side fin muscle removed	400 g (four whole fillets)	100%	
Salt	40 g	10%	② Grind together to fine powder.
Kombu powder (store-bought)	8 g	2%	③ Dust evenly over one side of fillets.
Sugar	8 g	2%	④ Lay fillets, seasoned side down, on kombu sheets.
			⑤ Dust evenly with remaining salt, and cover with second sheet of kombu.
			⑥ Vacuum seal, and refrigerate for 1 h to cure surface.
			⑦ Remove fillets from cure, pat dry, and vacuum seal.
Sous vide ponzu see page 2·313			⑧ To serve, slice fluke thinly. Serve ponzu on side.

(original 2002, adapted 2010)

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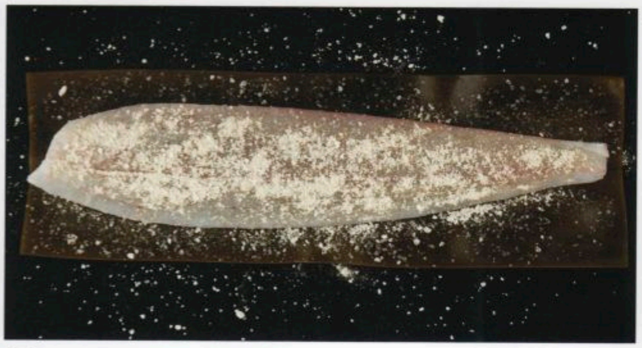

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EXAMPLE RECIPE

HOUSE-CURED BACON

Yields 3.5 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Salt	100 g	2.5%	① Mix to make cure.
Sugar	72 g	1.8%	
Insta Cure No. 1	24 g	0.6%	
Fermento	7 g	0.175%	
Black peppercorns, coarsely ground	4 g	0.1%	
Coriander seeds, toasted, finely ground	4 g	0.1%	
Mace, finely ground	4 g	0.1%	
Star anise, coarsely ground	4 g	0.1%	
Sodium erythorbate	2.2 g	0.055%	
Pork belly, bone in	4 kg	100%	② Rub cure thoroughly on surface of meat. ③ Let sit 10 min so that spices adhere. ④ Pack remaining cure around meat. ⑤ Vacuum seal. ⑥ Refrigerate for 1 wk, turning over once a day. ⑦ Brush away cure from surface of meat. ⑧ Hang cleaned meat on meat hook, and refrigerate uncovered for 1 wk in well-ventilated area so that cure can permeate all areas evenly. ⑨ Smoke in 77 °C / 170 °F smoker with 60% relative humidity for 7 h (wet-bulb temperature: 65 °C / 150 °F). ⑩ Chill for 12 h before using.

Although we use Fermento culture for flavor, this is a cured, rather than a fermented, bacon.

(2009)

EXAMPLE RECIPE

BLACKSTRAP MOLASSES COUNTRY HAM

ADAPTED FROM MICHAEL RUHLMAN AND BRIAN POLCYN

Yields 6 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Kosher salt	1.3 kg	100%	① Combine.
Insta Cure No. 2 (or DQ Curing Salt)	340 g	26%	
Dark brown sugar	450 g	35%	② Add to salt blend, and stir together.
Blackstrap molasses	617 g	47%	
Dark rum	210 g	16%	
Ginger, grated or minced	10 g	0.8%	
Juniper berries, crushed	8 g	0.6%	
Cayenne pepper	3 g	0.2%	
Coriander seeds, black, toasted and ground	1 g	0.08%	
Fresh ham, skin on, aitchbone removed	7 kg	540%	③ Rub cure all over ham, applying more to area around exposed bone. ④ Put in nonreactive container large enough for ham and for liquid that cure will draw out. ⑤ Place 7 kg of weight on ham, using platter or board with weights on top. ⑥ Refrigerate for 12–15 d (1 d per ½ kg). Turn ham; after 6 d, redistribute cure as necessary. ⑦ Remove ham from refrigerator, and rinse off cure under cold water. ⑧ Soak in cold water for 8 h to remove residual surface salt. ⑨ Set ham on rack, and refrigerate uncovered for 8 h. ⑩ Cold-smoke ham at 15 °C / 60 °F for 18 h. ⑪ Hang ham to dry in cool, dark place, ideally at 15 °C / 60 °F with 65%–75% relative humidity, for 7 wk.

(original 2005)

Curing or cooking instructions that give a specific amount of time by weight are almost always making a very crude approximation. Diffusion time does not depend linearly on weight. Nevertheless, over a small range of sizes, it can work acceptably well, as it does here.

After cold smoking, the ham can be cooked to a core temperature of 60 °C / 140 °F and served like a traditional baked ham.

MICROWAVED BEEF JERKY

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beef flank steak	500 g	100%	① Cut with grain into even, rectangular strips 5 mm / 3⁄16 in thick, and set aside.
Soy sauce	125 g	25%	② Combine.
Fish sauce	85 g	17%	③ Place meat strips in marinade.
Sugar	14 g	2.8%	④ Vacuum seal together, and refrigerate for 48 h.
Salt	5.3 g	1.06%	⑤ Drain.
			⑥ Place strips on paper towel-lined tray; pat strips dry.
			⑦ Lay three strips in center of microwavable plate.
			⑧ Microwave at 50% power for 1 min, and flip strips over. Repeat four more times for total cooking time of 5 min, and remove jerky.
			⑨ Repeat steps 7 and 8 with remaining strips, always working with batches of three.

(2009)

To dehydrate the jerky without a microwave, dry the marinated beef strips at 60 °C / 140 °F until leathery, 10–12 h.

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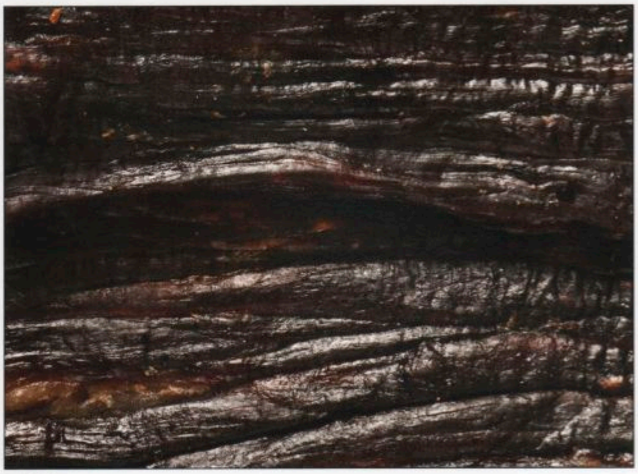

10 after 1 min

Beef jerky is excellent as it is. We also use it to make a crispy beef garnish by pounding it to separate its fibers, and then frying it in hot oil.

EXAMPLE RECIPE

CURED BEEF TENDERLOIN "BRESAOLA STYLE"

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beef tenderloin (or venison tenderloin), 5 cm / 2 in thick	1 kg	100%	① Remove silver skin, and trim tapered end for even curing. ② Set aside.
Espresso roast coffee, ground	50 g	5%	③ Grind together to medium coarse.
Salt	40 g	4%	④ Pack all over surface of tenderloin, and vacuum seal.
Sugar	40 g	4%	⑤ If making cured carpaccio, refrigerate for 1 wk. Flip bag every 2 d to ensure even curing.
Cocoa nibs	16 g	1.75%	⑥ Rinse, and pat dry.
Black pepper	10 g	1%	⑦ Slice thinly, and pound to desired thickness; or freeze, and slice paper thin on meat slicer.
Juniper berries	10 g	1%	⑧ If making true bresaola, cure for 3 wk.
Insta Cure No. 2	2 g	0.2%	⑨ Rinse, and pat dry. ⑩ Tie with butcher's twine, and hang for minimum of 1 wk and up to 1 mo in refrigerator. Hanging time determines dryness of final texture. ⑪ Slice thinly.
Fermented black garlic (store-bought)	80 g	8%	⑫ Blend until smooth, and pass through fine sieve. ⑬ Verify seasoning.
Extra-virgin olive oil	40 g	4%	
Lemon juice	15 g	1.5%	
White balsamic	13 g	1.3%	
Salt	to taste		
Wild arugula	50 g	5%	⑭ Spoon small amount of fermented garlic paste across each plate.
Wild blackberries, halved	30 g	3%	⑮ Arrange slices of cured carpaccio or bresaola on each plate.
Celery stalk, peeled and thinly sliced	25 g	2.5%	⑯ Garnish with celery slices, arugula, blackberries, and celery leaves. ⑰ Season with salt, olive oil, and lemon juice.
Celery leaves	10 g	1%	
Lemon juice	to taste		
Extra virgin olive oil	to taste		
Flaky sea salt	to taste		

(2010)

Cured Beef Tenderloin carpaccio

SEA URCHIN BOTTARGA

Yields 150 g

INGREDIENT	QUANTITY	SCALING
Sea urchin tongues (gonads)	200 g	100%
Salt	500 g	250%
Beeswax	500 g	250%

1. **Pass sea urchin tongues through fine sieve.**
2. **Pour into sous vide bag molded into shape of fish roe sac, which is a thin, tapered triangle.**
3. **Vacuum seal, and cook sous vide in 64 °C / 147 °F bath for 50 min.** Leave in bag, and chill in ice-water bath until hardened, about 20 min.
4. **Pack cooked sea urchin in salt.** Ensure all sides are completely covered, and refrigerate for 12 h.
5. **Remove from cure.** Rinse, and pat dry on paper towels.
6. **Wrap cured sea urchin in cheesecloth.** Tie both ends of cheesecloth with butcher's twine. Hang in refrigerator for 2 mo to yield a sliceable, fudge-like consistency, or for 3 mo to make dry enough to grate.
7. **Melt beeswax, and dip dried sea urchin carefully into wax to coat completely.**
8. **Vacuum seal, and refrigerate until needed.**

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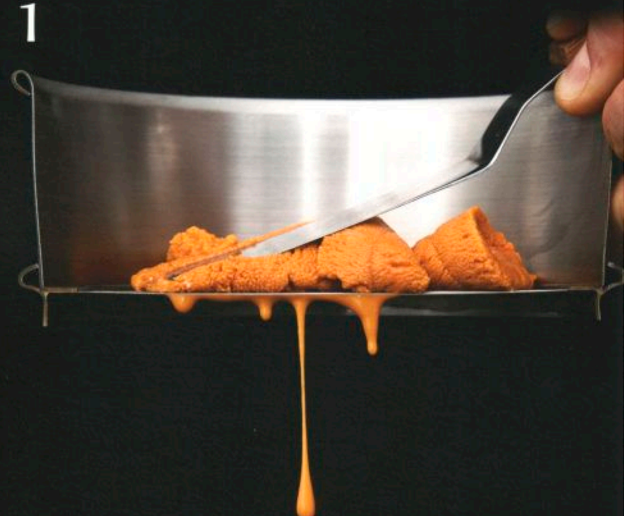

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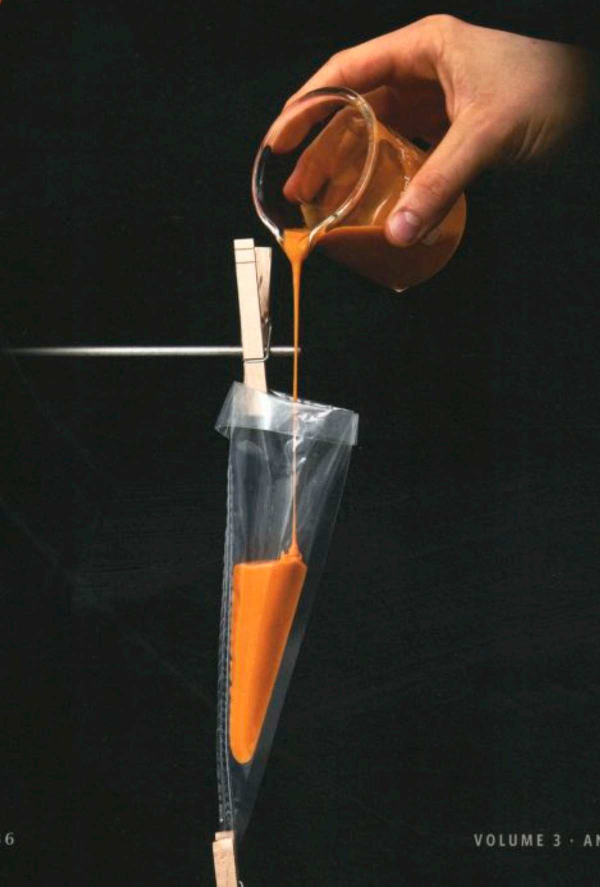

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EXAMPLE RECIPE

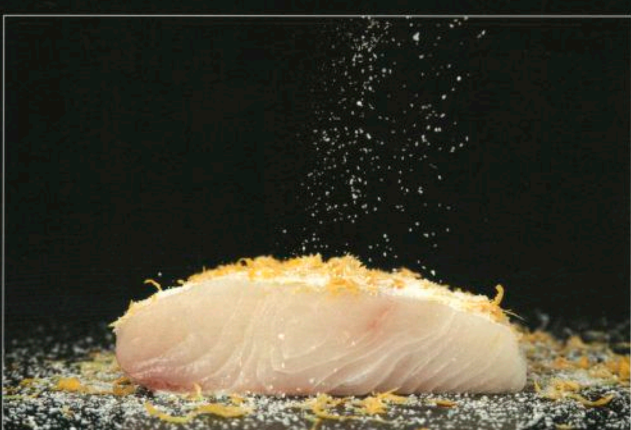
SALTED HALIBUT

Yields 1.2 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Salt	750 g	37.5%	① Mix together to form cure.
Sugar	150 g	7.5%	
Lemon zest, finely grated	15 g	0.75%	
Lime zest, finely grated	10 g	0.5%	
Halibut fillet, skin on, cut into strips 5 cm / 2 in thick	2 kg	100%	② Rub cure on strips to cover completely.
			③ Vacuum seal strips.
			④ Refrigerate for 48 h.
			⑤ Remove from bag, and rinse, discarding cure and rendered juices.
			⑥ Wrap single layer of cheesecloth around each cured strip.
			⑦ Tie both ends of cheesecloth with butcher's twine.
			⑧ Hang wrapped fish in refrigerator for 15 d to air-dry.
			⑨ Remove from cheesecloth.
			⑩ Vacuum seal, and refrigerate indefinitely until needed.
			⑪ To serve, soak in water or milk for 48 h, refrigerated, changing soaking liquid every 12 h.
			⑫ Use for making brandade or lutefisk.

(2008)

For a recipe for brandade, see page 5·152. For a lutefisk recipe, see page 200.

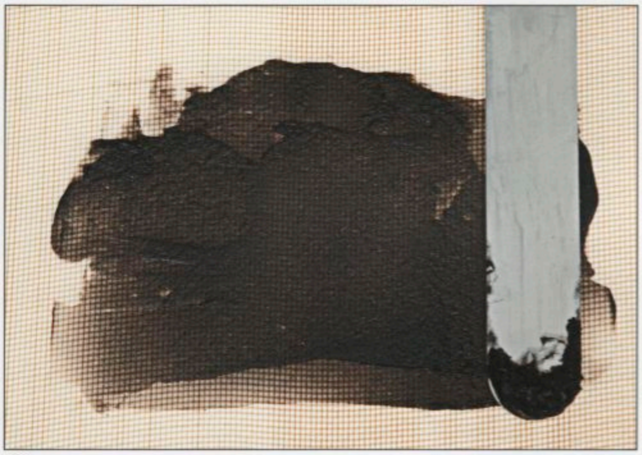


SEAFOOD PAPER ADAPTED FROM CARLO CRACCO

Yields 80 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
White fish (prawns, scallops, or squid may be substituted)	250 g	100%	① Blend to fine puree in food processor or Pacojet, if available.
			② Pass through fine sieve.
			③ Cast fish or shellfish puree paper-thin (1 mm / $\frac{1}{32}$ in thick) onto silicone baking mat.
Squid ink (optional)	1.25 g	0.5%	④ Cover with another silicone baking mat.
			⑤ Roll out evenly to 0.5 mm / $\frac{1}{64}$ in with rolling pin.
			⑥ Dehydrate at 70 °C / 158 °F until sheets are dry but still flexible, about 15 min.
			⑦ Remove top silicone mat, and return to dehydrator or oven until surface of sheet is leathery, about 3 min.
			⑧ Cut to desired dimensions, and reserve.

(original 2007, adapted 2010)



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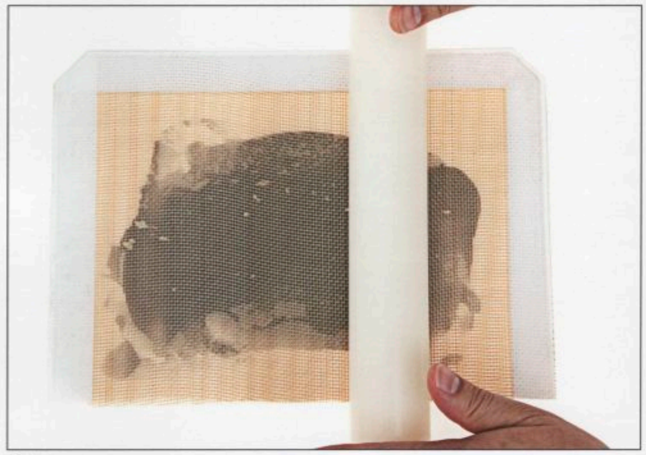

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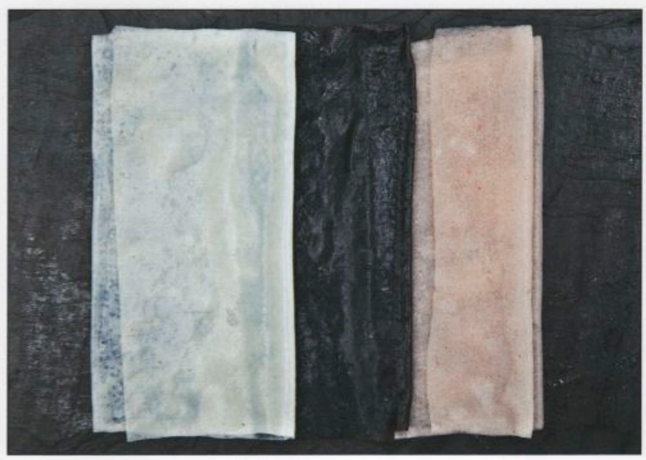


EXAMPLE RECIPE

BACON CHIPS WITH BUTTERSCOTCH, APPLE, AND THYME

ADAPTED FROM GRANT ACHATZ

Yields 160 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cured bacon strips, 10 cm / 4 in long and 2 mm / ¹⁄₁₆ in thick	100 g	100%	① Place bacon on dehydrator tray. ② Dehydrate at 80 °C / 175 °F for 3 h. ③ Store dehydrated bacon chips in airtight container.
Granny Smith apples, halved and cored	400 g	400%	④ Place on tray lined with silicone mat. ⑤ Roast in 190 °C / 375 °F oven for 30 min. ⑥ Cool. ⑦ Scoop out flesh from skins. ⑧ Puree flesh in blender. ⑨ Pass through chinois. ⑩ Spray acetate sheet with nonstick cooking spray, and wipe off excess liquid. ⑪ Spread puree with palette knife in layer 2 mm / ¹⁄₁₆ in thick. ⑫ Dehydrate at 70 °C / 160 °F for 45 min. ⑬ Cut resulting apple leather into strips, 3 mm by 10 cm / ⅛ in by 4 in.
Sugar	250 g	250%	⑭ Whisk together in small pot, and cook to 190 °C / 375 °F to make caramel.
Light corn syrup	150 g	150%	
Heavy cream	375 g	375%	⑮ Whisk into caramel to make butterscotch. ⑯ Heat to 115 °C / 240 °F. ⑰ Pour onto silicone mat, and cool. ⑱ Transfer to pastry bag. ⑲ Pipe dots of butterscotch onto each bacon chip, starting 2.5 cm / 1 in from top of strip, and leaving 6 mm / ¼ in between dots. ⑳ Wind six apple leather strips around each bacon chip, using butterscotch as glue.
Black pepper	to taste		㉑ Season.
Thyme leaves	to taste		㉒ Attach to bacon chips using small amount of butterscotch.

(original 2005, adapted 2010)

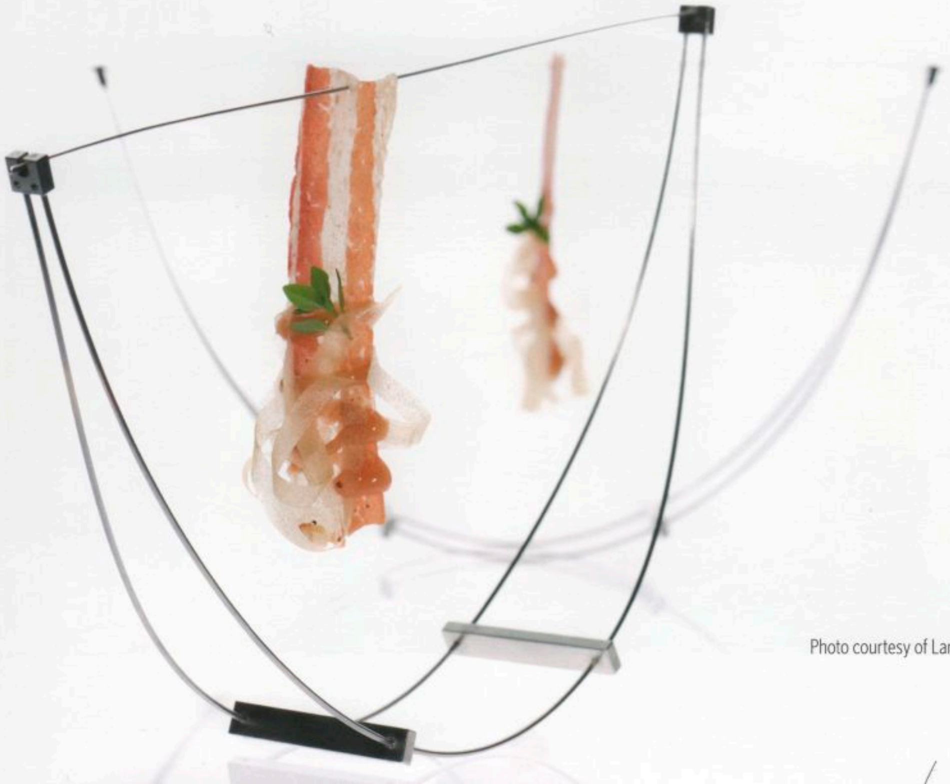


Photo courtesy of Lara Kastner/Alinea

MARINATING

Whereas brining and curing, discussed in the previous section, are about infusing meat with salt, marinating is a more general approach to altering the flavor and texture of food. Like brines and cures, marinades frequently contain salts, which modify the proteins in meat so that they hold more water, particularly after cooking. Marinades, however, usually also include several other groups of ingredients, such as acidic or alkaline compounds.

In life, the proteins in animal tissue have a nearly neutral pH. Many marinades work by pushing the pH way outside the normal range, making it acidic or alkaline. This shift in pH tends to break up the proteins and changes the flavor.

Acids can be added to the marinade directly—vinegar is the classic example—or indirectly by including bacteria that produces acidic fermentation products. Yogurt-based marinades take this latter approach. The acids react with proteins in the food, tenderizing it or even producing textures similar to those of cooked food, as occurs in the seafood dish ceviche. Alkaline marinades are the chemical counterpoints to acidic marinades, but they modify proteins in similar ways.

For more on heat conduction, see page 1·277. For more on brining and vacuum tumbling, see the previous section in this chapter on Salting and Drying.

Marinades can exploit a variety of other methods of action besides changing the pH of the food. Alcohol causes proteins to degrade, for example, and various enzymes chemically chew proteins to bits.

Marinades do more than just break down proteins, of course. Most add to or modify the flavor of the meat; in some cases, that is the primary function of the marinade, and any change to texture is incidental. Flavor-enhancing ingredients in marinades run the gamut from salts and sugars to herbs and spices.

The function of traditional marinades evolves over time, too, as foods change. The yogurt marinade for tandoori chicken originally was used to soften tough, old hens. These days, farm-raised chickens are usually much younger, so tenderizing isn't needed. But cooks continue to slather tandoori chickens in yogurt because they love the unique taste it gives to the meat.

Marinating, like brining, is a diffusion process. The time required scales approximately with the square of the thickness, so meat twice as thick takes four times as long to marinate. As a result, thin pieces marinate much more quickly than thick ones do. You can speed up marinating by using the same techniques used to accelerate brining: Jaccard tenderizing, injecting, and vacuum tumbling. In addition, pressure-marinating produces very fast results.

An acidic marinade, given enough time, can transform flesh in a manner akin to cooking with heat. A seafood ceviche is a particularly popular example of this technique.

Kung pao chicken, a popular Sichuan dish, is traditionally prepared by marinating chicken in an alkaline slurry, which ensures that the meat browns quickly in the hot wok.

Tenderizing with Acid

The scale of pH runs from 0 to 14, and living muscle maintains a chemical balance right near the middle of that, at a near-neutral pH of about 6.8 (see page 194). That is, it is neither acidic (low pH) nor alkaline (high pH). After slaughter, the pH of muscle steadily declines, so meat is, at a pH of around 5.5, more acidic than living muscle.

The conversion of muscle into meat increases its palatability in many ways, but at this lower pH, meat and seafood hold less moisture—and hold it less tightly—than muscles do. The reason this is true has to do with the spacing between the filaments that make up muscle fibers.

For more on the structure of muscle, including a detailed illustration, see page 6.

The contractile filaments inside living muscle fibers have just enough of a negative electrostatic charge, when the pH is near neutral, to keep themselves spaced well apart from one another (because like charges repel). Cellular water and other molecules flow in to fill the space thus opened among the filaments.

After slaughter, however, acidifying ions accumulate in muscle fibers and, because they carry positive charge, effectively cancel the negative charges on the filaments. As a result, the filaments no longer repel one another. They collapse into a tight bundle at the core of each muscle fiber, and as they do so, they squeeze out some of the liquid that was stored between them.

Not surprisingly, this has a profound effect on the juiciness of a cut of meat or a piece of seafood. Although the liquid forced from between filaments mostly remains inside muscle fibers in raw meat, cooking causes muscle fibers to shrink. The fibers spring leaks, and the juices start to escape. The more juices leak out of the food during cooking, the less juicy it is when you eat it.

Acidic marinades can reduce the loss of juices by reducing the extent to which the filaments collapse. Low-pH marinades work much like brining does. Recall from the previous section that brines imbue the food with chloride ions (from salt) that help filaments regain some of the natural

MARINATING STRATEGIES

All marinades are complex chemical treatments that infuse the food with tastes and aromas. Marinades transform flesh through numerous mechanisms, including those listed in the table below.

Many marinades use more than one mechanism: in boeuf bourguignon or coq au vin, for example, both alcohol and the acidity of wine contribute flavors and play roles in tenderizing, although the acidity is probably the more important of the two. Some mechanisms interact with each other. Fermentation generally produces alcohol or acids but also involves enzymes, many of which have a tenderizing effect. Many marinades include salt, which functions just as it does in a brine or cure. And they often include sugar and other flavorings that don't affect tenderness—they just taste good.

Strategy	Tenderizes connective tissue	Tenderizes muscle fibers	Swells with moisture	Draws out moisture	"Cooks"	Preserves	Example use	See page
acid	✓	✓	✓		at pH < 4.6	at low pH	fluke ceviche, kalbi steak	203, 199
alkaline	✓	✓	✓		at pH > 9.0	at high pH	kung pao chicken, lutefisk	205, 200
enzyme	sometimes	✓					pineapple-marinated sweet-and-sour pork	
fermentation		✓	usually			✓	chicken tikka masala	204
alcohol				✓	at high proof	at high proof	boeuf bourguignon, coq au vin, drunken prawns	

repulsion for one another that they have in living muscle. By expanding the space between them, brines draw water back into the meat.

Acidic marinades use positively charged hydrogen ions, rather than negative chloride ions, to do the same job. It may seem counterintuitive because the natural decline in pH after slaughter leads to filament collapse, but if the pH continues to decrease, the effect reverses. A surplus of positively charged hydrogen ions accumulates at the surface of the contractile filaments, and they go from having a negative charge (being spaced apart) to having a neutral charge (being packed together) to finally having a positive charge (being spaced apart again).

The pH doesn't need to drop too far below 5.5 before it has an easily perceptible effect on the juiciness of the flesh. That effect does take time to occur, however. Just like the ions from salt in brines and cures, hydrogen ions from an acidic marinade diffuse through flesh slowly. Acidity can mimic the action of salt in another way as well: taken too far, it can chemically alter (denature) the proteins so much that the flesh takes on a cooked texture.

If a ceviche-style preparation is what you're after, then protein denaturation is a good thing; otherwise, it can be undesirable. The threshold at which proteins begin to fall apart, albeit slowly, is around a pH of 4.8. The lower the pH, the faster and more completely this chemical transformation occurs. Of course, the texture that results from "cooking" with acidity is quite distinct from that which results from cooking with heat.

One benefit that distinguishes an acidic marinade from a salty brine is that, unlike salt, acids are capable of weakening collagen fibers in the connective tissue that surrounds both muscle fibers and bundles of muscle fibers, a process that also occurs during cooking (see illustration on page 80). By weakening this connective tissue, the marinade not only tenderizes a tough cut of meat but also frees the muscle fibers in it to swell further, and they draw in more liquid as they do. The meat ends up both juicier and more tender.

In ceviche, an acid makes raw fish flesh look as if it has been cooked (see photo on next page). Raw poultry and mammal meat transform in a similar way when marinated in acid, but this kind of preparation is nowhere near as popular for them as it is for fish and shellfish.

A prolonged soaking in a mildly acidic marinade will tenderize the collagen in a tough cut of meat, such as the flank steak shown here.

THE CHEMISTRY OF

pH

The scale used to measure the acidity or alkalinity (also known as basicity) of a solution is called pH. The precise definition is both technically complicated and unimportant for practical purposes, but it is useful to understand the basic outlines. Acids work by donating extra hydrogen ions to a solution. Alkaline substances (called bases or alkalies) in a solution scavenge and suck up hydrogen ions. The pH is a measure of the concentration of hydrogen ions dissolved in water on a logarithmic scale that runs from 0 to 14.

Pure distilled water has a neutral pH of 7.0, right in the middle of the scale. A pH lower than 7 indicates an acid; a pH higher than 7 indicates a base or alkaline solution. Each point on the pH scale represents a concentration of hydrogen ions that is higher or lower by a factor of 10 than that represented by the next point. The concept of pH was introduced by Danish chemist Søren Peter Lauritz Sørensen in 1909 and has become one of the most fundamental ideas in chemistry.

You can measure pH by using test strips or a pH meter (see page 2·316). The table above lists pH values for some familiar liquids, although many of these actually span a range of pH that depends on their specific composition.

Substance	pH
Bleach, lye	13
Soapy water	12
Ammonia	11
Baking soda	9
Pure water	7
Urine	6
Black coffee	5
Tomato juice	4
Orange juice	3
Lemon juice	2
Gastric acid	1

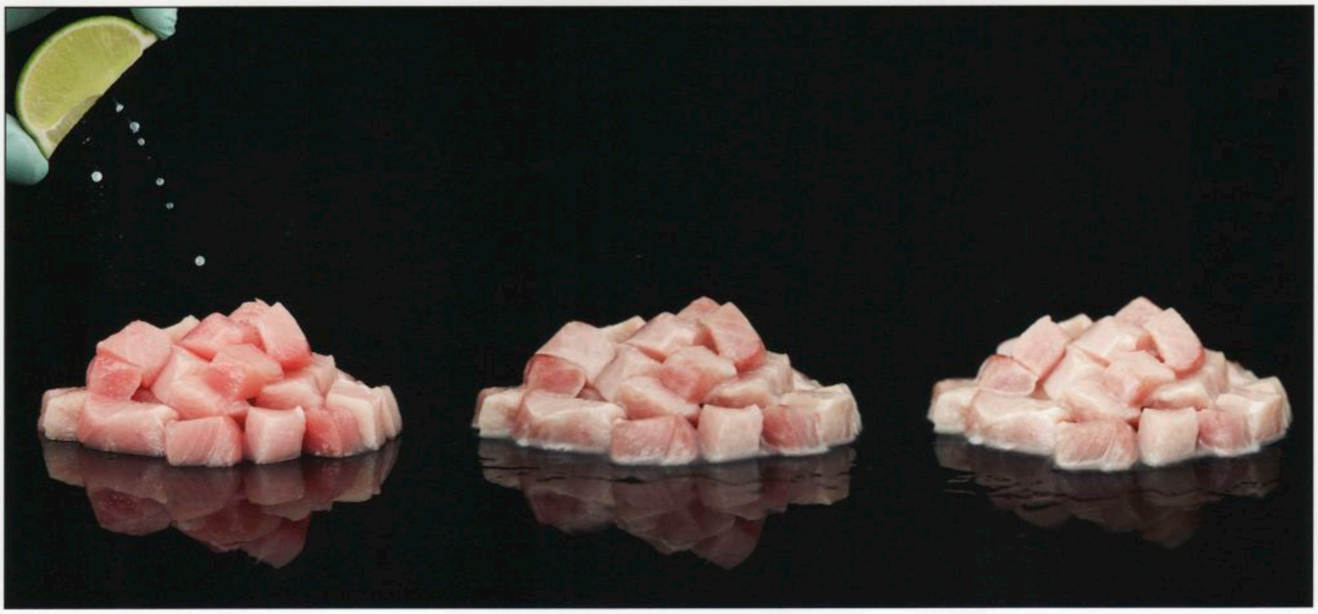
The Alkaline Alternative

Although most marinades lower pH, some work by shifting the pH in the opposite direction—that is, making the flesh more alkaline. Raising the pH also increases the water-holding capacity of meat and seafood, through a process that is broadly similar to the action of acidic marinades.

Raise the pH far enough by adding substances like baking soda, soda lime, or lye, and flesh takes on a texture that is quite different from that obtained by cooking with heat—or by immersion in an acid, for that matter. Perhaps the best-known example is the Scandinavian delicacy lutefisk, which relies on lye (sodium hydroxide) to transform cod into a gelatinous, off-white flesh.

Lutefisk is equally well known for its potent (some say revolting) aroma. In addition to increasing the tenderness and water-holding ability of meat and seafood, changing the pH can have pronounced effects on the flavor. Acidic and alkaline ingredients lend their own characteristic tastes and aromas, but these ingredients alter the balance of flavors created by various chemical reactions, like the Maillard reaction, that occur during cooking.

A strong acid like lime juice can be used to "cook" fish without heat. The low pH causes proteins to denature, or unravel, in much the same way that cooking does. The South American dish ceviche, in which fish is marinated in a strongly acidic marinade, exploits this effect. Because acid-denatured proteins scatter light the same way that heat-denatured proteins do, the fish turns an opaque white. Although the marinated fish may look cooked, however, its taste, texture, and food safety aspects are not the same.



There is no simple explanation of how and why flavor-creating reactions change as the pH of meats and seafood shifts, but the difference in flavor can be profound; a chicken breast or tuna steak marinated in acidic lemon juice and then chargrilled will have a noticeably different flavor that many people prefer. Similarly, lamb kebab marinated in yogurt and spices, and then roasted in a tandoor oven, owes part of its unique flavor to the way that acidity provided by the yogurt alters the meaty flavors created by the intense heat of the oven. The flavor and appearance of the classic Sichuan preparation of kung pao chicken (also known as *gong bao* chicken) owes a lot to a brief alkaline marinade, which both speeds the creation of appealing aromas and promotes quick browning during the stir-frying. This happens because, in general, raising the pH increases the rate of Maillard browning (see page 89).

Beyond acids and alkalines, a few other ingredients often feature in marinade recipes. Salt—covered on page 152—usually plays an important role. But intriguing and tasty effects can also be achieved by adding enzymes, alcohol, or fermentation to the marinating process.

Enzymes

Enzymes are biochemicals that are at work in every living cell. Enzymes are made of protein, and very often their function is to transform certain other kinds of proteins by snipping them into pieces, reshaping them, or stitching them together. Some enzymes greatly accelerate other kinds of chemical reactions.

One common source of enzymes in the kitchen is fruit juice, which besides typically being acidic is also rich in tenderizing enzymes. Pineapples, papayas, figs, kiwis, and certain other fruits—as well as the occasional root, like ginger—contain **proteolytic** (protein-cutting) enzymes: **bromelain** in pineapple and **papain** in papaya. As these biochemicals chop up the large protein structures in muscle, they make the food more tender. Bromelain is especially powerful because it snips through collagen in connective tissue as well as the proteins in muscle fibers.

Enzymatic tenderization is usually a good thing—but only up to a point. If allowed to work for too long, enzymes can create bitter-tasting protein fragments and cause the texture of the food to turn mushy.

Should you want to use juice in a marinade, be sure to get it in unpasteurized form; the high heat involved in pasteurization destroys the proteolytic enzymes. Most of the plant enzymes useful in cooking are also available as purified and powdered concentrates, however, and that is the best form to use if you can get it. The purified enzymes don't impart a flavor the way that a raw juice, like that of pineapple, inevitably does.

We find that one of the best uses of bromelain is in preparing meat juices for soups and stocks or in rendering, where it increases juice yield rather than adding tenderness. For more details, see page 2·288.

Alcohol

Many marinade recipes call for beer, wine, or some other alcohol, and some cooks and cookbooks ascribe miraculous tenderizing qualities to alcohol. The claim is dubious at best. In actuality, a dilute quantity of ethanol itself has little effect on meats and seafood.

This isn't to say that the wine in a marinade does nothing. Wine is both highly flavorful and quite acidic, so it can have a big impact on the juiciness, tenderness, and taste of the food. Indeed, with enough time, a particularly tart wine can even begin to "cook" the flesh—but it is the acid at work there, not the alcohol.

That said, alcohol solutions of higher proof than wine can certainly transform flesh. One notable (if somewhat exotic) example is Chinese drunken shrimp. In this traditional dish, live freshwater shrimp are submerged into *baijiu*—an 80–120 proof white spirit distilled from sorghum—to "get the shrimp drunk" before they are eaten alive. Although it is unlikely that the *baijiu* bath really makes the shrimp inebriated, it certainly has an impact on their flesh.

As alcohol slowly diffuses into flesh, shrimp or otherwise, it changes the nature of the liquid in it enough that the proteins start to denature. With enough time—or if the marinade is made "stiff" enough—the denaturation reaches the point that the food changes texture perceptibly. Unlike a change in pH, however, the addition of alcohol does not cause muscle fibers to swell, so it does not pull juices into the flesh. On the contrary, a highly alcoholic marinade will actually dry flesh out, due to osmosis. Water molecules, driven by the concentration gradient from meat to marinade, diffuse out of the food in an attempt to reestablish

Asian fish sauce and ancient Roman *garum* and *liquamen* (see page 5·121) are made from a kind of marinade. Bacteria growing on the fermented fish exude acid that ultimately dissolves the flesh into a liquid, which, despite is provenance, is quite delicious.

The protein-decomposing action of some fruit juices renders them unsuitable for making gelatin-based gels unless the proteolytic enzymes in the juice are inactivated first. Gelatin is a meat-derived protein, and the enzymes will break it down and cause the gel to fail. Pineapple, fig, kiwi, or ginger gels can be made with agar or other nonprotein-based gelling compounds (see page 4·68). Heating the fruit juice enough to inactivate the enzyme is another option, but it generally gives the fruit juice a cooked taste.

THE FAR-REACHING INFLUENCES OF CURRY

A meat curry generally consists of marinated meat coated with a sauce made from the marinade. Curries were developed in India not merely to impart flavor but also to help preserve the meat. Many of the spices used in curries have potent antimicrobial properties; in the days before refrigeration, these ingredients helped prevent dangerous bacteria from proliferating and thus retarded food spoilage. Fermented dairy products, which are used in some curries, contain beneficial bacteria that help keep undesirable microbes at bay.

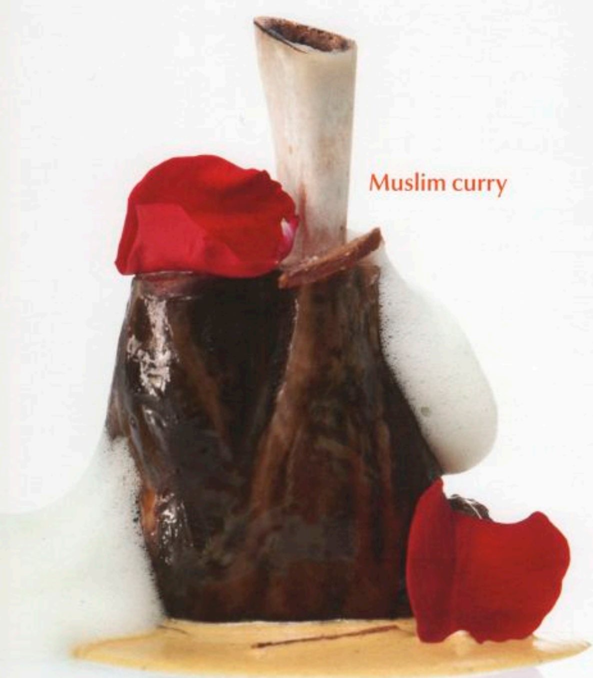
Throughout the centuries, regional variations in taste came to define different curries. Archeological evidence indicates that the prehistoric inhabitants of the Indian subcontinent consumed a wide variety of grains, fruits, and herbs supplemented by dairy products from domesticated animals. Moreover, India has long been a crossroads for travelers between Asia and Europe. Arab spice traders had a profound influence. The Mughal conquest introduced lamb and goat accentuated with spices, nuts, and dried fruits. As a result, curries incorporating these ingredients are staple fare in northern India today. This mingling of new ingredients with native ones influenced the cuisines of Goa, Kerala, and Chennai (formerly Madras). Thus, in the past 500 years, the culinary landscape of India has changed dramatically to produce a unique cuisine that has traveled far beyond the borders of India and has become instantly recognizable for its complex and fiery-hot flavors.

Mughal curry

Masala (Madras) curry

Kerala curry

Goan curry (vindaloo)

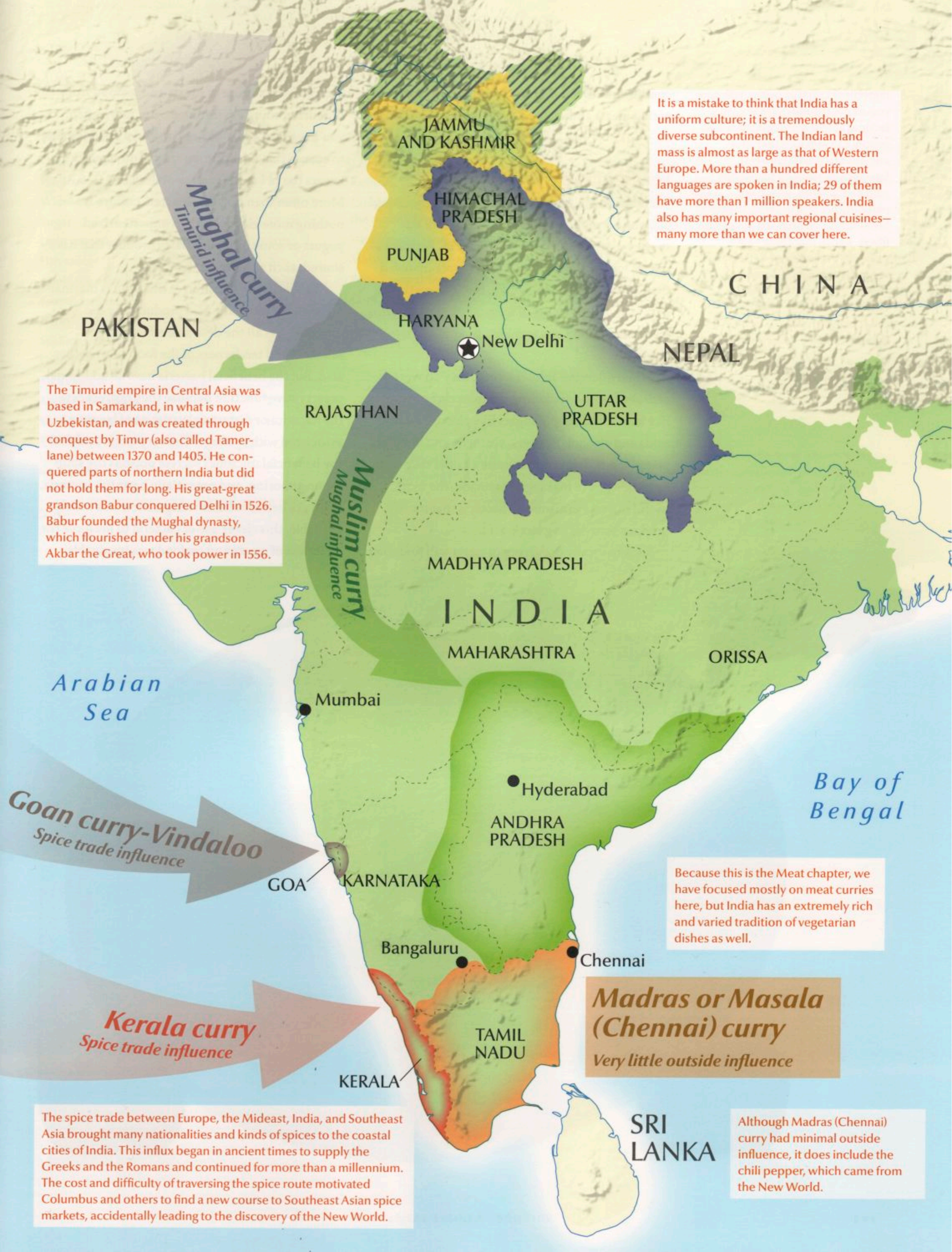


Muslim curry

Indian cuisine is also popular outside of India: former Foreign Secretary of the United Kingdom Robin Cook acknowledged that chicken tikka masala is "a true British national dish" in 2001.

Every curry has a lineage. Some curries are well-kept secrets within families, handed down over time—a heritage savored by generations.

For recipes for these curries, see page 5·89.



It is a mistake to think that India has a uniform culture; it is a tremendously diverse subcontinent. The Indian land mass is almost as large as that of Western Europe. More than a hundred different languages are spoken in India; 29 of them have more than 1 million speakers. India also has many important regional cuisines—many more than we can cover here.

The Timurid empire in Central Asia was based in Samarkand, in what is now Uzbekistan, and was created through conquest by Timur (also called Tamerlane) between 1370 and 1405. He conquered parts of northern India but did not hold them for long. His great-great grandson Babur conquered Delhi in 1526. Babur founded the Mughal dynasty, which flourished under his grandson Akbar the Great, who took power in 1556.

Because this is the Meat chapter, we have focused mostly on meat curries here, but India has an extremely rich and varied tradition of vegetarian dishes as well.

The spice trade between Europe, the Mideast, India, and Southeast Asia brought many nationalities and kinds of spices to the coastal cities of India. This influx began in ancient times to supply the Greeks and the Romans and continued for more than a millennium. The cost and difficulty of traversing the spice route motivated Columbus and others to find a new course to Southeast Asian spice markets, accidentally leading to the discovery of the New World.

Although Madras (Chennai) curry had minimal outside influence, it does include the chili pepper, which came from the New World.

Ingredients such as buttermilk and yogurt contribute more than just lactic acid to a marinade: they also supply calcium ions that spur enzymes to tenderize meat. Specifically, calcium stimulates calpain enzymes, which are naturally present in meat, to begin breaking down proteins in muscle fibers. Recall that these same enzymes are involved in tenderizing meat as it ages. For more details, see page 195. Adding calcium chloride (see page 157) or other calcium salts is a more direct way to stimulate calpains.

equilibrium. Drier is rarely better, so when marinating meats and seafood, go easy on the booze.

Fermentation

Bacteria, yeasts, and molds have been "processing" plant and animal matter since well before our species ever appeared to harness them. Fermentation of food is a huge topic and far more involved than we can discuss fully here. But it is worth noting that the process of fermentation transforms meat and seafood in a way akin to an acidic marinade.

When microbes ferment meat, they convert carbohydrates—including complex carbohydrates like starch and simple sugars like glucose—into acids and alcohol. Brewers, vintners, and distillers prefer yeasts that produce more alcohol than acid, but when you're making a marinade, the most useful microorganisms are bacteria that mostly produce sour-tasting lactic acid.

Such naturally occurring bacteria will find their way onto the surface of meats and seafood from the surrounding environment. But more often, you'll want to add a starter culture of *Lactobacillus* to ensure that acidification starts and steadily lowers the pH at the surface of flesh to 4.9–5.3. More often than not, the "starter" culture is nothing more elaborate than unpasteurized yogurt or some other raw dairy product that has soured, such as buttermilk.

In a sense, fermentation of this kind is marinating with bacteria. The acid produced by the microbes has all the desirable effects on the juiciness and tenderness of the food as any other acid. But the beneficial bacteria have an additional, preservative function because they outcompete the harmful or distasteful varieties of bacteria associated with spoilage. The very lactic acid that the beneficial microbes secrete poisons the soup for neighboring, and potentially harmful, bacteria. In an era before reliable refrigeration was widely available, this clever use of bacteria to preserve the freshness of meats and seafood was invaluable.

The ingenious Fizz-Giz system uses an ordinary two-liter plastic soda bottle and CO_2 cartridge to pressure-marinate meat at great speed. For details, see page 207.

EXAMPLE RECIPE

KALBI FLANK STEAK

Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Flank steak, trimmed	1 kg	333%	① Reserve.
Water	300 g	100%	② Combine, and stir until sugar is dissolved. The pH level of the marinade should be around 4.5.
Sugar	175 g	58.5%	③ Vacuum seal steak with marinade.
Light soy sauce	150 g	50%	④ Marinate in refrigerator for 5 d.
Fish sauce	75 g	25%	⑤ Remove steak from marinade, and vacuum seal again.
Apple juice (fresh)	50 g	16.5%	⑥ Cook sous vide in 54 °C / 129 °F bath for 1 h. Depending on how tender you like your flank steak, the cooking time can be increased to 24 h.
Toasted sesame oil	30 g	10%	⑦ Cool.
Mirin	23 g	7.5%	⑧ Trim steak to desired size, and sear both sides quickly.
Scallions, thinly sliced	20 g	6.5%	
Garlic, crushed	10 g	3.5%	
Rice vinegar	10 g	3.5%	
Korean chili flakes	5 g	1.5%	
Black pepper, coarsely ground	3 g	1%	
Kimchi see page 352	as desired		⑨ Slice, and serve with kimchi, butter lettuce and shiso leaves, kochujang paste, and other banchan (Korean side dishes).

(2010)

Instead of flank steak, thin slices of beef short ribs can be used.

Jaccarding the steak improves its tenderness directly and, if done before marinating, also makes the marinade work better. Vacuum tumbling for 30 minutes reduces marination time greatly. For more on Jaccarding, see page 50; for vacuum tumbling, see page 174.

LUTEFISK

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Halibut	1 kg (one large piece)	100%	① Remove skin, and cut away thin ends.
Water	3.5 kg	350%	② Whisk water and sodium hydroxide together until dissolved to make brine.
Sodium hydroxide	25 g	2.5% (7%)*	③ Place fish in brine, and refrigerate for 24 h.
Salt	25 g	2.5% (7%)*	④ Drain fish, and discard brine.
			⑤ Vacuum seal, and refrigerate for 24 h to allow brine to equilibrate through fish.
			⑥ Remove from bag, cover in fresh water, and soak refrigerated for 48 h.
			⑦ Change water, and soak again for 48 h, refrigerated.
			⑧ Drain.
			⑨ Vacuum seal, and refrigerate to store indefinitely.
Unsalted butter	100 g	10%	⑩ To serve, vacuum seal with fish.
			⑪ Cook sous vide in 50 °C / 122 °F bath for 45 min.
Salt	to taste		⑫ Season.

(2010)

(% of weight of water)

Lutefisk is an acquired taste and texture, but it has been a Scandinavian delicacy for many centuries.

The dimensions of the fish are important for a good final result. The fish should be uniform in size and at least 4 cm / 1½ in thick for the brining time to be accurate. Smaller pieces of fish require some experimentation with brining time. If making with salted halibut or cod, omit salt from brine.

EXAMPLE RECIPE

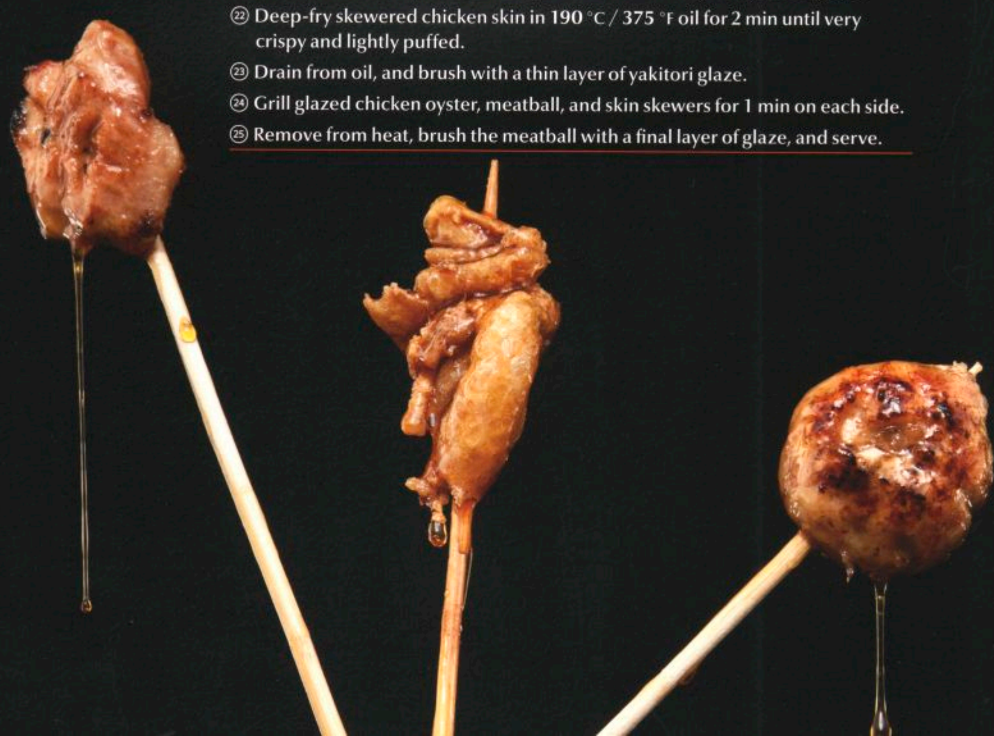
YAKITORI

Yields 600 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Mirin	400 g	100%	① Whisk together, and bring soy sauce mixture to a simmer.
Honey (clear)	220 g	55%	
Light soy sauce (no vinegar added)	200 g	50%	
Sake (dry)	200 g	50%	
Ginger juice (fresh)	10 g	2.5%	
Pineapple rind and flesh, cubed	550 g	137.5%	② Pour hot soy sauce mixture over pineapple cubes, and cool completely. ③ Vacuum seal, and macerate 12 h, refrigerated.
Rice vinegar	50 g	12.5%	④ Strain yakitori sauce.
Salt	30 g	7.5%	⑤ Season with vinegar and salt, and reserve.
Chicken skin	200 g	25%	⑥ Cook sous vide in 88 °C / 190 °F bath for 2 h. ⑦ Drain from cooking juices, pat dry, and cool. ⑧ Cut cooked skin into strips 2.5 cm by 12.5 cm / 1 in by 5 in. ⑨ Thread onto soaked bamboo skewers, and reserve.
Chicken oysters or thigh meat cut into 2.5 cm/ 1 in pieces, skinless	200 g	50%	⑩ Combine in the bottom of a 1 l whipping siphon to pressure-marinate. ⑪ Charge with two nitrous oxide cartridges, shake, and refrigerate for 20 min.
Yakitori sauce, from above	30 g	7.5%	⑫ Vent pressure, remove pieces from siphon, and skewer individually.
Chicken thigh meat, coarse ground	400 g	200%	⑬ Stir together until all components are evenly distributed.
Tokyo negi (Japanese leek), finely minced	45 g	11.25%	⑭ Make four meatballs 5 cm / 1 in. in diameter by using plastic wrap to shape tightly.
Egg white	35 g	8.75%	⑮ Skewer meatballs individually.
Yakitori sauce, from above	20 g	5%	⑯ Blanch in 190 °C / 375 °F oil for 5 s to set the shape of each meatball.
Toasted sesame oil	10 g	2.5%	⑰ Reserve.
Young ginger, finely minced	6 g	1.5%	
Salt	4 g	1%	
Sansho pepper, ground	1 g	0.25%	
Yakitori sauce, from above	200 g	50%	⑱ Reduce to 65 g (light syrup), about 15 min. Cool and reserve.
Japanese charcoal	as needed		⑲ Burn coals in the bottom of a hibachi or similar grill until coals are white. ⑳ Set grill screen on top of hot coals, and grill marinated chicken oysters and meatballs for 2–3 min on each side . ㉑ Remove from heat, and brush all pieces with a thin layer of yakitori glaze. ㉒ Deep-fry skewered chicken skin in 190 °C / 375 °F oil for 2 min until very crispy and lightly puffed. ㉓ Drain from oil, and brush with a thin layer of yakitori glaze. ㉔ Grill glazed chicken oyster, meatball, and skin skewers for 1 min on each side. ㉕ Remove from heat, brush the meatball with a final layer of glaze, and serve.

(2010)

For a step-by-step procedure for pressure-marinating, see page 207.



TUNA RIBBONS WITH GINGER MARINADE

ADAPTED FROM JEAN-GEORGES VONGERICHTEN

Yields 600 g (eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lime juice	100 g	33%	① Vacuum seal together.
Sugar	80 g	27%	② Cook sous vide in 55 °C / 131 °F bath for 1½ h.
Makrud (kaffir) lime leaves, thinly sliced	20 g	6.5%	③ Cool lime syrup completely. ④ Strain. ⑤ Measure 40 g of syrup, and reserve.
Ginger, peeled, thinly sliced	60 g	20%	⑥ Sauté in dry pan until slightly charred, about 5 min.
Rice vinegar	50 g	17%	⑦ Blend with ginger and reserved lime syrup until smooth.
White soy sauce	40 g	13.5%	⑧ Reserve ginger marinade.
Shoyu	36 g	12%	
Grapeseed oil	30 g	10%	
Avocado, peeled and thinly sliced	100 g	33%	⑨ Season avocado slices, and arrange in serving bowls.
Lime juice	to taste		
Salt	to taste		
Tuna (sashimi-quality), cut into thin, spaghetti-like ribbons	300 g	100%	⑩ Gently combine tuna with radish slices, chili oil, and lime leaves. ⑪ Top each avocado portion with spoonful of tuna mixture. ⑫ Pour ginger marinade around bowls, and serve.
Breakfast radish, sliced very thinly on mandoline	50 g	17%	
Spiced chili oil see page 2·330	25 g	8.5%	
Makrud (kaffir) lime leaf, fine julienne	5 g	1.5%	

(original 1997, adapted 2010)

EXAMPLE RECIPE

FLUKE CEVICHE ADAPTED FROM ERIC RIPERT

Yields 500 g (four to eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Fluke fillet (sushi-quality)	400 g	100%	① Slice on bias into segments, 1.75 cm by 5 cm / 11⁄16 in by 2 in. ② Lay slices in single layer on large plate. ③ Cover with plastic wrap, and refrigerate.
Fluke fillet, diced	80 g	20%	④ Combine. ⑤ Cover, and refrigerate for 1 h to macerate. ⑥ Strain through fine sieve, and reserve 50 g of fluke juice.
Lemon juice (fresh)	30 g	7.5%	
Lime juice (fresh)	30 g	7.5%	
Red onion, sliced	20 g (quarter of onion)	5%	
Sugar	13 g	3.25%	
Fine sea salt	10.5 g	2.5%	
Rendered fluke juice, from above	50 g	12.5%	⑦ Combine in bowl to make marinade.
Red onion, julienne	16 g	4%	
Extra-virgin olive oil	12 g	3%	
Cilantro, julienne	10 g	2.5%	
Tomato, blanched, peeled, and finely diced	10 g	2.5%	
Jalapeño pepper, minced	4 g	1%	
Basil, julienne	2.5 g	0.5%	
Mint, julienne	1.2 g	0.3%	
Lemon-infused olive oil	to taste		
Espelette pepper	to taste		⑧ Season fluke slices. ⑨ Cover slices with marinade, and allow to stand for 2–5 min, depending on desired firmness. ⑩ To serve, divide ceviche among four small bowls. ⑪ Garnish with more pepper, and serve immediately.
Salt	to taste		

(original 2005)

CHICKEN TIKKA MASALA

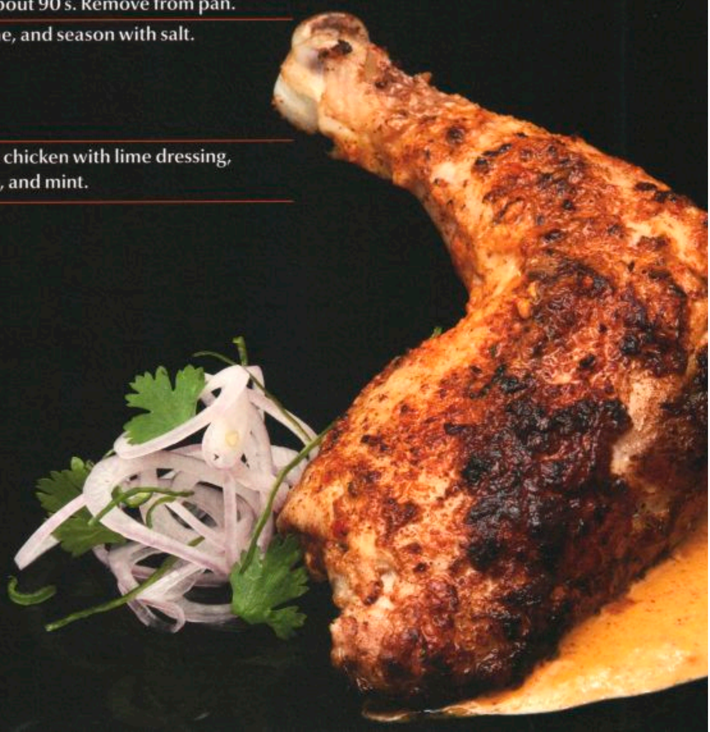
Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	24 g	5%	① Pour hot water over saffron threads.
Saffron threads	0.5 g	0.1%	② Cover, steep for 10 min, and then strain water, and reserve.
Coriander seeds, toasted	5 g	1%	③ Toast spices in dry skillet or **170 °C / 340 °F** oven until aromatic.
Cumin seeds, toasted	5 g	1%	④ Cool.
Cinnamon, toasted	1 g	0.2%	⑤ Grind spices to fine powder, and reserve.
Clove, toasted	1 g	0.2%	
Greek-style strained yogurt (plain, full fat)	250 g	50%	⑥ Blend together to fine paste. ⑦ Add spice powder and saffron-infused water to make marinade.
Neutral oil	100 g	20%	⑧ Reserve 50 g for later use.
Shallots, thinly sliced	25 g	5%	
Ginger, fine paste	24 g	4.8%	
Garlic, fine paste	10 g	2%	
Kashmiri chili	10 g	2%	
Annatto seeds	8 g	1.5%	
Green Thai chili, finely chopped	5 g	1%	
Bay leaves, fine julienne	1 g	0.2%	
Chicken breast, skinned	500 g	100%	⑨ Clean, and trim off any excess fat.
Chicken thigh, boneless and skinned	500 g	100%	⑩ Cut thighs and breasts into total of eight pieces, 125 g each. ⑪ Slice three cuts across the thick side of each thigh for marinade to penetrate.
Marinade, from above	200 g	40%	⑫ Place all chicken pieces in 200 g of marinade, and toss to coat thoroughly.
			⑬ Vacuum seal, and refrigerate for 12 h.
Clarified unsalted butter	40 g	8%	⑭ Remove chicken from marinade.
			⑮ Vacuum seal breasts and thighs in two separate bags with 20 g each of clarified butter.
			⑯ Cook breasts sous vide in **60 °C / 140 °F** bath for 2 h.
			⑰ Cook thighs sous vide in **65 °C / 149 °F** bath for 1½ h.
Marinade, from above	50 g	10%	⑱ Simmer for 5 min.
			⑲ Cool at room temperature.
			⑳ Brush over cooked chicken.
Clarified butter	as needed		㉑ Heat thin film of clarified butter over high heat. Sear chicken pieces, skin side only, until crisp, about 90 s. Remove from pan.
Lime juice	100 g	20%	㉒ Combine, and season with salt.
Shallots, finely sliced	50 g	10%	
Green chili, finely sliced	15 g	3%	
Salt	to taste		
Cilantro, fine julienne	to taste		㉓ Garnish chicken with lime dressing, cilantro, and mint.
Mint, fine julienne	to taste		

(2010)

For better marinade penetration, use a Jaccard tenderizer after slathering the chicken with the marinade, but be careful not to break the blades on the chicken bones.

Kashmiri chili punctuates a dish with bright red color and is only mildly hot.



EXAMPLE RECIPE

GONG BAO CHICKEN ADAPTED FROM FUCHSIA DUNLOP

Yields 500 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chicken breast, boneless	400 g	100%	① Cut into 1.5 cm / ⅝ in strips. ② Cut strips into small cubes, and reserve.
Water	50 g	12.5%	③ Whisk together.
Light soy sauce	10 g	2.5%	④ Mix into chicken, taking care to coat all pieces evenly.
Potato starch	7 g	1.75%	
Shaoxing wine	5 g	1.25%	⑤ Vacuum seal, and refrigerate for 12 h to marinate.
Baking soda	1 g	0.25%	⑥ Remove chicken from marinade, and reserve.
White chicken stock see page 2·301	20 g	5%	⑦ Whisk together until everything is incorporated. ⑧ Reserve resulting sauce.
Sugar	15 g	3.75%	
Chinkiang vinegar	12 g	3%	
Toasted sesame oil	5 g	1.25%	
Dark soy sauce	4 g	1%	
Light soy sauce	4 g	1%	
Potato starch	1 g	0.25%	
Neutral oil	5 g	1.25%	⑨ Heat wok, and add oil.
Dried red chili pepper	8 g	2%	⑩ Add chili and pepper when oil is about to smoke.
Sichuan peppercorns (whole)	8 g	2%	⑪ Stir-fry until crisp and fragrant. ⑫ Add marinated chicken, and fry on high flame for about 5 min.
Scallions, whites only, thinly sliced	24 g	6%	⑬ Add to wok, and stir-fry until chicken is cooked, about 2 min.
Garlic, thinly sliced	18 g	4.5%	⑭ Add sauce, and cook until thick, about 45 s.
Ginger, thinly sliced	18 g	4.5%	
Peanuts, blanched and peeled	75 g	19%	⑮ Roast peanuts in 170 °C / 340 °F oven until colored golden brown, or use pressure-cooked fried peanuts (see page 5·65).
Salt	to taste		⑯ Add peanuts, and adjust seasoning.

(original 2003, adapted 2010)

Known as kung pao chicken to millions of American fans of Chinese food, this is a classic dish. The alkaline marinade, which includes baking soda, tenderizes the chicken and also promotes the Maillard reaction when the chicken cooks.

The baking soda marinade technique works beautifully with other lean cuts of meats, such as pork and beef tenderloin.

BEET JUICE–FED OYSTERS ADAPTED FROM DAVE ARNOLD AND NILS NORÉN

Yields 12 oysters

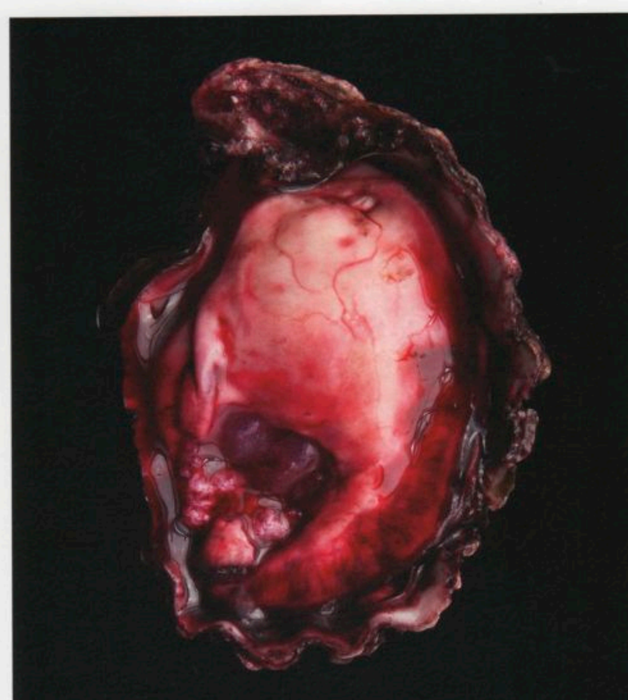
INGREDIENT	QUANTITY	SCALING	PROCEDURE
Kusshi oysters	12 oysters		① Rinse oysters thoroughly to remove any grit. ② Arrange, upright and evenly layered, in metal container.
Red beet juice	1.25 kg (from 2 kg of beets)	100%	③ Blend. ④ Strain juice through fine (500 micron / 0.02 in) sieve. ⑤ Pour over oysters to cover.
Aquarium salt	32.5 g	2.6%	⑥ Seal container tightly with lid. ⑦ Refrigerate for 48 h. Do not disturb, or oysters will not feed on juice.

(original 2008, adapted 2008)

5a

Using a 500 micron sieve to strain the juice is essential to prevent the oysters from suffocating on larger particles.

5b



HOW TO Pressure Marinate

Gas-pressure marinating originated with Michael Lee Harvell, the "Mr. Fizz" of Fizz Giz Biz, which manufactures an inexpensive carbonation kit known as the Fizz-Giz. A retired mechanical engineer who worked in the pressure-treated-lumber industry, Harvell tried forcing marinade into meat by using gas pressure. In 2010, he posted a video on YouTube that showed how to use his kit and an empty plastic soda bottle to dramatically speed the marination of chicken breast with teriyaki sauce (see photos on page 198). Nils Norén and Dave Arnold then promoted the method in their blog.

The technique can be used to speed any sort of marinating or brining. Norén and Arnold have also used the method to speed alcohol infusion in a whipping siphon. We have found that any gas works, including compressed air. Carbon dioxide adds acidity and should not be used with an alkaline marinade. Carbon dioxide also carbonates the meat (see page 2·458), but the carbonation dissipates when the meat is cooked or heated.

The Fizz-Giz kit works at 3.8 bar / 55 psi. In our experiments, we used 5.5 bar / 80 psi and found that the meat gained 2% of its weight in marinade after 1 min, 4% after 3 min, 5.5% after 5 min, and 6.5% after 20 min.

Pressure vessels used for carbonated fountain drinks offer a large capacity.

The alcohol extracts on page 2·326 can be made very quickly by using pressure. Simply combine vodka or any other neutral spirit with an amount of spices or aromatics equal to 10%–20% of the liquid by volume. Charge the mixture to 5.5 bar / 80 psi (by using two nitrous oxide cartridges in a 1 l siphon), and allow it to macerate under pressure at room temperature for 10 min. Although this procedure does not yield as many layers of flavor as longer extraction methods, it is a practical solution when speed is crucial.

1 **Cut chicken, or desired meat, into 2 cm / ¾ in cubes (not shown).**

2 **Place in soda or whipping siphon, carbonating chamber, or other pressure vessel.**

3 **Cover with flavorful liquid.** Adding liquid equal to about 10% of the weight of the meat is ideal.

4 **Charge vessel with carbon dioxide, nitrous oxide, or compressed air.** The ideal chamber pressure is 5.5 bar / 80 psi. Agitate the pressure vessel to distribute marinade and pressure evenly over the pieces of meat.

5 **Marinate for 20 min for best results.** Then release the pressure, remove from the vessel, and cook as desired.

3 min

5 min

20 min

SMOKING

One of the earliest approaches to building a smoker was to dig a hole in the ground, hence the term barbecue "pit." In common usage, it is now applied to any smoking equipment; even an elaborate stainless-steel smoker with digital controls might be called a pit. The person tending the equipment can also be called a "pit boss."

That the appeal of the smell of smoke to humans is based in our genes is not as farfetched as it may sound. Most animals are terrified of fire; humans are fascinated by it. We may enjoy the smell and flavor of smoke at least in part because of millions of years of human experience with cooking fires.

For more on PID control, which employs a proportional-integral-derivative algorithm to attain and maintain a set point, see page 1·270.

Smoking food is nearly as old as humanity itself. It seems plausible that nomadic humans discovered the benefits of smoking food while drying the surplus flesh of a hunt or catch to preserve it for leaner times. There was, of course, the distinct flavor and colorful appearance that we're still familiar with today, but early man probably liked smoked food mainly because it didn't rot. Hot-smoking over an open fire doubtless came first, but slowly drying food to its core by smoking it over a cool, smoldering fire was more effective when preservation was the paramount concern. Although the wide availability of refrigeration has rendered the preservation aspect of smoking obsolete, that hasn't diminished demand.

Perhaps it's hardwired into our genes, but the appeal of smoked food remains nearly universal today. Some people cherish traditional smoked foods crafted by an artisan; others find excitement and satisfaction in exotic Modernist preparations, garnished by evocative wisps of smoke. But whether it is applied with craftsmanship or with Modernist daring, smoked food can be truly delicious—or it can be truly awful. A few practical tips can help you avoid the biggest pitfalls when smoking meat or seafood.

The Fire

As discussed in chapter 7 on Traditional Cooking (see page 2·132), the role of the fire in smoking is to burn at approximately 400 °C / 750 °F and produce gases from pyrolysis that flavor the meat. Higher and lower temperatures can be used but do not produce the same taste. Around the world, a variety of woods are used for smoking, in the form of logs, chunks, chips, sawdust, and pellets.

Besides smoke, the fire also generates heat. Even so-called hot-smoking uses relatively low air temperatures, no higher than 107 °C / 225 °F. Cold-smoking ranges down to refrigerator temperatures.

Smokers vary in how they control the fire and smoke, but we can offer a few general guidelines. Avoid trying to create more smoke by using wet wood or water to dampen the fire. This reduces the pyrolysis temperature so much that acrid, poor-quality smoke results. It is better to control the temperature by other means, such as by throttling the smoker using the damper or a PID-controlled fan that automatically aerates the fire. These methods can work well, but you still must take care not to drive the temperature too low.

A neglected topic in smoking is the wet-bulb temperature, which plays a critical role in both the

THE INVENTION OF

The Inverted Flame Firebox

Pellet-style smokers were devised to make it easy to keep a firebox supplied with a small amount of fuel; an auger keeps a cup's worth of tiny, log-like pellets topped up and smoldering. Many smokers of this kind are available with a simple **bang-bang** (or in some cases a **proportional-integral-derivative**) controller that turns a fan on and off to supply or deny oxygen to the smoking wood, which in turn increases or decreases its temperature. This is a reasonably effective way to control the temperature in the smoker, but it has the disadvantage that while the fire is starved of air (when the fan is off), the quality of the smoke can suffer.

Inventor Bill Karau has devised a clever, and patented, approach that overcomes this limitation. The Karubecue smoker (www.karubecue.com) maintains a set cooking temperature by using a thermostatically controlled fan to periodically draw hot, high-quality smoke into a sealed smoking chamber from an external firebox.

The smoke is sucked in from the bottom of a fire built from chunks of burning wood. When hot smoke isn't needed, the smoke and flames heat nothing but the outdoors. This approach turns conventional open pit-style barbecue on its head, which is why Karau calls his invention the Inverted Flame Firebox. People who smoke a pipe do essentially the same thing, drawing smoke down though the pipe bowl.

Pork spare ribs are among the most popular meats for smoking and barbecuing.

PARAMETRIC RECIPE

HOT- AND COLD-SMOKED MEATS AND SEAFOOD

Smoking is a surface treatment, so the thinner the food, the greater the smoke flavor in the interior. Thin slices, individual chicken parts, or fillets soak up more of the smoke flavor than do large pieces of food. A brine, cure, or marinade, though optional, is often necessary to achieve traditional tastes and textures.

SMOKING MEATS AND SEAFOOD

1 **Select a recipe from the table below, and prepare the meat as indicated.** See the referenced pages for further instructions.

2 **Smoke.** Suggested smoking temperatures, humidities, and times are listed in the table. Not all smokers permit humidity control, but an improvised wet-bulb thermometer will help (see next page). Adjust the smoking time to impart more or less smoke flavor.

3 **Cook sous vide or otherwise.** Some smoked foods, such as hams or smoked salmon, are meant to be consumed raw after smoking.

4 **Season and finish.** Many barbecued items are seared briefly at high heat or glazed. Finish by adding spices, dry rubs, or sauces.

Best Bets for Smoking Meats

	Prep		Smoke							
			Dry-bulb temperature		Wet-bulb temperature			Time		
Ingredient	Method	See page	(°C)	(°F)	(°C)	(°F)	Relative humidity	(h)	Cook	See page
Cold-smoked										
pork, Boston butt	n/a		10	50	6.5	44	60%	24	yes	108
pork ribs	n/a		10	50	6.5	44	60%	24	yes	5·66
foie gras, torchon	cure	176	10	50	6.5	44	60%	24	optional	146
ham	cure	183	10	50	6.5	44	60%	24	optional	108
salmon (Scottish)	cure	212	10	50	6.5	44	70%	24	no	
pork cheek	brine	168	10	50	6.5	44	60%	24	yes	108, 5·35
pork chop	brine	168	10	50	6.5	44	60%	24	yes	96
sablefish, black cod	brine	179	10	50	6.5	44	60%	24	optional	5·170
whitefish	brine	168	10	50	6.5	44	60%	24	yes	102
beef fillet, raw	n/a		10	50	8	46	80%	24	yes	96
caviar and fish roe	n/a		10	50	8	46	80%	12	no	
oyster	n/a		10	50	8	46	80%	24	optional	5·205
foie gras, raw	n/a		25	77	18	64	50%	4	no	
salmon, Russian style	cure	168	25	77	18	64	50%	4	no	
chicken, whole	brine injected	168	25	77	18	64	50%	4	yes	99, 2·178
pork chop	brine	168	25	77	18	64	50%	4	yes	96
Hot-smoked										
beef fillet, cured	cure	185	52	126	48	118	80%	12	no	
beef cheek pastrami	brine	213	77	171	62	144	50%	4	yes	108
beef short ribs	n/a		77	171	66	151	60%	4	yes	108, 5·79
brisket pastrami	brine	213	77	171	62	144	50%	7	yes	108
pork belly (for bacon)	cure	182	77	171	66	151	60%	7	optional	108
beef tongue	brine injected	168	77	171	66	151	60%	4	yes	108
chicken, whole	brine injected	168	77	171	66	151	60%	4	optional	99, 5·114
beef flatiron	n/a		60	140	55	131	77%	4	yes	108, 5·49
pork ribs	n/a		65	149	57	135	65%	7	yes	108, 5·78
pork butt	n/a		65	149	57	135	65%	7	yes	108, 5·66
sausage	n/a		52	126	48	118	80%	12	yes	238, 242

formation of the smoke **pellicle** and in determining the temperature that meat actually cooks at. A widespread observation among barbecue cooks is that a large piece of meat, like a pork shoulder or a brisket, will undergo a temperature "stall" in which the temperature plateaus rather than rising continually. It is often argued that the stall occurs due the collagen in the meat converting to gelatin (see page 80). But that conversion, though real, is not the cause of the stall. The actual reason is that the meat cooks at the wet-bulb temperature until the exterior dries out—see The Barbecue "Stall," next page.

We strongly recommend using an improvised wet-bulb thermometer to check your smoker or barbecue. The wet-bulb temperature (and humidity) can be controlled by putting pans of water in the smoker or by spraying the walls of the smoker with a mist of water periodically. Proper humidity control is probably the single best thing you can do to improve the quality of smoked meat.

The Flesh

Getting smoke to adhere to flesh so that it develops an attractive pellicle and robust smoky flavor requires the right surface conditions. If the surface is too wet, then condensing smoke will fail to undergo reactions with the food that would give it an appealing appearance and a smoky aroma.

A bone-dry surface is no better because a small amount of moisture is necessary for these same reactions to occur. In either case, the result is smoked food that, at best, has a weak smoked flavor and a poor appearance and that, at worst, tastes sour from an accumulation of unreacted, unpleasant-tasting volatile acids and carbonyls from the smoke. Luckily, optimal conditions tend to prevail inside a smoker.

Meat is generally at least 70% water, so it always has an internal water source. The temperature of meat in a smoker will generally be the wet-bulb temperature for the vast majority of the smoking period, until the surface of the meat is very dry.

The ideal surface for smoke to adhere to is a slightly tacky one that forms while the meat is at the wet-bulb temperature. To achieve this, one generally wants the relative humidity to be 60%–70%. In cold-smoking, this is often impractical, so one smokes with a humidity of 80%–90%.

The Finish

Toward the end of smoking, when the surface has dried, the stall breaks and the temperature of the food begins slowly rising to the dry-bulb temperature inside the smoker, or what most people think of as the smoker's temperature. Up to this point, we haven't said much about what the temperature should be inside the smoker. This is because, while that is an important consideration, good—though different—results can be had over a wide range of temperatures: hot smoke, cool smoke, or truly cold smoke can each give food a great smoked flavor. But poor-quality smoke from a mismanaged fire or a poorly prepared surface will always result in smoked food that is nowhere near as good as it could be.

Applying plenty of high-quality smoke to a tacky surface at the desired cooking temperature isn't enough; you have to allow time for the smoke to finish its job. This is sometimes called "setting the rind," but the process is about more than giving a cut of meat or a piece of seafood a firm, colorful surface.

Much of a food's smoked flavor is actually created when reactions occur between components of the smoke (mainly **carbonyls** and **phenols**) and components of the food (particularly proteins and fats). These flavor-generating reactions take time; they are relatively fast at hot-smoking temperatures and quite slow at cold-smoking temperatures. This is one reason why cold-smoking is done over days, while hot-smoking can be finished in hours. Cut the time short, and the flavor will be weak.

Use some caution, though: you can overdo the setting step. A lot of barbecue champions in the American South like to hot-smoke for a really long time to develop a very dark, almost jet-black rind and a deep smoke ring. But take it too far, and the smoky aroma of the meat actually begins to dissipate from ongoing reactions in the meat or simply from being evaporated off the surface from prolonged heating. As with many things in life, it's important to know when to stop.

For more on the formation of the pellicle, see page 2·132. For more on how the temperature of the smoke affects the resulting flavor of a smoked food, see page 2·138.

Many barbecue recipes have you mop sauce on the meat during smoking. Doing this interferes with smoke penetration, however, so it is best to wait until the smoke has penetrated the food sufficiently. Then you can slather on the sauce to form a glaze or crust on the meat.

For more on the importance of wet-bulb and dry-bulb temperatures, see page 1·319 in The Physics of Food and Water. For more on how these temperatures influence cooking and drying, see page 2·102 in Traditional Cooking and page 2·431 in The Modernist Kitchen.

A good approach to monitoring the humidity in a smoker is to construct a simple wet-bulb thermometer (shown above; also see page 1·319) and place it inside the smoker. By measuring both the dry-bulb temperature and the wet-bulb temperature, the relative humidity can be determined using a psychrometric chart (see page 1·323) or by searching for a relative humidity calculator online. One such web site can be found at www.ringbell.co.uk/info/humid.htm

THE CHEMISTRY OF

The Barbecue "Stall"

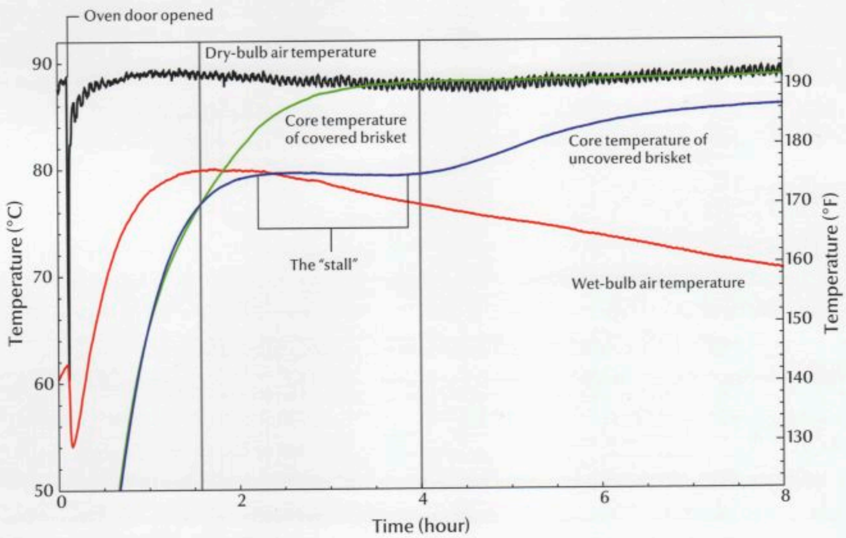
The "stall" is widely known among serious barbecuers. Well into cooking, the temperature of uncovered meat stops rising and may even fall slightly before it climbs again. Most barbecue experts say the stall occurs when connective tissue in the meat softens and fat starts to render in earnest. That does occur, but it doesn't cause the stall.

The stall is quite real—but is not due to the softening of collagen, as the graph at right shows. We cooked two briskets side by side in a convection oven, which mimics the air temperature in a smoker but is much more consistent and thus better suited for the experiment. We left one brisket uncovered (blue curve) and vacuum-sealed the other (green curve). Sensors measured the core temperature of each brisket as well as the dry-bulb (black curve) and wet-bulb (red curve) air temperatures in the oven.

The stall clearly occurs in the uncovered brisket 2–4 hours into the cooking, as the wet-bulb temperature in the oven falls. The stall ends after about four hours because by then the surface of the brisket has dried out enough that it is above the wet-bulb temperature. The temperature of the vacuum-sealed brisket, in contrast, rises steadily to the set point of the oven, reaching it in about three hours. Any effect due to collagen or fat rendering would occur in both briskets, but we see the stall only in the uncovered one.

Early in the cooking, the wet-bulb temperature rises as evaporation from the uncovered brisket increases oven humidity, which reaches a peak at a relative humidity of about 72%. But the humidity then begins to drop as water evaporating from the brisket can no longer replenish water vapor lost to air venting out of the oven. By the eight-hour mark, the humidity is below 50%, and the wet-bulb temperature is down almost 10 °C / 18 °F from its peak.

The core of the uncovered brisket stalls. In this test, we left the brisket dry, but if we had slathered it with sauce periodically as many barbecue chefs do, we would prolong the stall by keeping the surface wet.



EXAMPLE RECIPE

RUSSIAN SMOKED SALMON

Yields 1.2 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Salt	225 g	15%	① Combine to make cure.
Sugar	120 g	8%	
Salmon fillet, whole side, skin on, pin bones removed	1.5 kg	100%	② Pack evenly onto both sides of fish. ③ Vacuum seal, and refrigerate fish for 12 h to cure. ④ Rinse off cure from surface of fish. ⑤ Vacuum seal, and refrigerate for another 24 h to allow salt to fully diffuse through meat. ⑥ Smoke at 25 °C / 77 °F with 60% relative humidity for 4 h. ⑦ Vacuum seal. ⑧ Refrigerate until use.

(2009)

For lox-style salmon, use a 3% salt and 1.5% sugar rub (with weights relative to the weight of the fish), and vacuum seal the fish refrigerated for 48 h.

For Scottish-style salmon, use a 3.5% salt rub, and vacuum seal refrigerated for 36 h. Follow the remaining steps described in the recipe for both styles.

EXAMPLE RECIPE

BEEF CHEEK PASTRAMI

INSPIRED BY FROM JEAN PAUL CARMONA AND DAVID KINCH

Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Wagyu beef cheeks, cleaned	1 kg (about 4 cheeks)	100%	① Trim off any silver skin and excess fat.
Water	2.25 kg	225%	② Boil 500 g of water with sugar and salts to dissolve.
Brown sugar	145 g	14.5%	③ Remove brine from heat, add remaining water, and cool.
Salt	75 g	7.5%	
Insta Cure No. 1	15 g	1.5%	
Coriander seeds, toasted	3.5 g	0.35%	④ Combine aromatics with cooled brine.
Black peppercorns	2.5 g	0.25%	⑤ Vacuum seal beef cheeks with chilled brine.
Mustard powder	2.5 g	0.25%	⑥ Refrigerate for 72 h.
Pink peppercorns	2 g	0.02%	⑦ Remove cheeks from brine, and reserve brine.
Cinnamon stick, toasted and crushed	1 g	0.1%	⑧ Pat dry cheeks.
			⑨ Reserve.
Fennel seeds	1 g	0.1%	
Cloves (whole)	0.5 g	0.05%	
Red pepper flakes	0.25 g	0.025%	
Bay leaf	0.2 g	0.02%	
Juniper berries	75 g	7.5%	⑩ Grind together coarsely in coffee grinder to make spice rub.
Sugar	75 g	7.5%	
Black peppercorns	72 g	7.2%	⑪ Rub cheeks with 50 g (5% of their weight) of spice rub.
Coriander seeds, toasted	42 g	4.2%	
Garlic powder	10 g	1%	⑫ Smoke for 4 h at 77 °C / 171 °F.
Salt	10 g	1%	⑬ Boil reserved brine, and skim off surface foam.
Chili flakes	6.5 g	0.65%	⑭ Strain and cool.
			⑮ Vacuum seal smoked cheeks with 1 kg of cooled brine.
			⑯ Cook sous vide in 62 °C / 144 °F bath for 72 h.
			⑰ If serving immediately, rest for 15 min at room temperature, and slice. Otherwise, cool quickly in ice-water bath, and refrigerate.

(original 2009, adapted 2010)

Food critic Jeffrey Steingarten (see page 1·65) likes to say that New York City has its own local barbecue tradition: the pastrami prepared by the city's many Jewish delicatessens. The most famous places for pastrami are Carnegie Deli in Midtown and Katz's Deli in the Lower East Side.

Pastrami might seem quite different from Southern barbecue, but it certainly qualifies as part of that cuisine: cured and spiced meat that is smoked and then cooked low and slow.

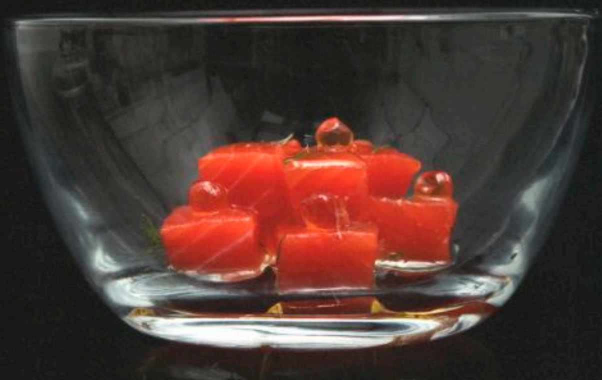
This pastrami recipe also works well with other cuts of meat. Simply use the table below to adjust the brining time, and see page 108 for cooking times and temperatures.

Cut	Brine (d)
short rib, bone in	6
short rib, boneless	3
beef tongue	7
brisket, fatty end	7

This beef cheek pastrami is fully cooked but remains red in the center due to the curing salts used.

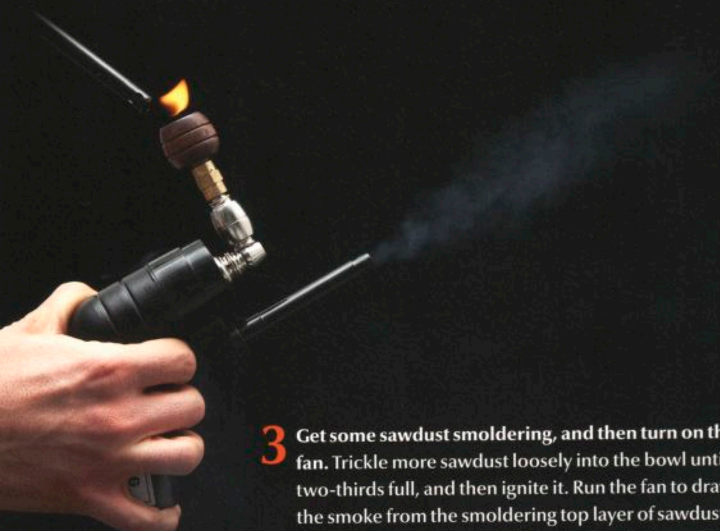
HOW TO Pack and Light Your Smoke Gun

A smoke gun is just a pipe with a fan that draws smoke through a bed of smoldering sawdust. This setup enables the fan to effectively "puff on" the pipe. Lighting the pipe is easy, but getting pleasant smoke from it requires care—just ask anyone who smokes a pipe how tricky this can be. What you want is a compact bed of glowing sawdust at the bottom of the bowl and smoldering sawdust just above this bed. This arrangement allows the smoke to be drawn down through a hot zone where the acrid components in the fumes are burned up. In this respect, a smoke gun is like the Inverted Flame Firebox described on page 208. Used with care, a smoke gun is a fantastic tool for imbuing food with a light smoked aroma or for garnishing a dish with wisps of smoke—a technique pioneered by chefs Grant Achatz and Joan Roca.

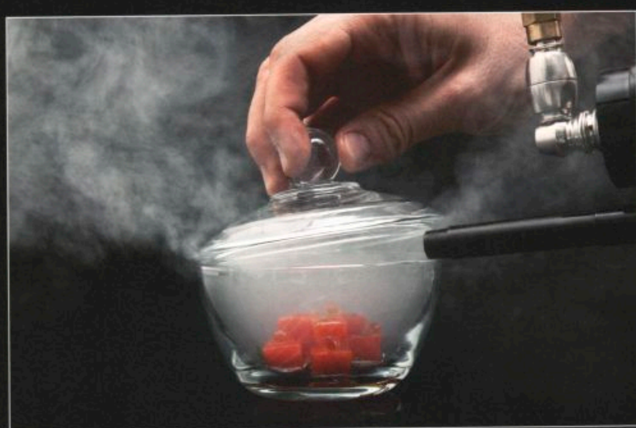


1 Prepare the food. Place the food into a container that can be sealed to hold the smoke.

2 Form a bed of glowing sawdust. Loosely fill the bowl with sawdust, and then gently tamp the dust into a compact bed until the bowl is half full. The sawdust should have no hard clumps that will restrict airflow. Ignite and char the sawdust with a match or lighter. Move the flame around to char the bed evenly, and then let the sawdust flame burn out.



3 Get some sawdust smoldering, and then turn on the fan. Trickle more sawdust loosely into the bowl until it is two-thirds full, and then ignite it. Run the fan to draw the smoke from the smoldering top layer of sawdust through the glowing bed of sawdust coals beneath it and out the gun barrel.



4 Apply the smoke. Replenish the smoke in the container as needed. When more smoke is desired but the sawdust in the gun bowl has been consumed, trickle a little more sawdust into the bowl, and relight it.

EXAMPLE RECIPE

SMOKED OCTOPUS ADAPTED FROM JOAN ROCA

Yields 300 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Baby octopuses, heads removed and set aside for other use	150 g	100%	① Pat dry, and coat lightly with oil.
Frying oil	as needed		② Sear on grill until just cooked through, about 4 min, turning once.
Baked potato foam see page 4·281	150 g	100%	③ Vacuum seal. ④ Warm in 70 °C / 158 °F bath.
Pistou basil leaves	to taste		⑤ Cover four glass bowls with layer of plastic wrap, pulling tightly on each until plastic is invisible.
Salt	to taste		⑥ Top plastic wrap with warmed potato foam.
Sweet smoked paprika (Pimentón de la Vera, dulce)	to taste		⑦ Top foam with octopuses. ⑧ Season and reserve.
Oak wood sawdust, finely ground	15 g	10%	⑨ Place in smoke gun, and warm end of gun. ⑩ Poke tip of gun into plastic wrap, and fill bowl with smoke. Repeat quickly for remaining three bowls. ⑪ Serve immediately.

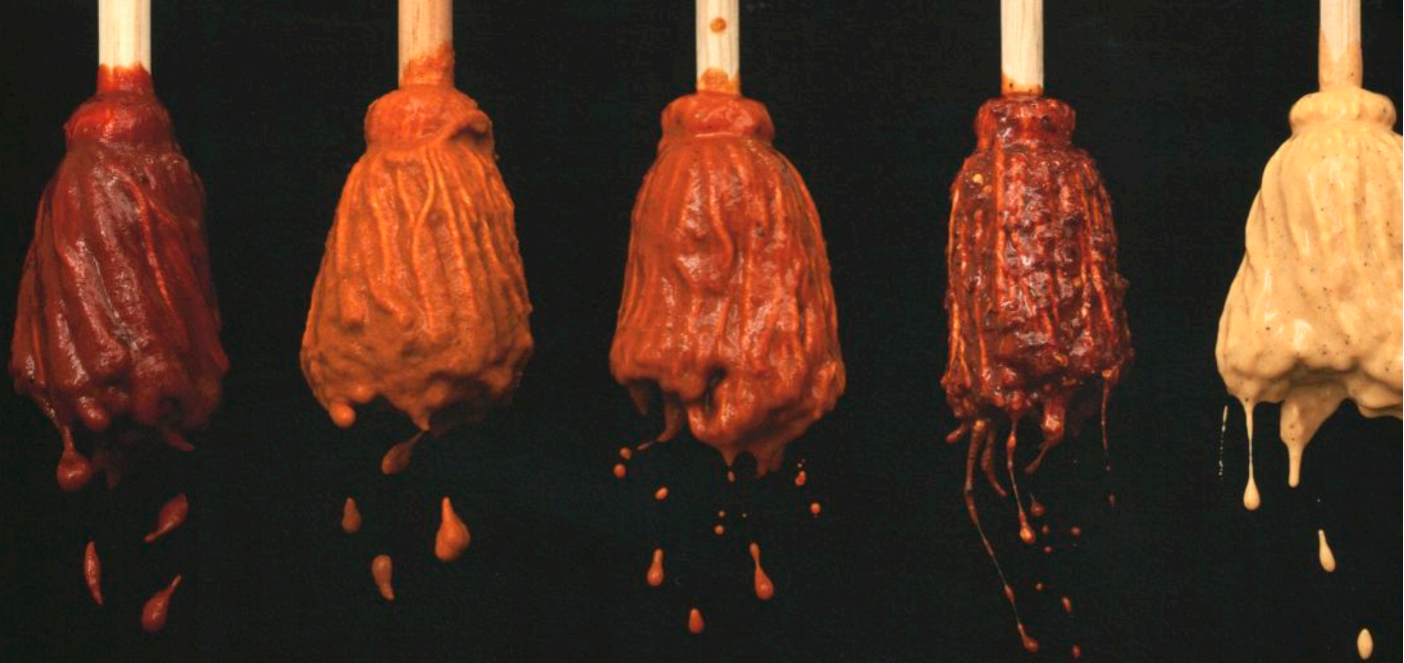
(original 2005)

Although the heads are removed, the arms of each octopus should still be connected to its body.


5


7


10



SOUS VIDE BBQ

Barbecue cooking involves two separate elements. One is using smoke to flavor meat. The other is using long, slow cooking to tenderize tough cuts. The traditional approach to barbecue tries to accomplish these two different goals at the same time, but that makes for some difficult compromises. Many barbecue techniques involve wrapping the meat in foil for part of the cooking because most barbecues and smokers have too hot and dry an environment—the foil acts a bit like a sous vide bag in controlling humidity.

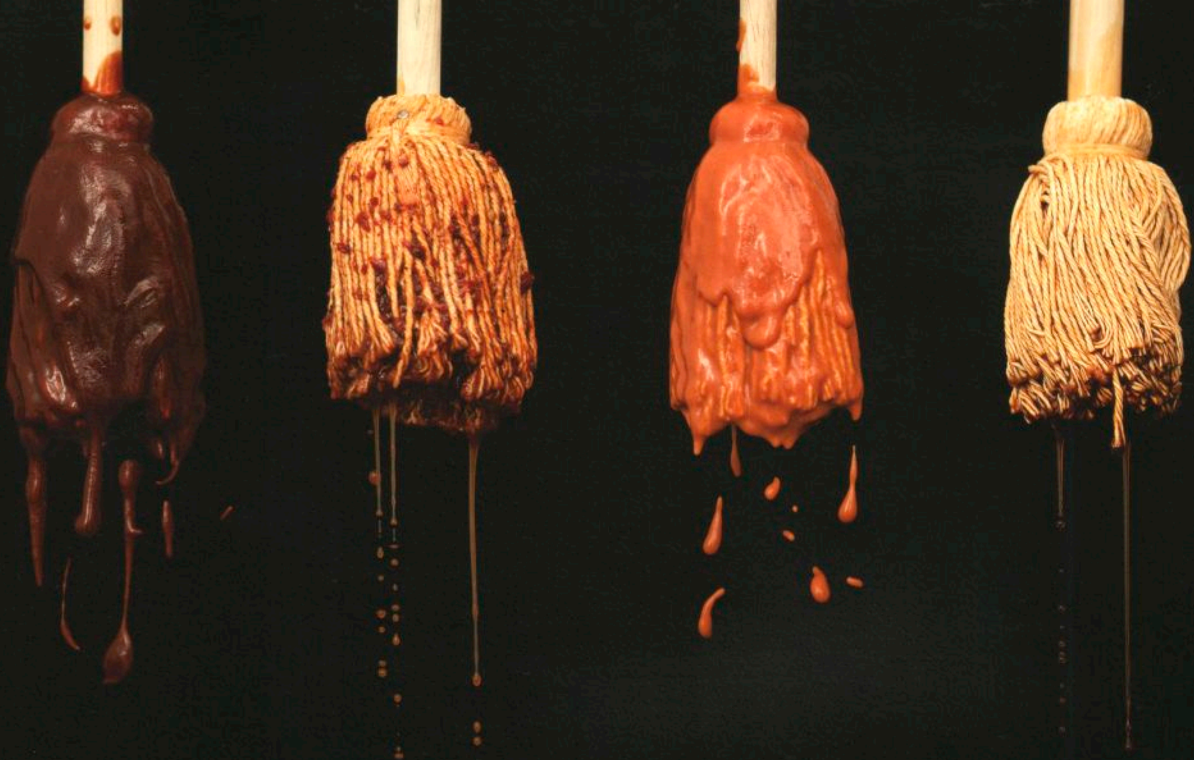
Sous vide cooking is, in our opinion, by far the best way to achieve the perfect long, slow cooking. So rather than improvise something with foil, we perform our barbecue with (at least) two distinct steps—smoking to impart the smoke flavor and sous vide cooking to achieve the optimum texture and doneness.

Smoking before a long sous vide cooking step has the advantage that proteins in the flesh remain intact and able to react readily with smoke. As with any smoking process, the food's surface must be neither too wet nor too dry, and smoking must be done for long enough to impart a strong smoky flavor and to set the rind. Skimp on smoking, and after sous vide cooking, the smoked flavor will be weak and muddy; the appearance won't fare any better.

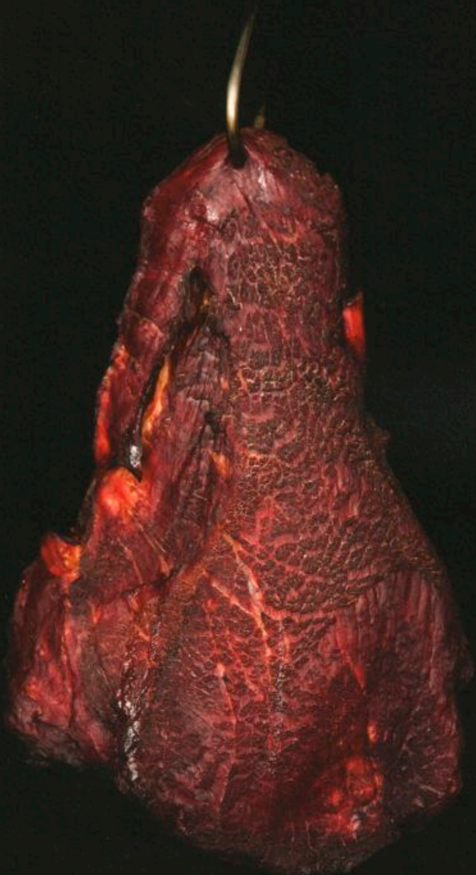
This draws attention to an important point: smoked food continues to change while being cooked sous vide. Its pellicle darkens, the rind becomes firmer, and the smoky flavor mellows. But often, this suits the smoked food.

The alternative, of course, is to smoke the food after cooking it sous vide. This also works well, but a longer smoking time is required to develop a robust smoked flavor and appearance. This is because precooking denatures a large fraction of the proteins in a cut of meat or piece of seafood, which leaves the flesh less reactive to the smoke.

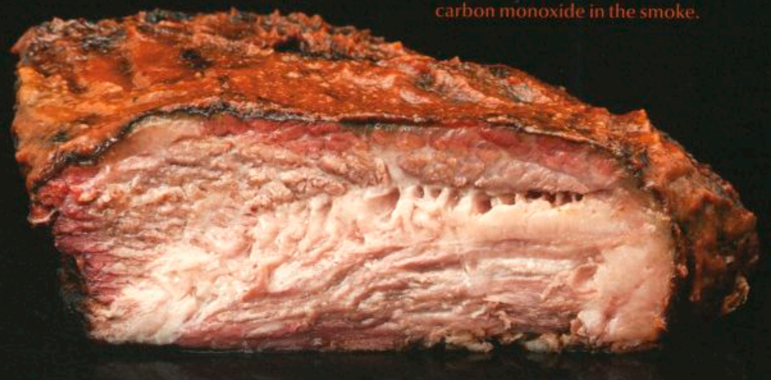
Whichever approach you choose to take—and you should try both ways to judge the differences for yourself—the remarkable texture that is the hallmark of sous vide cooking and the consistency it brings to smoking make it the best way to smoke meats and seafood that we've found. Instead of sous vide, you could use a combi oven, CVap oven, or low-temperature steamer for the sous vide step.



For the recipes for the nine barbecue sauces depicted here, see page 5·66.



Some barbecue enthusiasts assume that you cannot get a proper smoke ring if the meat is smoked after sous vide cooking. In general, this is not true. Cooking temperatures below 70–75 °C / 158–167 °F leave enough myoglobin intact for a smoke ring to develop when the myoglobin reacts with nitrogen oxides and carbon monoxide in the smoke.



LAND OF BBQ

In many parts of the world, regional foods attract cult-like followers who argue passionately about which variety is the best and most authentic. Festivals and competitions pit rivals against each other directly, and the participants often tightly guard their secret recipes. In France, cassoulet and bouillabaisse give rise to such fanaticism; in Texas, chili fuels this kind of passion. And in the central and southeastern United States, barbecue has given rise to myriad microregional variations—many more than a map of this size could show. We have highlighted a few of the styles to give a sense of the impressive scope of this authentic culinary art form.

The popularity of pork ribs makes them the most well-loved barbecue meat, available almost everywhere. Barbecue is also often served in a sandwich. That is particularly true of pulled pork, which ranges from finely chopped meat (mixed with sauce to make a sort of puree) to coarse chunks. Pulled pork is still the dominant form of barbecue in North Carolina, and it is typically available in the Deep South and Memphis but hard to find west of those regions. Beef, on the other hand, is virtually unknown east of Kansas City and is almost mandatory west of it. Sausage as a barbecue meat is found primarily in Texas. There are exceptions to all of these rules, of course.

Kansas City is a major barbecue town with its own traditions, as well as influences drawn from Texas and the Southeast. Beef brisket and pork ribs dominate here, and mutton is available in some places. The thick sauces are tomato-based and usually feature sweet, sour, or hot themes (sometimes all three). The influential Kansas City Barbecue Society hosts the annual American Royal "world" championship. Smoking here features oak, hickory, and fruit woods.

Memphis, another major barbecue center, is also home of a big "world" championship, called Memphis in May. Pork ribs are the rule here, but pork shoulder and whole hog are also served. Dry rubs are part of the local style, as are oak and hickory for smoking. You'll find a wide range of sauces in Memphis, including sweet, hot, sour, and mustard-based sauces.

Texas barbecue was originally inspired by "barbacoa," the Mexican term for dishes like pit-cooked cow head and tongue. That traditional Mexican style is not barbecue in the modern sense because the meat was steamed in a pit without wood smoke. Today, these dishes are usually made by steaming the meat in a bain marie, and then serving it in tacos and tamales.

West Texas (or "cowboy") barbecue is usually cooked directly over mesquite coals. It is smoking, not grilling. But heat reaches only some areas directly, with other parts cooked by indirect heat. The traditional forequarter cuts, including beef clod, have largely been supplanted by brisket, and pork ribs, chops, and other meats have been added by popular demand. The tomato-based sauces are spiced with ancho chili powder.

The barbecue of east Texas resembles that of the Deep South, except that beef ribs, beef brisket, and sausage are common in Texas, and pork usually appears as ribs. Sauces are sweet and spicy, and the wood is typically hickory or pecan.

Central Texas attracted many German and Czech immigrants in the 19th century. They started the tradition of selling smoked meat at butcher shops rather than restaurants. Today, these meat markets have evolved into dedicated barbecue restaurants, but they retain some of their storefront heritage. In some, the meat is served on butcher paper, not plates, with limited side dishes. Sauce is discouraged, and some barbecue joints don't even put it out. Beef brisket, pork ribs, and sausage (100% beef or a pork-beef mix) dominate the menu. They mainly use oak, but sometimes pecan or hickory, to smoke the meat.

Although St. Louis is not a major barbecue center, the most common way to trim pork ribs is called "St. Louis-style," and the city is known for barbecued pork snouts and pork "steaks," which are slices of pork shoulder.

In Kentucky, barbecue features pork ribs and shoulder. Mutton is common here but rare elsewhere. The preferred wood is hickory. Tomato-based sauces with bourbon and vinegar are popular, as is a Worcestershire-based sauce with vinegar, black pepper, and brown sugar.

Eastern North Carolina has a strong tradition of pulled pork from whole hog smoked over oak and hickory. The meat is removed (pulled) from the bone, chopped, and sprinkled with a thin sauce made from vinegar, chili flakes, black pepper, and salt.

In western North Carolina, the focus is on pulled pork, usually from the shoulder. It is smoked over oak and hickory, and then served with a tomato catsup-based sauce.

South Carolina barbecue includes pork ribs and pulled pork from the shoulder, smoked over hickory and oak. The sauce is mustard-based ("Carolina gold"), with brown sugar and pepper.

In the Deep South (Alabama, Georgia, and Eastern Tennessee), barbecue is a mixture of pork ribs and pulled pork. It is smoked over hickory, oak, or fruit woods. Sauces vary widely but tend to be either sweet or spicy—sometimes both.

Odd as it may seem, towns named Lexington are barbecue centers in every state in the region where one is present.

Many famous (or not-so-famous but excellent) barbecue restaurants/pits can be found outside of the regional centers highlighted here. The best are often off the beaten path: although every major city has barbecue restaurants, the quality is often shockingly low compared to those just a few miles into the countryside.

Barbecue can be found in all southern states within the U.S., but not all of them have distinctive barbecue traditions of their own. In Florida, food traditions vary across the state. Styles in the northern panhandle are similar to those across the borders in Alabama and Georgia. In the central and southern parts of the state, the food bears the influence of the huge influx of residents who winter or retire there from other parts of the country. In Louisiana, rich food traditions that draw on creole and Cajun heritage tend to overwhelm local barbecue culture.

There are many different spellings of the word barbecue, including barbeque, bar-be-que, BBQ, and many others. There appears to be no firm consensus on which is correct.

RESTRUCTURING

"Laws, like sausages, cease to inspire respect in proportion as we know how they are made." This witticism appeals to a common attitude about sausages: that they are the products of unscrupulous butchers whose dirty dealings rival those of politicians. We beg to differ. Sausage making is an ancient and honorable activity that over the ages has produced some delicious results.

Sausage making is essentially about manufacturing a perfect cut of meat from imperfect parts. The final product has an ideal ratio of fat to lean meat, is tender, is portioned to the right size, is boneless, and comes well seasoned. The art of sausage making lies in constructing this perfect meat product from scraps of meat too small to use by themselves, from meat parts not suitable for eating directly (like blood), or from meat that is too tough to eat in its native form. Sausage also provides a use for fat that can't be eaten alone and repurposes a host of other ingredients that separately aren't very impressive but that together make a great "cut" of meat—albeit one that is totally artificial.

This transformation is accomplished by grinding and mixing the constituent parts and setting them into a solid gel. Lean meat is blended with fat, mimicking the marbling of a prime cut. Tough meat is tenderized by grinding. Casing holds it all together until heat causes the sausage to gel.

In addition to the dramatic restructuring afforded by sausage, less dramatic remodeling of meat is facilitated by the enzymes that "glue" bits of meat together.

The terms "artificial" or "restructured" meat connote an industrial food process, and sausage making has indeed been modernized. But the practice of making artificial meat cuts is quite old. The word "sausage" derives from the Latin *salus*, meaning salt, the substance used to help bind and preserve the minced meat. In Roman times, sausage mixtures were encased in animal intestines or stomachs. The Romans inherited sausages, like so many other things, from the Greeks and other civilizations before them. Sausage was being made at least as early as the 8th or 9th century B.C., as evidenced by this excerpt from *The Odyssey* of Homer:

Attend ye noble suitors to my voice.
Two paunches lie of goats here on the fire,
Which fill'd with fat and blood we set apart
For supper;

Blood sausage of this sort is made to this day.

It would be impossible for us to cover every possible variation in this venerable art. Germany alone reportedly has more than 350 different types of traditional sausage. The goal of this section is to explain the basics and provide an overview of Modernist sausage and restructured meat.

Basic Principles of Sausage

Sausage is the prototypical restructured meat and so is a useful place to begin our discussion. All sausage making involves taking ground or chopped meat, fat, and other ingredients and combining them into a mixture often called a forcemeat or, in cases where it is a smooth mixture, a meat batter. This mixture must set into a meat gel, and much of sausage making entails setting up the right conditions for this gel to form. The texture of the resulting sausage depends largely on the qualities of the gel.

Coarse Sausages

In coarse sausages, the constituent parts are in rough form, as the name implies, and are often still recognizable as small chunks of meat, fat, or other ingredients. It is common for coarse sausage to have pieces that are 2–6 mm / 1⁄16–1⁄4 in. in diameter. This coarseness is a key feature of the final taste and texture, but enough of a gel must form to stick the components together. Otherwise, a coarse sausage will separate into grainy meat and grease when its casing is cut during eating.

The simplest coarse "sausage" is ground meat such as the ubiquitous hamburger. In this case the goal is to have just enough of a meat gel form that the hamburger patty holds together, but not so

Flushing a meat grinder with liquid nitrogen keeps the grinder cold so that it cuts the meat more cleanly. Flushing with ice water will have the same effect. Skillful use of a bit-and-plate grinder requires paying attention to such operational details.

Pork butt is in some ways the ideal sausage meat: cheap, widely available, and high in quality and fat. For many sausages made from pork butt, little or no fat needs to be added because the meat supplies enough of its own.

Pork leg meat is also an excellent sausage meat. Because of its low fat content, however, fat must be added to sausages made from the meat. Beef chuck and clod (shoulder) are good sausage meats as well.

much that it becomes rubbery. The optimum texture requires careful handling (see page 334). Meatballs and meatloaf are other minimal types of coarse sausage. Italian pork sausage is an example of a simple coarse sausage that uses a casing rather than free-form molding.

Emulsified Sausages

Emulsified sausages are mixed completely so that the meat and fat form a smooth, emulsified batter that sets into a uniform gel. The trick here is to make the sausage in such a way that the emulsion does not break and the fat does not separate at any point before consumption.

Classifying sausage as coarse or emulsion focuses on the nature of the forcemeat, but sausage can also be named on the basis of other traits. Cased sausages are stuffed into natural casings (usually the intestines of sheep, pigs, or cows) or synthetic ones made of collagen extracted from meat. They are usually formed into links: separate cylinders made by twisting the casing. Bulk sausage is sold as a raw forcemeat and shaped by the chef; uncased or skinless sausage is formed by using a mold or a temporary casing that is peeled off later.

Fresh Sausages

Fresh sausage is prepared raw and kept refrigerated until it is cooked just before serving. But some types, including frankfurters, are cooked once during preparation (to set the protein gel) then a second time before serving.

Fermented Sausages

Fermented sausages are inoculated with microorganisms (bacteria, molds, or other fungi) that produce lactic acid and other compounds that both preserve the meat and add characteristic flavors. Curing salts are often added to fermented sausages to aid in preservation, as well as for flavor. Fermented sausages may be treated like fresh sausages or, if they have been dried sufficiently, can be kept safely at room temperature and served raw, just as country hams are.

Fresh and fermented sausages are often smoked, usually at a late stage in their production. Fermented sausages are frequently dried slowly to fully preserve them. Note that these classifications of coarse, emulsified, fresh, and fermented sausages can and often do occur in combination. Some combinations are more common than others, but among the thousands of traditional sausage recipes, nearly every possible combination exists.

A slick coating on presalted meat is laden with the protein myosin, which helps the sausage meat stick together when it is cooked.

Making a Gel

A key aspect of sausage making is creating a cohesive gel to hold the sausage together. The casing is there only to hold the sausage together until the gel sets. The process of gelling is sometimes referred to as binding the sausage. How you create the gel depends on what type of meat you are using and how it is handled and treated.

The meats used to create sausages leak proteins, particularly myosin, when they are ground and packed together. Upon being heated, the myosin gels, binding the sausage. The amount of binding depends on the species of animal, the specific cut of meat, and how the meat is handled.

Shrimp, crawfish, and lobster meats all have high binding power. They are ideal for binding a seafood sausage, but if you add too much the texture can get rubbery. The classic mammalian sausage meat is pork muscle (such as leg or shoulder), which has good binding power. Organ meats like stomach, tripe, and diaphragm (also called weasand meat) generally have poor binding properties and are called filler meats. Although it isn't technically a meat, blood is a common sausage ingredient that acts as a filler but is also an excellent binder. Filler meats contribute protein and some flavor but need to be mixed with other binding agents. Their main role in sausage is economic; cheap cuts of meat that might otherwise be discarded can be used and can eliminate the need for nonmeat fillers. Fat has essentially no binding power—indeed, it causes binding problems.

The binding power of pork and most other muscle meats can be increased by certain handling and treating practices. Myosin extraction increases when meat is subjected to high salt concentrations (6% and above). That is too much salt for a sausage overall, so the proper technique is to cube the muscle-meat portion of the sausage and apply all of the salt desired in the final sausage mixture.

Most sausages have between 1% and 2% total salt content by weight, but when that amount is spread on the meat cubes alone it forms a concentrated brine (see page 170). Allowing the brined meat to sit (ideally in a vacuum-sealed bag) for 4–48 h before grinding will produce plenty of myosin and increase the meat's binding power. Tumbling the cubed meat will shorten the wait time needed or, alternatively, produce more myosin in the same wait time.

Myosin extraction is increased even more by phosphate salts, particularly **sodium tripolyphosphate** and **tetrasodium pyrophosphate**. These salts, which should always be dissolved in a small quantity of warm water before being mixed with the meat, draw out myosin so well that you have to be careful not to overdo it; a little bit goes a long way. Effective concentrations are typically less than 0.3%—and often much less.

A different approach to creating a gel is to add a binder to the sausage. One group of binders consists of nonmeat proteins that, like myosin, also form a protein gel. Powdered protein extracts from soybeans and milk (casein or whey protein) are often used, as are eggs (whites or whole egg). Another class of binders encompasses the hydrocolloid gels such as alginate (see page 4·124). These substances form gels even in low concentrations of 0.5% or less.

Activa, a brand of transglutaminase enzyme, is an almost magical binder for sausage because it cross-links proteins, causing them to stick together even if they have no natural binding power. It is a very powerful ingredient for sausage making and can help to produce good sausages from meat that otherwise would never gel. Adding 0.25% Activa TI or RM (see page 354) generally makes an excellent sausage with a good bite texture—a property called *knack* in German. A poach test is the best way to determine whether the binding power of your sausage is sufficient; for instructions, see page 325.

Ironically, water plays a key role in binding sausage meat into a gel. It's not unusual for sausage makers to add 5%–10% water (by weight) to the forcemeat or batter. This step is necessary to dilute the myosin and other gelling agents enough that they can coat the other constituents of the sausage. Water is typically added as ice to help control the temperature of the meat during grinding or pureeing in a chopper. The added water also makes the mixture easy to stuff and softens the ultimate product, making it tender. And water helps to make the sausage moist and juicy.

In Germany and many other countries, meats are "hot-boned" and ground for sausage before the carcass has entered rigor mortis (see page 32). This approach improves the binding quality of the meat in part because natural phosphates are still present in the flesh. Most cooks don't have this option and must make sausage with meat that has already entered rigor mortis. That is certainly possible but requires presalting, tumbling, or adding phosphates.

Fermented or cured sausages are often served raw or only lightly cooked, a fact that should be considered if you plan to serve them to immune-compromised people. See page 1·178 for details.

The fat in a well-made sausage can contribute 25%-30% of its weight. How that fat is incorporated makes the difference between a rich and delicious link and one that is greasy.

Mayonnaise is an emulsion that has a very high percentage of fat—often more than 90%. All that fat tastes great as long as it stays emulsified. But if the emulsion breaks, the mayonnaise becomes unappealing. The same is true for a sausage: if the fat "greases out," or separates from the meat, the sausage will be much less appealing.

Incorporating and Holding Fat

Fat is one of the key constituents of sausage, typically accounting for 25%–30% of its weight. Fat adds flavor, tenderness, and juiciness and was, for our ancestors, an important source of nutrition. But while fat is a necessary ingredient, it is also a problematic one, and many techniques in sausage making have been devised specifically to cope with it.

It is very important to make a distinction between fatty tissue—the form of fat in animal flesh—and fat molecules, which are the primary component of pure, rendered fat. The two are not the same. In animal flesh, fat molecules are sequestered in cells that are surrounded by connective tissue. When you cut, chop, or grind meat, the cells rupture, allowing the fat molecules to leak out. When meat is heated, collagen molecules and connective tissue contract (see page 80), forcing the fat molecules out of the cells. This is exactly the result we are looking for when we render fatty tissue to get pure fat. But when it happens in sausage, the leaking fat is likely to draw complaints that the sausage is "greasy."

Adding fat to sausage isn't just about providing succulence and rich flavor; fat is essential for tenderness, too. Eliminating fat from sausage can make it tough and rubbery because the pieces of meat gel too strongly. Dispersed droplets of oil create tenderizing weak spots in cooked sausage. Low-fat sausage formulations use microcrystalline cellulose and other ingredients to simulate this effect.

The challenge with sausage, then, is to keep the fat stable in the raw forcemeat or batter and to have it stay that way while the sausage sets into a gel as it is cooked for service. There are three basic ways to meet this challenge.

The first approach, used in many coarse-textured sausages, is to start with high-quality fatty tissue. Be careful what you choose: many fat-containing tissues in meat cannot be added directly to sausage because they have too much sinew or other components that make them difficult to eat (skin is a good example). The fat in pork shoulder, fatback, or kidney fat, on the other hand, is ideal for sausage.

With high-quality fatty tissue as the base, the goal is then to keep the fat cells intact, subjecting them to as little mechanical disruption as possible. Careful grinding technique is key—we don't want to overgrind or allow the mixture to get too hot. The pure fat molecules in pork fatback melt at 30–40 °C / 86–104 °F. Even if the bulk mixture is much cooler than that, friction can easily raise the surface temperature of the fat cells into this range when they're forced through the grinding plate.

Grinding the fat separately from the meat is also helpful. Chilling the fat helps keep the temperature low even with the heat induced by grinding. Do the grinding in small batches, and cool the grinder between them. For a Modernist touch,

Mixing ground meat and fat with any liquid, seasonings, and binders is the final step in preparing the sausage for stuffing. Keep the ingredients and equipment ice-cold to avoid smearing the meat and the fat.

rinse the grinder with liquid nitrogen before grinding and between batches.

This approach works best if the fat is coarse, so do the grinding with the 6 mm / ¼ in plate or a larger one. The ground fat should be kept chilled until it is gently mixed with the ground meat and other ingredients.

The second strategy is to make a fully emulsified sausage. In this approach, the meat and fat are coarsely ground separately, and then moved to a Buffalo chopper or food processor to be pureed with water (added as ice to keep the temperature near freezing) and other ingredients into a smooth batter. The goal is to break the fat into tiny droplets surrounded by dissolved and suspended protein so that when the protein gels, the fat is trapped and cannot escape.

The term "emulsified" sausage is used because the fat-in-protein mix is comparable to an oil-in-water emulsion (see page 4·196) such as mayonnaise. But the sausage batter is *not* a true emulsion—a liquid dispersed in a liquid—because the fat in the batter is a solid, not a liquid. Saturated fats such as pork fatback do not melt below 30 °C / 86 °F, and the batter is generally held at or below 15 °C / 59 °F. The batter is not an emulsion but a **colloidal suspension** of solid fat, undissolved proteins, and meat particles in a liquid matrix of dissolved proteins (see page 4·12). Generations of butchers and charcuterie books nonetheless refer to these sausages as "emulsified."

The trick, then, is to get the meat to gel before the fat melts. The batter is stuffed into casings and gently heated, usually in stages. First it is brought to 55 °C / 130 °F. Traditionally, it is then brought to a final internal temperature of 65–71 °C / 149–160 °F, setting the protein gel and trapping the fat in place.

The third way to deal with fat is to make a true emulsion that suspends fine droplets of fat—much like those that occur in fat cells—in a gel, which stands in for the collagen that traps fat inside fat cells.

This approach combines a mixture of water and a nonmeat protein source (such as soy protein isolate, whey protein, or sodium caseinate) with either homogenized fat tissue or pure, rendered fat by using a blender or rotor-stator homogenizer at a temperature that liquifies fat (65–80 °C / 149–176 °F). The mixture is then chilled until it sets into a gel. In this case, the nonmeat protein forms a gel that fully encapsulates the fat.
A Modernist take on this method is to use a hydrocolloid gel like alginate, gellan, or guar gum to help emulsify the fat, or to allow use of an oil or rendered fat.

Once set, the gelled emulsion can be ground and incorporated into sausage in much the same way that conventional fat is used in either coarse-ground or emulsified sausages.

For more on Buffalo choppers, see page 333.
For recipes for Modernist sausages, see page 348.

Other Ingredients

Meat, fat, binders, and water are the main ingredients in a sausage. Salt (sodium chloride) adds taste and also plays an important role in extracting the protein for binding, as phosphates can. Very few sausage recipes, however, include only these basic constituents. Many other ingredients are incorporated into sausage, generally in a mixing stage after the forcemeat or batter is made.

THE TECHNIQUE OF

The Poach Test

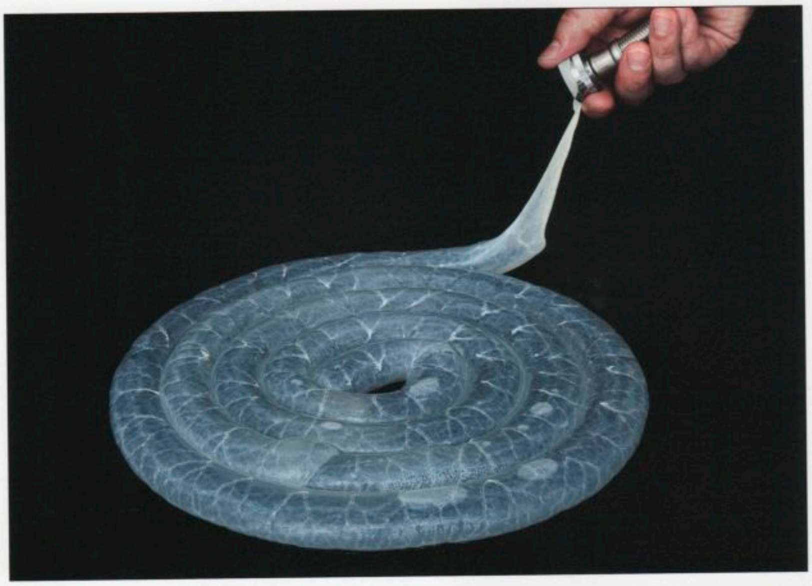
Proper binding can make or break the quality of a batch of sausage. The best way to fine-tune your sausage mix is to do a poach test. As soon as the sausage is mixed, place a small amount (a tablespoon) in a plastic bag or a folded piece of plastic wrap, and poach it in water. If you are using Activa, then the water should be no hotter than 56 °C / 132 °F to avoid thermally degrading the Activa, and you should poach for 6–7 min to achieve a hot set (see page 353). If you are not using Activa, then the water can be above 56 °C / 132 °F, and you can poach for 3–5 min to set the protein gel. Then remove the sausage meat, and judge the texture.

If the meat is too crumbly or falls apart, you need to increase the binding. You could correct the texture of the next batch of sausage by altering the pregrinding treatments (see page 328) or by increasing the amount of lean muscle meat you incorporate. To salvage the current batch, your best bet is to mix in some Activa or some phosphate. Add an amount of Activa equal to 0.1%–0.25% of the total weight of the sausage mix, or 0.05% phosphate dissolved in a little water, and blend well.

If the poached sausage is too stiff or rubbery, you need to decrease the binding. For the next batch, you have many options: you can decrease the amount of lean meat in the mix, shorten the presalting time, or decrease the amount of phosphate or Activa you use. If you want to salvage the current batch of sausage, about the only thing you can do is add some additional fat, water, or filler, such as bread crumbs or panko, to dilute the binding.

Curing salts, principally sodium nitrite, do the same thing for the meat in a sausage that they do for other cured meats. In low doses, these salts help keep meat pink—the colors typical of frankfurters, chorizo, and bologna are due to curing salts. They also add characteristic cured meat flavor. In higher concentrations when used in combination with fermentation and adequate drying, they allow the creation of sausages that can be kept unrefrigerated in the same manner as other cured meats. Curing salts are added soon after grinding. Because they are used at a very low concentration, they are often dissolved in water that is then sprinkled over the meat before mixing.

Prepare the casing (top) by flushing out the salt with warm water, and then soaking it for 30 minutes. This makes it pliable enough to stuff without bursting. Manage the fullness of the casing (bottom) by controlling how quickly it slides off the horn as it fills.



Fillers or extenders are nonmeat products that are added to sausages for a variety of reasons. The primary reason is traditionally an economic one: adding wheat flour, oatmeal, starch, or bread crumbs makes the sausage cheaper per unit of weight because fillers cost less than meat and fat and are even less expensive than binders such as soy and whey protein.

Just as the curing salts once used for preservation are now desired for the taste and texture they help create, many fillers are added these days as much for their flavor as for their cost. British bangers wouldn't taste right without toasted bread crumbs. There are also functional reasons to add fillers. Low-fat sausages (those having 15% fat or less), for example, often need additional water-binding ingredients, like starch, to make them tender.

Sugar is a common sausage ingredient that can serve dual purposes. Sugars supply some functional advantages, such as making the sausage brown better because of the Maillard reaction, but their main purpose as an ingredient is simply to make the sausage taste sweet. Sugar can be added either directly in the form of sucrose or (more often) glucose, or as a flavored syrup such as maple syrup.

Seasonings such as herbs and spices are another important component of sausage. The herbs and spices used in emulsified sausages must be ground much finer than they are for other food. One reason is that the coarser grinds appropriate for other kitchen uses create a gritty feel on the tongue. The other is that the characteristic tastes of sausages such as frankfurters depend in part on the spices (for frankfurters, white pepper, coriander, nutmeg, and allspice) being perceived together as a blend rather than separately. Liquid infusions (see page 2·310) can be used as an alternative to fine-ground spices. At the other extreme, some coarse sausages feature whole peppercorns, so the fine spice rule does not always apply.

Fermented sausages are typically inoculated with a live culture of an organism that causes the fermentation. These cultures are isolated from successful sausage-making operations to provide some certainty that the desired microorganism is growing on, or in, your sausage. The most common cultures are fermenting bacteria, although some yeasts and molds are also used.

As an alternative to true fermentation, you can use a product like Fermento, a slow-acting acidulant that releases lactic acid into the sausage. Because fermentation bacteria also produce lactic acid, this effect can mimic some of the taste of fermentation, but it is an imperfect substitute at best. Many people mistakenly believe they are creating a fermented sausage with Fermento, but they are just adding a tart acid and whey proteins that have been fermented in advance and added to the product. Citric acid is also sometimes used for this purpose.

Many of the other ingredients commonly added to sausages do not fall into any of the preceding categories. Italian mortadella often contains whole pistachio nuts and myrtle berries. Other nuts, as well as dried fruits such as raisins, cured fruits such as olives or capers, and fungi such as truffles, may also make an appearance in sausage. Some fresh sausages also include finely diced apple or other fresh fruits or vegetables.

Stuffing Sausages

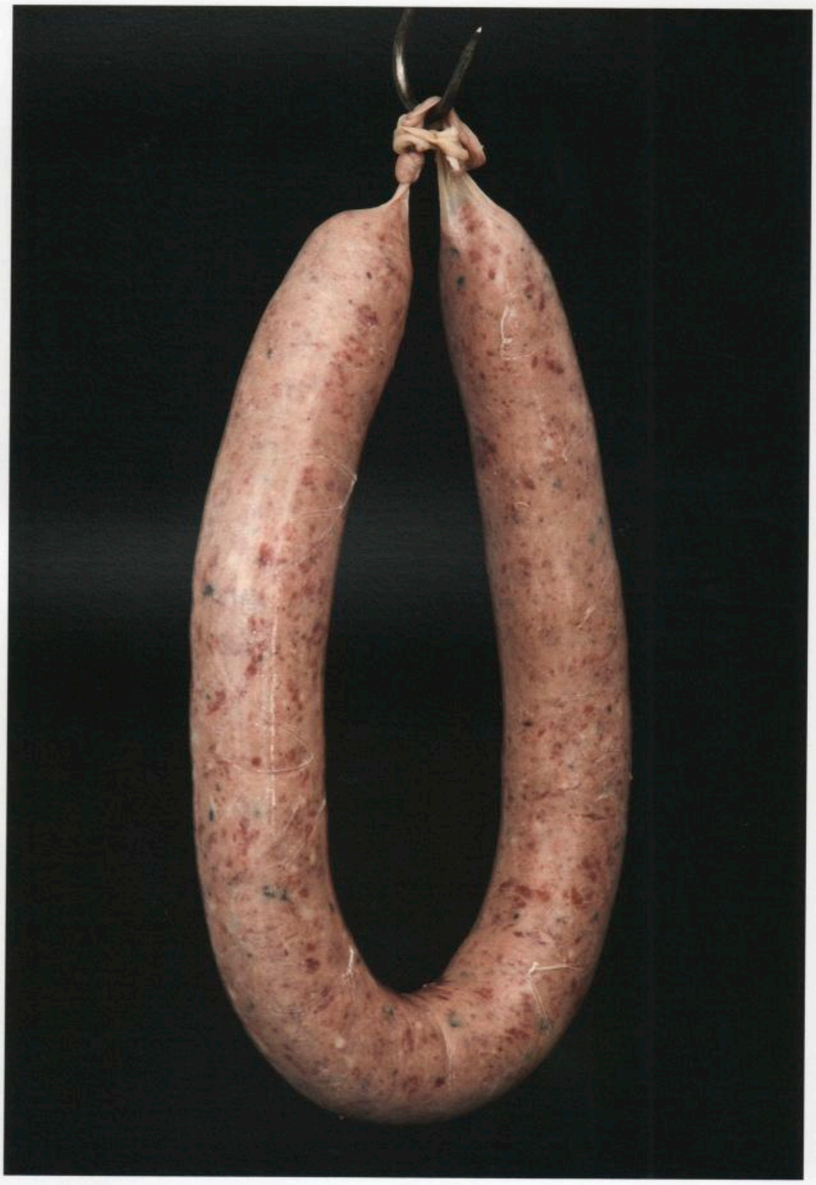
The protein-based gels that hold sausage together are set with heat, so something else must keep the sausage intact until the gel sets. That service is typically performed by the sausage casing. Traditional casing material is the cleaned intestines of sheep, pigs, or cows; there are also synthetic casings made of collagen extracted from animal skin, and there are plastic casings meant to be removed before consumption.

Natural and synthetic casings come in bundles called hanks. Synthetic casings are all the same length, whereas a hank of natural casings has some variation. Both natural and synthetic casings must be rinsed free of salt and soaked in warm water before use to make them pliable. Adding 2% sodium tripolyphosphate to the water will result in a very supple and pliable casing that is also more tender after cooking.

A sausage mixture should be stuffed as soon as it is made, or it will firm up and become difficult to work with. The best tool for the job is a sausage stuffer, a device that drives a piston down a cylinder and extrudes the sausage meat from a funnel called the horn. Slide the prepared casing over the stuffing horn until all of it is on, and then start turning the crank. The rate of cranking and the speed at which you allow the casing to come off the horn determine how full the casing gets. Overfilling may cause ruptures either during the filling process or during cooking.

It is also important to avoid air pockets, which may expand and pop during cooking. (Such eruptions are the source of the term "banger.") Air pockets can also cause oxidation, discoloration, and even spoilage. You can clear surface air pockets by pricking the casing with a needle and squeezing the air out. Eliminate interior air bubbles by vacuum packing the sausage mix. Then open the bag and pack the compressed meat into

Hanging sausages in a refrigerator overnight allows them to set up, an important step that is often overlooked.



HOW TO Grind Meat and Fat

Meats of different textures or origins should be ground separately. Likewise, remove fat from the meat, and grind it separately after you have finished grinding the meat. To obtain fine grinds, start with a coarse grinding plate, and move to finer plates in stages.

Pregrinding treatments such as those described in the table at right are chosen based on binding strategy. When used together, these treatments are especially effective at enhancing the amount of protein extracted (and the binding strength of the ground meat). They are essential when making emulsion-style sausage.

1 **Trim off sinew, silverskin, and connective tissue, and separate fat from meat.**

2 **Cut into 2.5 cm / 1 in cubes.**

3 **For meat, use a pregrinding treatment as desired (see table).** Pretreatment is not necessary for grinding fat.

4 **For meat, chill to near freezing** (as low as -1 °C / 30 °F). **For fat, chill to below freezing** (as low as -10 °C / 14 °F).

5 **Rinse grinder with liquid nitrogen or ice water.**

6 **Start with a large grinding plate (4–6 mm / 3⁄16–1⁄4 in or 10 mm / 3⁄8 in).**

7 **Grind in small batches, and make sure the meat and the grinding plate do not get too hot.** Check them with a thermometer.

8 **Chill grinder between batches with ice water or liquid nitrogen as necessary.**

9 **Replace the grinding plate with one that has a finer aperture if needed, and repeat steps 4–8.**

In traditional sausage making, fat receives no preparation other than trimming and chilling.

For more on Modernist approaches to sausage making, see the recipes beginning on page 348.

Pregrinding Meat Treatments

You can use the pretreatments in this table either alone or in combination after meat has been trimmed and cubed. The appropriate pretreatment varies with the type of sausage and the amount of binding strength needed. Do not pretreat hamburger, fermented sausage, or sausage containing Activa.

Method	Ingredients	Procedure	Notes
presalting	salt (in amount given by sausage recipe)	sprinkle on lean meat portion, vacuum seal, and refrigerate for 4–48 h	for coarse or emulsified sausage
adding phosphate	a blend of sodium tripolyphosphate and tetrasodium pyrophosphate, such as Nutrifos 088 blend (0.015%–0.3% of meat weight)	dissolve phosphates in warm water, and then mix with meat	extracts myosin very well (sometimes too well)
tumbling	salt or phosphates or both as described above	vacuum tumble for 30 min (no refrigeration required)	accelerates myosin extraction by salt or phosphates

Typical Aperture Sizes of Grinding Plates

Because grinding plates sized in millimeters are slightly different than those sized in inches, the resulting grinds are not exactly equivalent.

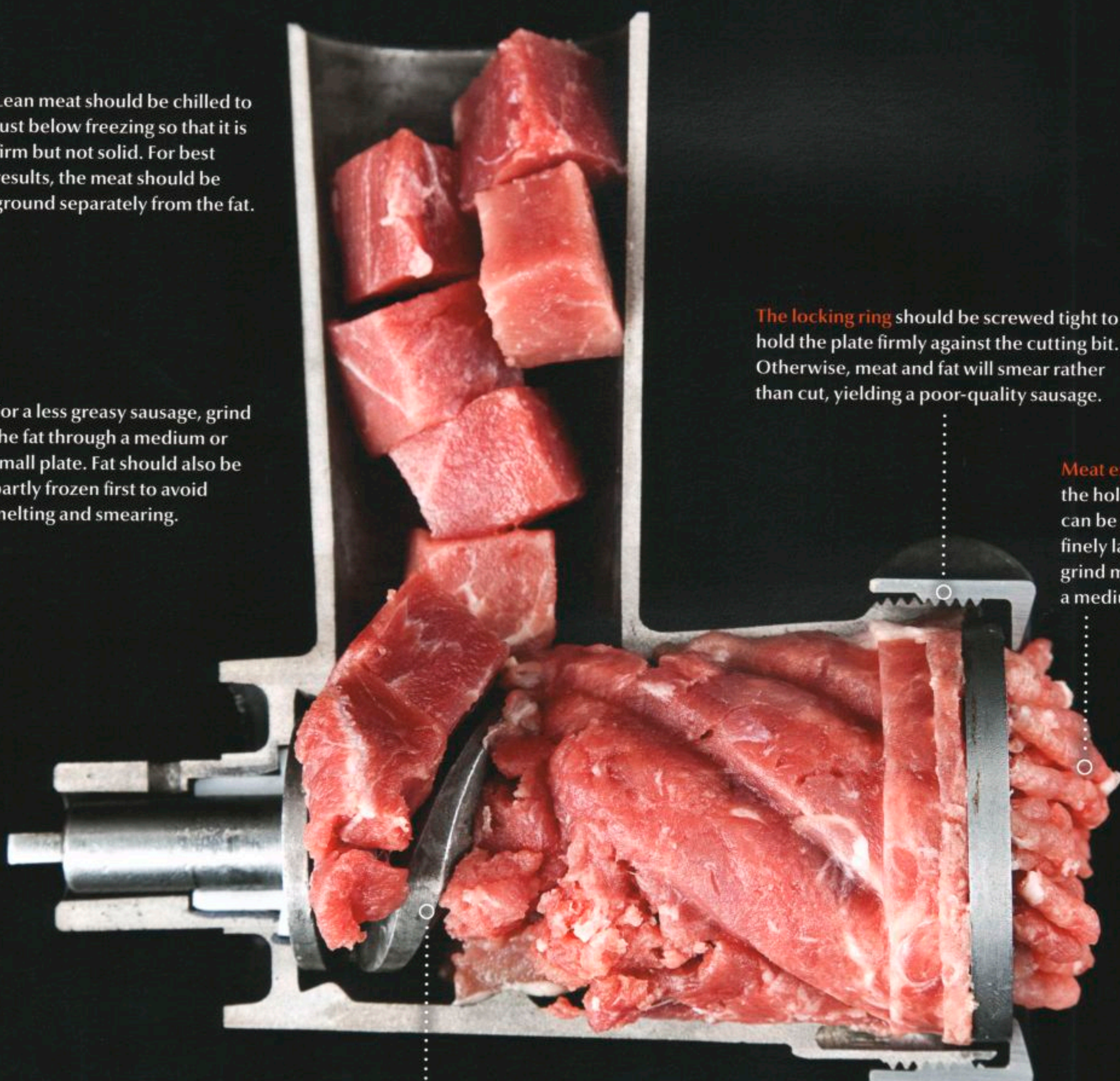
Aperture (mm)	(in)	Note
2	1⁄16	considered fine plates; suitable for filler meats or for approximating the smooth texture of an emulsion-style sausage
3	1⁄8	
4	3⁄16	considered medium plates; commonly used for coarse-ground sausages
6	1⁄4	
10	3⁄8	usually reserved for dried, fermented sausages; the larger apertures approximate the effects of traditional hand chopping
12	1⁄2	
16	5⁄8	

GRINDING MEAT LIKE A PRO

A bit-and-plate grinder is the most useful tool for preparing forcemeats. But forcing meat and fat through the grinder in a haphazard fashion will never yield a good result. A skilled sausage maker selects a grinding plate that is sized appropriately for the task, keeps the cutting bit sharp and snug against the plate, and is mindful of the cutting temperature and how the meat and fat are working through the grinder.

Lean meat should be chilled to just below freezing so that it is firm but not solid. For best results, the meat should be ground separately from the fat.

For a less greasy sausage, grind the fat through a medium or small plate. Fat should also be partly frozen first to avoid melting and smearing.



The locking ring should be screwed tight to hold the plate firmly against the cutting bit. Otherwise, meat and fat will smear rather than cut, yielding a poor-quality sausage.

Meat extruded from the holes in the plate can be ground more finely later. Always grind meat through a medium plate first.

The auger pulls and compresses pieces of meat and fat, heating them in the process. Chilling the grinder head and cooling the meat and fat to just below freezing ensures the clean cutting essential for the highest-quality sausage.

The spinning bit (not visible) cuts cubes of meat or fat forced against the plate by the auger.

An unconventional approach to grinding or chopping is to freeze meat with liquid nitrogen, and then shatter it with a mallet to produce a heap of broken shards. When they thaw, the shards supply a texture that is interesting and unusual for forcemeats such as coarse-ground sausages, and for tartare as well (see page 64).

The bowl or Buffalo chopper is the butcher's tool of choice for making emulsified sausage batters. But if you don't make sausage in volume, you may be better off with a food processor.

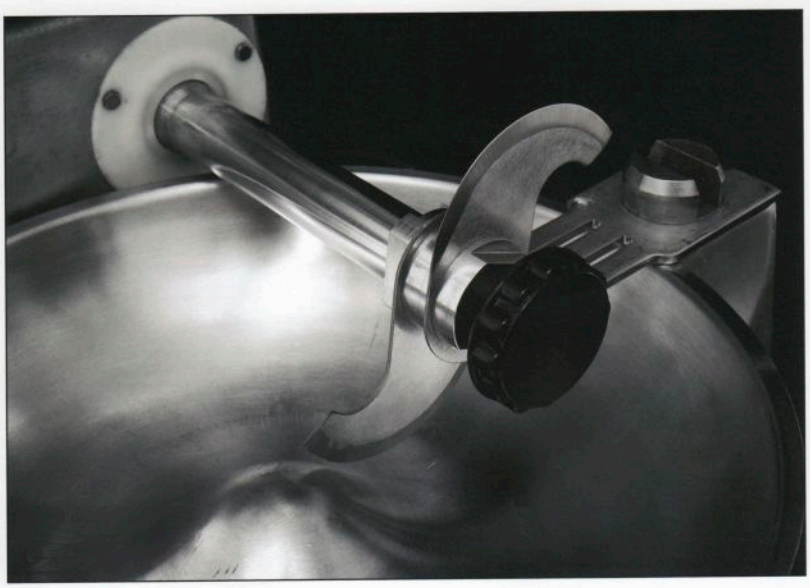
the stuffing cylinder. Be careful to avoid putting more air into the mix as you load the stuffer.

After stuffing, sausage can be linked (if desired) by tying off one end of the casing, and then gently pinching it between your thumb and forefinger at regular intervals. Give each pinch three or four twists. Alternate the direction of the twist (from clockwise to counterclockwise) from one pinch to the next so that the chain of links won't easily unravel.

Skilled sausage makers usually twist and fold the links over one another to string them together in groups of three. This technique keeps the links from unraveling and shortens the length of the strand, which makes it easier to hang in a walk-in refrigerator.

Sausage is not always put into casings. A terrine is formed in a pan or a mold, and some sausage is molded into free-form shapes such as patties or meatballs. Sausage may also be used as a stuffing for poultry or as the filling for ballotines.

Many fresh sausages are ready to cook and eat as soon as they have been made. But however you form your sausages, it's a good idea to hang them in the refrigerator overnight so that the meat mixture stiffens into a more stable mass for cooking. Once they have set, many emulsion-style sausages are precooked at a low temperature, and some sausages will be smoked.



Tools for Grinding or Chopping

The cutting, grinding, or chopping of meat (those processes collectively known as **comminution**) always represents a compromise between conflicting requirements. Ideally, you'd like to rip apart as many muscle fibers as possible for a tender and cohesive sausage, while leaving the fat cells intact. Alas, there is no good way to do both at once.

Complicating matters is the fact that grinding and chopping generate a large amount of frictional heat. The finer you mince the meat, the more of a problem this can become. Even if the average temperature of the meat rises just a little as it is ground, the peak heating at the cutting surfaces will be much higher. The blade can easily become hot enough to denature myosin. Too much frictional heating also causes the naked bits of fat to melt into oil and coalesce. Together these factors produce sausage that becomes crumbly and greasy when cooked.

For this reason, it's best to start with meat that is chilled to somewhere between –1.5 °C and 0 °C / 29 °F and 32 °F. The meat should be cold enough that it's very stiff—semifrozen, but not frozen solid. As long as the temperature of the mass of meat stays at or below 5 °C / 41 °F during grinding or chopping, the temperature at the cutting surface will not become unacceptably high.

Another excellent strategy for combating frictional heating is to supply whatever water the recipe calls for in the form of crushed ice, and freezing some of the water in the meat itself. Prechilling the grinder with a slurry of ice chips also helps to keep everything cool. Better yet, rinse the grinder periodically with liquid nitrogen; that is certainly the fastest way to bring its temperature down.

If you are grinding a large amount of meat, stop between batches to rechill the equipment as necessary. Be careful not to pour liquid nitrogen into the grinder when it is full of meat, however. Frozen meat could jam the grinder, or the sudden expansion of vaporizing nitrogen could cause an explosion.

During grinding, add water and other liquids to meat in the form of ice chips during chopping or grinding to help keep the mixture's temperature down. Sprinkling liquid nitrogen over the top of a meat batter will also cool it without diluting it. Just don't use so much that you freeze the batter.

Frictional heating is even more of a problem when you are making a meat puree than it is when you are grinding meat because so much interaction occurs between the blade and the meat. It is not uncommon to finish pureeing the sausage mixture and find that the blade is greasy. That means it has gotten hot enough to melt the fat—a bad omen that suggests the sausage is likely to "grease out" when cooked. To prevent this, grind the meat coarsely in a conventional grinder, and then chill it before the pureeing step.

If you are making emulsion-style sausage, you should grind the meat and the fat separately. Then, when the ground fat is added to the chopped meat, let the mixture warm a bit so that the protein coats the fat better. Keep temperatures below 15 °C / 60 °F to avoid destabilizing the mixture.

Even when you are not making emulsion-style sausage, it's still a good idea to grind fat and meat separately. The reason is that meat comes under a certain amount of pressure in a grinder. Muscle tissue is generally tougher than fat, so grinding it creates higher pressures. If the meat and fat are ground together, the more delicate fat gets distorted and squeezed. Many sausage recipes call for grinding fat and meat together, and you can often get away with it, but separate grinding usually yields better results.

The same is true for meats of different consistencies. Filler meats such as organ meats, lips, snouts, and the like should be ground separately from lean muscle meat and are usually ground very finely to avoid any adverse effect on texture. Even lean meats may be better ground separately. The beef and pork in kielbasa combine best, for example, if the beef is ground separately from the pork, and ground with a finer plate.

Meat grinding and chopping equipment ranges from simple hand-cranked units to enormous industrial machinery. In between, you'll find small commercial grinders and a variety of attachments driven by motorized countertop mixers.

Bit-and-Plate Grinders

The classic meat grinder contains a hopper and a worm screw or auger that, when rotated, forces the meat against a plate with holes in it (also known as the die). A blade or a bit attached to the end of the auger sweeps across the interior face of the plate, forcing meat through the holes. The diameter of

A food processor is the ideal tool for making meat batters for emulsified sausages. Stop the blade periodically and use a rubber spatula to mix in any material that sticks to the sides of the bowl.

A Pacojet beaker is a very convenient way to make meat batters, but extra measures may be needed to achieve adequate binding. Use phosphate, Activa, or both when making Pacojet-processed sausage.

the holes, which typically ranges from 2–16 mm / 1⁄16–5⁄8 in, largely controls the texture of the ground meat.

Most sausages (including hamburgers) are ground with a 4–6 mm / 3⁄16–1⁄4 in plate, although plates with larger holes are sometimes used for especially coarse-ground sausages, and very fine plates are recommended for grinding any filler meat being incorporated into a sausage. The smaller the holes, the larger the number of pieces created. A plate with 3 mm / 1⁄8 in holes, for example, yields more than 77,000 bits of meat for each kilogram passed through it.

For very fine grinding that borders on pureeing, it's usually best to start with a medium grinding plate, and then pass the meat through the grinder a second time by using a fine plate. Doing the grinding in stages not only reduces the stress on the machine but also minimizes excessive frictional heating that can ruin the result.

In any event, make sure the threaded collar that holds the plate against the cutting bit is screwed on tightly. A loose-fitting plate causes the rotating bit to stretch, tear, and smear meat and fat rather than cut them cleanly. The bit should sweep against the plate with no gaps or wobbles.

Hand-cranked grinders work more slowly than their motorized counterparts, and with hand cranking it is easier to avoid overloading the auger and compressing and stretching chunks of meat behind the bit and plate. If meat is fed in faster than it can be cut and extruded, then the auger repeatedly pushes and pulls on the meat, rupturing muscle fibers and increasing the amount of myosin extracted. This isn't always a bad thing, but it creates inferior textures in forcemeats such as hamburger patties, which are best when the pieces of meat are loosely bound together.

Bowl Choppers and Food Processors

To achieve a finer mixture than you can get with a meat grinder, you'll have to puree the meat. In butcher shops, the standard tool for this job is a device known as a "Buffalo chopper" or bowl chopper. It has an S-shaped blade that looks very much like the one in a food processor, but it is mounted vertically in a shallow bowl that slowly rotates to make sure all of the meat gets mixed.

A hand-cranked sausage stuffer can make excellent sausage. Motorized units are also available for high production but are much more difficult to control.

These machines are designed expressly for making emulsified sausage, and they do a good job, but unless you make large quantities of it on a regular basis, a food processor might be a better choice. The only problem with food processors is their mixing turnover; you must periodically stop the machine and use a rubber spatula to blend in any material stuck to the sides.

Pacojet

A very different approach to pureeing meat uses a Pacojet (see page 2·406), which can grind ingredients that are frozen solid. This machine is commonly used to prepare sorbets, ice creams, soups, or sauces, but it can also be used to puree meat. Place the pieces of meat and enough liquid to fill the spaces between them into the Pacojet beaker, and then put the filled beaker in a freezer. When "pacotized," the frozen meat will turn into a fine powder that has many uses (see page 62).

Frozen meat powder (or frozen fat powder) can be used to make a meat batter for emulsified sausages, but it will generally require more binding than the same mixture would if it were conventionally ground. There are several ways to increase the binding by extracting myosin, including presalting followed by refrigeration, tumbling (which speeds the extraction), and using phosphates. Perhaps the best way of all to enhance binding is to use the enzyme Activa.

Safety Issues

Grinding meat raises some important safety issues, even if you never go near a spinning blade. The interior of muscle meat is usually sterile, but grinding or chopping turns meat inside out and carries any pathogens that might be contaminating the meat surface into the interior. It also greatly increases the surface area of the meat, exposing more of it to oxygen, which tends to discolor the meat, makes fat go rancid more rapidly, and fosters the growth of many kinds of spoilage bacteria.

The best way to avoid these effects (and, not incidentally, to make sausage of the highest quality) is to grind meat shortly before use.

Don't overcook the sausage! Many recipes call for precooking emulsified sausages to at least 70 °C / 158 °F, owing perhaps to the misguided but widespread food-safety philosophy that prescribes temperatures alone (see page 1·182). All sausage should be cooked until pasteurized, but that can be accomplished at 55 °C / 130 °F, the baseline temperature we recommend. In general, we cook sausage the same way that we cook the meat it is made of: we aim for a core temperature that varies for each type of sausage but generally ranges from 55–60 °C / 130–140 °F. We hold the meat at that temperature long enough to pasteurize it. For holding times, see the table on page 1·184.

PARAMETRIC RECIPE

HAMBURGERS

The hamburger has a colorful past, reflected in the many ways ground beef has been prepared. Legend has it that 13th-century Mongol riders put patties of minced lamb or mutton under their saddles to tenderize the meat, and then ate it more or less raw. As the Mongols swept across Russia, their humble patties became steak tartare, a delicacy.

The citizens of Hamburg, Germany, imported tartare and began eating it in sandwiches. In the U.S., the first modern beef burger was reportedly served in 1885, either at the Outagamie Country Fair in Wisconsin or at the Erie Country Fair in Pennsylvania. Today, grilling burgers has become a form of pop art, but no one pays much attention to the preparation of the raw patties. The technique shown here yields a patty that quickly crumbles in the mouth—the hallmark of a succulent hamburger. We adapted it from Bernard Mense.

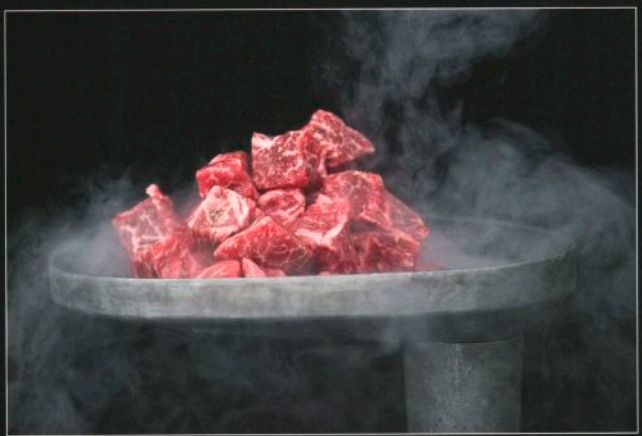
Best Bets for Burgers

Meat blend	Ingredients	(scaling)	Leanness (% fat)	Cook (°C)	Cook (°F)
rare beef	fillet mignon	100%	20	52	126
	rib eye cap	45%			
short rib	short-rib meat	100%	30	54	129
MC team favorite	short-rib meat	100%	25	56	133
	aged rib eye	100%			
	hangar	25%			
steak-house blend	chuck	100%	25	54	129
	sirloin	50%			
	flank	50%			

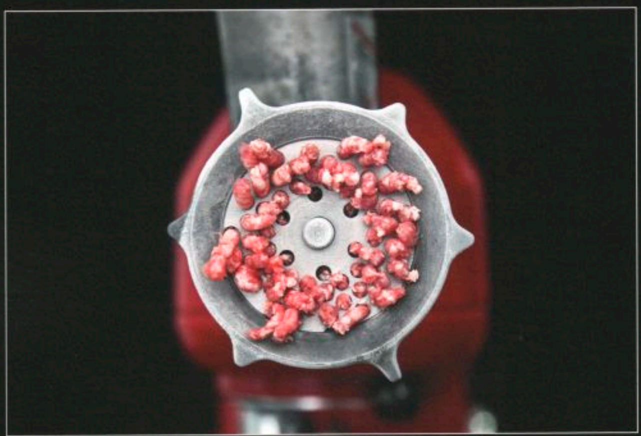
MAKING BURGERS

1 **Choose a blend of well-marbled meat, and chill the meat deeply.** The table Best Bets for Burgers lists several good options, each of which has a different flavor, texture, and cooking profile.

2 **Put ice cubes or liquid nitrogen in the grinder to chill it to just above 0 °C / 32 °F.**



3 **Cut.** Cut away any large chunks of fat from the meat, and cut into cubes about 2 cm / ¾ in on a side. Chill the meat to −1 °C / 30 °F. Do not salt the meat.



4 **Grind the cubes through a 3–4 mm / ⅛–³⁄₁₆ in plate.** (For tender meat blends, chop by hand, and then shape into a loose patty 3 cm / 1¼ in thick, and skip to step 9.) When using a grinder, tighten the collar to prevent mashing and tearing. Don't force the meat through the grinder; let the auger pull it through.

5 **Collect the extruded strands of ground meat in a cylindrical mold cut in half and lined with plastic wrap.** (Select a mold slightly wider than the diameter desired for the patties.) Slowly pull the mold toward you as the meat exits the grinder so that the strands run straight along the mold. Build up layers of strands to fill the mold.

6 **Repeat with a second mold, and then press the two molds together to form a complete cylinder of meat.**

7 **Use the surrounding plastic wrap to remove the meat from the mold.** Tighten the wrap slightly to gently compress the cylinder—but take care not to overtighten and mash the meat together, which will make the patties less tender. The meat cylinder can be frozen at this point, but then it will have to be sawed into patties.

8 **Use a sharp knife to cut hamburger discs of the desired thickness.** Remove the plastic wrap from the cut patties, and refrigerate them until cooking.

9 **Cook, season, and garnish.** See the recipes for Mushroom Swiss Burger on page 5·11 and for Sous Vide Hamburger on page 86.

When is the best time to add flavorful liquids and powdered seasonings to ground beef? Mixing them with the cubed meat before grinding is not the best approach because most additives bind the meat strands together. Seasonings containing salt, for example, extract the meat protein myosin, which forms a strong, elastic gel when cooked. That may be desirable in sausage making, but it produces a rubbery burger.

For the tenderest burgers, season the meat after you have cut it into patties. Avoid adding eggs, starches such as bread crumbs, or protein-laden liquids such as milk. During cooking, these ingredients gel and act like edible glue.

PARAMETRIC RECIPE

COARSE-GROUND SAUSAGES

Many kinds of traditional sausages blend coarse-ground meat and fat with water, spices, herbs, and other flavorful ingredients such as onion, garlic, or maple syrup. The trick in making such sausages is often getting them to hold together with the right consistency—you don't want the meat to fall out of its casing when cut, but neither should it be rubbery. By using Activa or polyphosphate as a binder, you can obtain just the firmness you prefer.

MAKING COARSE SAUSAGE

1. **Choose a recipe and a binding strategy, which will determine the pregrinding treatment if any—see page 328.** Depending on the strategy selected, add salt and any polyphosphates during this step. Add Activa, if needed, during step 3.

2. **Grind meat and fat separately (see page 328).** Before grinding, freeze the meat partially, and freeze the fat fully. Optionally, prepare a fat gel with fatty tissue or a rendered fat or oil, as described on page 348.

Best Bets for Coarse-Ground Sausages

Sausage recipe	Meat	(scaling)	Fat	(scaling)	Liquid	(scaling)	Spice and herbs	(scaling)
sweet Italian	pork shoulder	100%	pork fatback	25%	water	14%	sweet paprika	1.7%
							oregano, fresh	1.7%
							basil, fresh	1.7%
							fennel seed, cracked	1.1%
							coriander seed, finely crushed	0.6%
							hot pepper flakes (optional)	0.2%
							black pepper, coarse-ground	0.1%
British banger, adapted from Heston Blumenthal	pork shoulder	100%	pork fatback	50%	water	30%	black pepper	0.4%
							white pepper	0.4%
							mace	0.3%
							nutmeg	0.3%
							ginger powder	0.1%
Kielbasa	pork shoulder	100%	pork fatback	30%	water	20%	marjoram	0.50%
Kminkowa	pork shoulder	*(80%)**	pork fatback	35%			caraway, coarsely ground	0.35%
	beef chuck	*(20%)**					white pepper	0.20%
breakfast-style	pork shoulder	100%	pork fatback	35%	water	16%	sage	0.70%
	duck breast, skinless	100%	whole duck skin	50%			black pepper	0.20%
							ground ginger	0.15%
cotechino	pork shoulder	100%	pork jowl fat	60%	water	5%	wild fennel seed	0.30%
							rosemary	0.20%
							lemon zest, finely grated	0.10%
merguez	lamb shoulder	100%	pork fatback	22.5%	water	6%	sweet paprika, smoked	0.80%
							oregano	0.80%
							hot pepper flakes	0.30%
							black pepper	0.25%
Thai chicken inspired by David Thompson	chicken thigh	100%	chicken skin and fat	20%	fish sauce	5%	lemongrass	1.1%
			pork fatback	20%	soy sauce	1%	cilantro	1.0%
							galangal	0.6%
							makrud lime leaves	0.6%
							dried Thai red chili	0.2%
							long pepper	0.1%
							cassia	0.1%

*(*set total weight of pork shoulder and beef chuck to 100%*)

3 **Combine the ground meats and fats with liquid, spices, and fresh herbs, plus other ingredients in a kitchen stand mixer.** The spices should be finely ground, and the herbs finely minced. If using Activa, add it now.

4 **Mix at low speed with a paddle mixing blade.** Keep mixture below 15 °C / 59 °F.

5 **Perform a poach test (see page 325) to check that the sausage binds properly.** If binding is insufficient, add polyphosphate or Activa (but not both)—each yields a somewhat different texture. If binding is too strong, add water (up to a few percent) or fillers such as bread crumbs.

6 **Form, mold, or stuff, as discussed on page 340.**

7 **Cook in a water bath to the core temperature indicated in the table.** Note that vacuum sealing the meat will affect the cooked texture.

Polyphosphate blend refers to Nutrifos 088 or a similar proprietary blend of polyphosphate salts formulated for sausage recipes. Using a tripolyphosphate blend produces a highly cohesive and elastic texture, whereas using Activa yields a firm but more crumbly texture.

Polyphosphate blend and Activa are typically used at less than 0.1% and 0.25%, respectively, of the total weight of the sausage. The baker's percentages given in the table are equivalent to these concentrations.

Pork shoulder is normally 25% fat. It can be replaced with lean meat (leg, loin, neck) and fat at a ratio of 3 parts meat to 1 part fat. This substitution will affect binding strength and may require adjusting the binding strategy used.

Other Ingredients	(scaling)	Salt (scaling)	Binder (optional, select one)	(scaling)	Cook (°C)	Cook (°F)	Note
sugar	2%	3.2%	Activa	0.25%	58	136	
			polyphosphate blend	0.10%			
white bread, toasted	10%	3%	Activa	0.175%	58	136	Toast bread at 170 °C / 340 °F until dry and golden brown, about 30 min.
grain mustard	4%		polyphosphate blend	0.070%			
Tate & Lyle Golden Syrup	2%						
garlic, finely minced	0.50%	3%	Activa	0.175%	55	131	Grind using a 2 mm / 1⁄16 in plate. Dry sausages for 2 d at 2–6 °C / 35–42 °F and 85% relative humidity. Smoke for 1–2 d at 10 °C / 50 °F and 85% relative humidity.
Insta Cure No. 1	0.25%		polyphosphate blend	0.070%			
sugar	0.45%						
maple syrup, smoked	3%	2.6%	Activa	0.25%	59	5	
sweet onion, finely chopped	2%		polyphosphate blend	0.10%			
whole green lentils, cooked	40.0%	3.8%	Activa	0.25%	57	135	
Parmesan, grated	4.5%		polyphosphate blend	0.10%			
roasted red pepper, minced	8.00%	2%	Activa	0.25%	55	131	
garlic, minced	1.40%		polyphosphate blend	0.10%			
sugar	0.25%						
shallot, finely minced	3.0%	2.3%	Activa	0.25%	60	140	Mix finely ground spices and herbs with shallot, coconut, and garlic to make a paste.
fresh coconut, finely grated	3.0%		polyphosphate blend	0.10%			
garlic, finely minced	1.0%						

(binder selections in orange are those we prefer)

PARAMETRIC RECIPE

EMULSION-STYLE SAUSAGES

Making emulsified sausage is more complex than making coarse sausage because you must ensure that the protein gel traps the fat; otherwise, it will leak out when cooked. An alternative to using fatty tissue directly is to pre-emulsify oil, rendered fat, or the fatty tissue.

EMULSIFYING A SAUSAGE MIX

1. **Choose a recipe from the table of Best Bets below.**

2. **Grind meat and fat separately, as described on page 328.** Use a pretreatment for the meat, which will affect binding ingredients.

3. **Puree ground meat in a food processor or bowl chopper.** Keep the temperature below 15 °C / 59 °F. Add liquids chilled or frozen to keep meat cool. Optionally, sprinkle the meat with liquid nitrogen to chill it.

Best Bets for Emulsion-Style Sausages

Sausage variety	Meat	(scaling)	Fat	(scaling)	Liquid	(scaling)	Spices and herbs	(scaling)
blood sausage	n/a		pork fatback, small dice and blanched foie gras fat, rendered	42% 16%	pork blood whole milk Calvados (or applejack)	100% 20% 8%	bay leaf, powdered	0.3%
bratwurst	pork shoulder veal shoulder	100% 33%	pork fatback	52%	whole milk heavy cream	9% 9%	white pepper ginger powder nutmeg	0.5% 0.3% 0.3%
boudin blanc, chicken	chicken thigh	100%	rendered chicken fat pistachio oil	33.0% 8.5%	infused milk (see page 103) alcohol reduction (see note)	107% 3.7%	quatre épices (see page 2·403)	0.2%
boudin blanc, veal or blend	veal shoulder (or chicken/veal mix)	100%	veal jowl fat pistachio oil	33.0% 8.5%				
frankfurter, all beef	beef chuck	100%	beef fat	55%	water	40%	liquid smoke (optional) mustard powder onion powder sweet paprika white pepper coriander seed nutmeg	1.50% 1.25% 1.00% 1.00% 0.25% 0.20% 0.10%
frankfurter	beef chuck pork leg	*(65%)** *(35%)**						
ham and cheese	pork shoulder	100%	Gruyere cheese, grated	35%	water	35%	n/a	
mortadella	pork shoulder	100%	pork fatback, blanched (see note)	100%	water white wine (dry)	60% 7%	white pepper coriander seed garlic powder nutmeg cinnamon	0.35% 0.30% 0.25% 0.10% 0.10%
shellfish	scallop, shrimp, or lobster	100%	n/a		heavy cream alcohol reduction (see note)	55% 15%	chervil chive tarragon white pepper star anise	1.0% 1.0% 1.0% 0.1% 0.1%

**(set total weight of beef chuck and pork leg to 100%)*

4 **Add the fat, and continue to puree.** Keep the mixture cold.

5 **Chop or fold in the spices and fresh herbs, plus other ingredients.** The spices should be finely ground, and the herbs finely minced.

6 **Do a poach test (see page 325).** Adjust the binder as needed.

7 **Stuff or mold the sausage.**

8 **Smoke the sausage (optional).** For best results, the wet-bulb temperature should not exceed 56 °C / 132 °F during smoking.

9 **Cook sous vide or steam at temperature indicated.** To pasteurize, hold at cooking temperature for time indicated on page 1·184. Plunge into cold water or use a cold-water shower.

10 **Peel sausages if they are in removable casings.**

Other ingredients	(scaling)	Salt (scaling)	Binder	(scaling)	Cook (°C)	Cook (°F)	Note
onions, minced chesnut puree (store-bought) fine breadcrumbs apple, small dice chestnut flour	100% 20% 13% 10% 5%	5.4%	Activa RM	0.6%	82	180	Combine flour, puree, milk, and half of the foie gras fat. Bring to boil. Chill. Emulsify blood into mixture, and reserve. Sweat apples and onions in remaining foie gras fat until very tender. Deglaze with Calvados. Chill. Combine apples and onions with fatback, bread crumbs, Activa, and seasonings. Fold in blood, and mold. Before cooking, blanch in boiling water for 1 min.
whole egg soy protein concentrate	8.5% 7.0%	5%	n/a		55	130	
egg white egg yolk Sicilian pistachios black truffles, optional	16.2% 4.4% 11.0% 7.0%	4.4%	n/a		61	142	For alcohol reduction, combine 14.7% cognac, 11% Madeira, and 3.7% white port, and reduce to one-eighth of starting volume.
glycerin monostearate skim milk powder Insta Cure No. 1 dextrose	2.00% 1.85% 0.15% 0.20%	4.5%	Activa or polyphosphate blend (not both)	0.22% 0.09%	60	140	For hot-smoked version, air-dry for 30 min after stuffing. Smoke for 90 min at 70 °C / 158 °F and 85% relative humidity. Poach at 70 °C / 158 °F to core temperature of 68 °C / 154 °F. Plunge in cold water for 2 min. Refrigerate until cold, and peel.
sodium citrate pullman loaf, frozen (see note)	0.2% as needed	4%	n/a		55	130	Add sodium citrate to boiling water, and blend in cheese until smooth. Cool. Blend with meat. Slice frozen bread very thinly. Wrap cooked, uncased sausage in bread slice, and fry in butter until crisp.
Sicilian pistachios, peeled Micro crystalline cellulose (Avicel CG 200, FMC BioPolymer brand) Insta Cure No. 1	18% 7% 0.55%	4.6%	Activa	0.25%	55	130	Reserve 25% of pork fatback, and cut into 1 cm / ½ in cubes. Blanch in boiling water for 10 s, and then cool. Fold into the sausage mix along with the pistachios before stuffing.
whole egg sodium caseinate	11.0% 0.4%	2.5%	n/a		65	149	For alcohol reduction, reduce two parts dry sherry and one part cognac by half, and cool completely.

HOW TO Form and Finish a Sausage

STUFFING

Prepared sausage mix should be stuffed promptly because it quickly becomes firm and difficult to stuff. Fresh sausages are usually stuffed into natural casings that have been preserved in salt. The casings should be rinsed in water for 30 minutes to wash out the salt and make them pliable. Stuffing is done by packing the sausage mix into a canister and using a piston to force it out a tapered tube, called the horn, that holds the casing. How quickly the casing is allowed to slide off the horn controls how fully the sausage is stuffed. It is important to avoid creating air pockets because the meat will discolor around them; they also fill with water and create a hospitable environment for spoilage-causing bacteria. Eliminate any bubbles by pricking the sausage with a needle and forcing the air out.

LINKING

There are many, many ways to link sausage. Indeed, whether and how it is linked are often defining characteristics of a sausage variety. The easiest method is to pinch and twist the stuffed casing at equal intervals along its length, alternating the direction of the twist. More elaborate techniques involve folding links over one another to shorten the length of the chain, making it easier to hang for setting, drying, and smoking.

SETTING AND DRYING

Often overlooked, this is an important step in sausage making. While refrigerated overnight, the abundant salt in the mix causes the pieces of ground or chopped meat to absorb any free-flowing liquid, firming the sausage and stabilizing it for a more cohesive result when cooked. The surface drying that occurs while sausages hang (or sit on a rack) is also important for getting a good result if the sausages will be smoked.

SMOKING OR COOKING

Many traditional fresh sausages are cold-smoked at 10–20 °C / 50–68 °F for 1–14 d. These should still be considered a raw product that must be cooked to be safe to eat. Hot-smoking for a few hours is also common. This strategy will impart some smokiness to a sausage and, at the same time, fully cook the sausage. Of course, smoking can be skipped, and fresh sausage can just be cooked. However the cooking is done, a combination of temperature and time suitable for pasteurization (see page 1·184) is essential.

VARIATION: Molding with Plastic

Casings are not an essential feature of sausage. If made well, a cooked sausage should be cohesive—either from meat proteins that form a gel, which holds everything together, or from added binders that do the same. Thus, a casing only serves to hold a well-made sausage together while it cooks and can be stripped away afterwards, as those on traditional sausages like frankfurters are. Using plastic wrap or sous vide bags to mold the sausage mix into links is an easy way to avoid the hassle of sausage stuffers and salted casings. However, be sure to use polyethylene-based plastic wraps, not inexpensive PVC-based wraps. The high fat content of sausage means it will readily absorb some of the undesirable compounds in PVC plastics (see page 2·206).

VARIATION: Stuffing with a Whipping Siphon

Although large air bubbles can be a nuisance in sausage making, aerating a sausage batter is a classic way to get a sausage to "plump" during cooking as the numerous small bubbles swell in size just before the sausage mixture gels. Traditionally, aeration has been done by whipping egg whites and folding a wet sausage batter into the egg-white foam before stuffing. A smooth batter that is suitably loose from added liquid can also be aerated with a whipping siphon. Foaming the mixture stiffens it enough to be stuffed, and when cooked the multitude of extrafine air bubbles will plump the sausage up and give it an incredibly delicate and tender texture.

VARIATION: Molding with Activa

Although many chefs think of it as a Modernist ingredient, Activa was originally devised for meat preparations. With it, you can form a sausage without the need for a casing of any kind, including plastic wrap. Activa even makes it possible to mold forcemeat mixtures into unusual shapes. Simply blend 0.25% Activa (TI or RM are both suitable) into the sausage mix when blending in seasonings. Pack the prepared sausage mix into a mold, and refrigerate it overnight before cooking. The Activa will form a gel that holds the meat together without a casing.

VARIATION: Flattening into Sheets

Thin sheets or slabs of sausage can be made by using sous vide bags as a temporary casing. Vacuum pack the sausage mix or batter in a sous vide bag. Use a rolling pin to flatten the sausage into an even slab or sheet. For coarse or emulsified sausage, cook (or precook) as usual at 56 °C / 132 °F for 2 h or by using some other time-and-temperature combination. For fast-fermented sausage, ferment sous vide, and precook. Carefully cut away the edge of the bag, and unpeel it to free the completed sausage sheet or slab. The thinner you make the sausage sheet, the more binder you may need to hold the sausage together. Extra phosphate or Activa will help accomplish this objective.

EXAMPLE RECIPE

ITALIAN SAUSAGE

Yields 1.8 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pork shoulder, cubed and chilled to -1 °C / 30 °F	1 kg	100%	① Chill coarse grinder die and extruder bowl. ② Grind pork shoulder and fatback separately through chilled die into chilled bowl. Keep forcemeat chilled.
Pork fatback, cubed and frozen	300 g	30%	③ Fold ground meat and fat together, and reserve.
Ice water	140 g	14%	④ Finely mince fresh basil and oregano.
Salt	20 g	2%	⑤ Grind fennel seeds and toasted coriander seeds to fine powder.
Sugar	20 g	2%	
Basil	17 g	1.7%	⑥ Coarsely grind peppercorns.
Hungarian paprika	17 g	1.7%	⑦ Combine seasonings, and fold into forcemeat.
Oregano	17 g	1.7%	
Fennel seeds, toasted	11 g	1.1%	
Coriander seeds, toasted	6 g	0.6%	
Hot pepper flakes	2 g	0.2%	
Black peppercorns	1 g	0.1%	
Hog casings, 32–35 mm / 1¼–1⅜ in. in diameter	as needed		⑧ Stuff seasoned forcemeat into casing. ⑨ Twist links to desired lengths. ⑩ Refrigerate sausages for at least 1 h. ⑪ Poach or steam sausages at 61 °C / 142 °F until core temperature reaches 60 °C / 140 °F, about 25 min.

(2009)

EXAMPLE RECIPE

FRANKFURTER

Yields 2.2 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beef chuck, cubed and chilled to -1 °C / 30 °F	1 kg	100%	① Chill fine die and extruder bowl. ② Grind beef chuck and fat separately.
Beef fat, cubed and frozen	550 g	55%	③ Puree ground meat and ice until smooth.
Ice, crushed	400 g	40%	④ Add fat, and continue to puree until smooth. ⑤ Reserve ground meat mixture chilled.
Salt	33 g	3.3%	⑥ Grind nutmeg, white pepper, and toasted coriander seeds to fine powder.
Skim milk powder	18.5 g	1.85%	
Mustard powder	12.5 g	1.25%	⑦ Fold spices and additives into cold ground-meat mixture.
Onion powder	10 g	1%	
Sweet paprika	10 g	1%	
Nutmeg	5 g	0.5%	
Insta Cure No. 1	3.3 g	0.33%	
White pepper	2.5 g	0.25%	
Glycerin monostearate (4mular brand)	2.2 g	0.22%	
Coriander seeds, toasted	2 g	0.2%	
Dextrose	2 g	0.2%	
Sheep casing, 2 cm / ¾ in. in diameter	as needed		⑧ Stuff forcemeat paste into casing. ⑨ Twist links to desired lengths. ⑩ Refrigerate sausages for at least 1 h. ⑪ Poach or steam links at 61 °C / 142 °F to core temperature of 60 °C / 140 °F, about 25 min.

(2009)

The sausages can be cold-smoked at 10 °C / 50 °F for 24 h or hot-smoked at 52 °C / 125 °F for 12 h. See page 208 for details on smoking.

For a novel freeze-frying finishing procedure, see page 86.

EXAMPLE RECIPE

BOUDIN BLANC

Yields 2 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
1% milk	750 g	103%	① Vacuum seal together.
Button mushrooms, thinly sliced	75 g	10%	② Cook sous vide in 85 °C / 185 °F bath for 1 h. ③ Strain.
Clarified unsalted butter	50 g	7%	④ Measure 725 g of infused milk, and reserve refrigerated.
Sweet onions, thinly sliced	50 g	7%	
Dried morels, ground to powder	5 g	0.7%	
Bay leaf	0.75 g	0.1%	
Thyme	0.5 g	0.07%	
Cognac	100 g	14%	⑤ Combine, and reduce to 25 g.
Madeira wine	75 g	10.5%	⑥ Cool completely, and reserve.
White port	25 g	3.5%	
Infused milk, from above	725 g	100%	⑦ Puree until smooth, while keeping temperature below 7 °C / 45 °F.
Chicken thighs, finely ground	680 g	94%	⑧ Refrigerate for 10 min.
Egg whites, blended	110 g	15%	
Egg yolks, blended	30 g	4%	
Salt	30 g	4%	
Quatre épices see page 2·403	1.5 g	0.2%	
Rendered chicken fat	227 g	31.5%	⑨ Blend into chilled chicken puree until fully emulsified.
Pistachio oil	58 g	8%	⑩ Optionally, for aerated texture, transfer mixture to 1 l whipping siphon and charge with two cartridges of nitrous oxide. Omit the added pistachios and truffles pieces in step 11.
Green Sicilian pistachios, quartered	75 g	10.5%	⑪ For regular boudins, fold into mixture to make forcemeat.
Black truffles, optional finely minced	50 g	7%	
Natural casings, 4 cm/ 1½ in. in diameter	as needed		⑫ For aerated texture, shake siphon vigorously, and dispense forcemeat directly into casings. ⑬ For regular boudins, stuff casings with forcemeat.
Frying oil	as needed		⑭ Poach or steam sausages (boudins) at 61 °C / 142 °F to core temperature of 60 °C / 140 °F, about 35 min. ⑮ Puncture membrane of sausage with needle in several places to prevent explosion. ⑯ Sear boudins in oil until evenly golden and slightly puffed.

(2008)

If not using a siphon, whip the egg whites separately. Fold the emulsified mixture into the whipped egg whites, and stuff.

Fried Chicken Sausage, page 349

PARAMETRIC RECIPE

FERMENTED SAUSAGE

Fermented sausages use the action of bacteria, yeasts, and molds to both preserve and flavor meat. Making a fermented sausage is much like making coarse fresh sausage but is simpler because you don't need to worry as much about binding.

You control the fermentation, which happens after stuffing, by controlling the temperature, the bacterial cultures, and the carbohydrates added to feed the microbes. There are three approaches: slow, medium, and fast. Slow methods, which use cool temperatures of 15–25 °C / 59–77 °F and 70%–80% relative humidity, take days, weeks, or even months to complete, but they produce traditional dry sausages that do not require refrigeration. Like medium fermentation, which uses somewhat higher temperatures, the slow method requires the use of an incubator that controls both temperature and humidity. Laboratory incubators or industrial environmental chambers (used to test electronics) also work.

Fast fermentation, which uses much higher temperatures of 30–45 °C / 86–113 °F, is more convenient because it typically finishes in just a day or two, and you can use sous vide methods to incubate the mixture. Regardless of the fermentation speed, if the result is not adequately dried, it requires refrigeration at or below 12 °C / 54 °F. Additional drying or smoking can be done after fermentation is complete.

FERMENTING SAUSAGES

1 **Select a sausage recipe and a fermentation approach.** The table Best Bets for Fermented Sausages below lists several good options, and the Fermentation Methods table at right suggests cultures and parameters for slow, medium, and fast methods.

2 **Select a culture and a curing salt.** We recommend Bactoferm F-LC culture, which works for all three approaches; for slow-fermented sausages, Bactoferm T-SPX produces a more traditional flavor. Follow manufacturer's instructions for rehydrating the culture before use. Use the curing salt indicated in the table on the next page.

3 **Grind trimmed meat and fat separately.** For details, see page 328. Recommended grinding plate dimensions are given in the table below.

4 **Combine all ingredients.** To avoid degrading the activity of the culture, mix the curing salt, carbohydrates, and seasonings into the meat thoroughly before adding the culture. Add the salt and fat last. Quantities in the recipes below are given relative to the principal meat used. For example, when making chorizo add 3 g salt, 0.3 g curing salt, 0.02 g culture, and 25 g fatback to every 100 g of pork shoulder. Use a stand mixer with a paddle mixing blade; run the mixer at low speed.

5 **Stuff.** Stuff the sausage mixture into casings of the dimensions indicated in the table.

Best Bets for Fermented Sausages

Sausage	Meat	(scaling)	Fat	(scaling)	Grind (mm)	Grind (in)	Salt (scaling)	Curing salt (scaling)	Culture (scaling)
salami	pork shoulder beef, chuck	100% 40%	pork fatback	25%	5 2	3⁄16 1⁄16	4.2%	0.4%	0.03%
saucisson sec	pork shoulder	100%	pork fatback	35%	5	3⁄16	3.0%	0.3%	0.02%
pepperoni	pork shoulder beef chuck	100% 42.5%	pork fatback	40%	5	3⁄16	5.1%	0.4%	0.02%
chorizo	pork shoulder	100%	pork fatback	25%	8	5⁄16	3.0%	0.3%	0.02%
lap cheong	pork shoulder	100%	pork fatback	20%	10	3⁄8	3.0%	0.3%	0.02%

Fermentation Methods

Method	Curing salt	Ferment				Dry			
		(°C)	(°F)	(d)	(%RH)	(°C)	(°F)	(%RH)	(d)
Slow, dried	Insta Cure No. 2	18	64	10	85	12	54	70	25–40
Medium, semidried	Insta Cure No. 1	24	75	3	85	15	59	70	10–25
Fast, fresh	Insta Cure No. 1	37	100	1	100	n/a	n/a	n/a	n/a

Fast fermentation lowers the pH of the sausage more quickly and further by using fast-acting cultures that work at higher temperatures, but require higher sugar content. And provided the food is refrigerated, you can skip the lengthy drying step.

6 **Ferment by holding at the temperature, relative humidity (%RH), and time indicated in the table above.**

7 **Smoke, dry, or both (optional).** Dry at the temperature and humidity shown in the table above until sausage has lost at least 25% of its original wet weight for semidried, or about 50% for dried sausage; approximate times are listed in the table above. To encourage a coating of mold to grow on the outside of the casing, dip the sausages into a solution of Christian Hansen M-EK-4 mold culture before drying. For more information about smoking meat, see page 208.

VARIATION: Fermenting Sous Vide

1 **Follow steps 1 to 5 on the previous page.**

6a **Vacuum seal sausages together in a single row.** Be careful not to squish the sausages when sealing them in the bag.

6b **Ferment sous vide in a water bath, combi oven, or water-vapor oven at the desired temperature—usually 37 °C / 100 °F—for 1 d.**

6c **Pasteurize at 55 °C / 130 °F for 2–3 h (optional).**

6d **Cool.** The sausages must be refrigerated.

7 **Vacuum dry, or dry conventionally at the temperature, humidity, and time indicated in the table above (optional, see page 2·433).** Drying can simulate the texture of a sausage made with the traditional, slow-dried approach.

Carbohydrate	(scaling) (slow/medium/fast)	Seasonings	(scaling)	Casing (mm)	Casing (in)
dextrose	0.35%/0.7%/1.1%	black pepper, coarsely ground	0.15%	75	3
		garlic, finely minced	0.10%		
dextrose	0.25%/0.5%/0.75%	hazelnuts, peeled, roasted, and coarsely chopped (optional)	9.0%	75	3
		black pepper, coarsely ground	0.7%		
		garlic, finely minced	0.1%		
dextrose	0.35%/0.7%/1.1%	red chili powder	1.25%	60	2⅜
		hot paprika	1.10%		
		allspice	0.75%		
		cayenne (optional)	0.50%		
		black pepper	0.50%		
dextrose	0.25%/0.5%/0.75%	hot pimentón de la Vera	0.7%	33	1⁵⁄₁₆
		Ancho chili powder	0.7%		
		cayenne pepper	0.2%		
		garlic, finely minced	0.2%		
dextrose	0.25%/0.5%/0.75%	soy sauce	3.00%	20	¾
		Shaoxing wine	1.00%		
		monosodium glutamate	1.00%		
		cassia, finely ground	0.15%		

We have chosen to use bacterial cultures supplied by the Christian Hansen company. The kind and quantity of fermentation sugars have been tailored to the culture listed. If you are using a different fermentation culture, adjust the kind and quantity of sugars as advised for that specific culture.

Lap cheong sausages ferment while cold-smoking for 6 h at a dry-bulb temperature of 45 °C / 115 °F and 70% relative humidity (wet-bulb temperature of 38 °C / 100 °F).

The technique of using bacterial fermentation to prevent meats from spoiling is thought to have been invented in China 2,000 years ago. Fermented sausages didn't become widespread in Europe until around 1700. They reached the United States along with the waves of European immigrants who arrived in the early 20th century.

The Christian Hansen company produces cultures in its Bactoferm product line for many styles of fermented sausage.

Letting ground meat sit awhile, as butchers and industrial meat processors commonly do, gives pathogens and spoilage bacteria time to grow and rancid flavors time to develop.

Because contaminants may be mixed throughout ground meat or any dish containing it, the meat should be cooked so that its core becomes fully pasteurized. The time-and-temperature combinations required to do so are given in chapter 3 on Food Safety, in tables beginning on page 1·184.

Fermented Sausages

In the 1940s, food scientists began to understand the role of fermentation in the preparation of sausage. They transformed a once-secret art into a highly technical science. We can offer only a broad overview of that science here, but that is enough to understand the recipes we include for fermented and dried sausages on the two previous pages and on the next two pages.

The basic process of grinding, mixing, and stuffing is essentially the same for fermented sausages as it is for coarse-ground fresh sausage. Pregrinding is not needed. Meat and fat are ground separately, and the freeze-dried starter culture is revived in room-temperature water. The fermentation cultures used in sausage making consist mainly of bacteria that produce lactic acid and other flavorful organic acids. If nitrate-containing curing salts are used, other kinds of bacteria are also required to convert nitrate into nitrite.

The ground meat and fat and the starter culture are combined with salt and other ingredients. Carbohydrates must be added to feed the bacteria, which do not consume meat. This ingredient is important because if too little is added, the culture starves, and spoilage bacteria may take over. A glucose (dextrose) dose of 0.5%–1% of the meat weight usually works well.

Some recipes call instead for starch or powdered milk, which contains lactose. Bacteria consume these more slowly, so it takes more time for the pH to drop. This delay affords more time for the characteristic fermented flavor to develop, but it also allows potentially harmful bacteria to grow. So choosing the carbohydrate source is a balancing act. Many sausage makers use a blend of sugar sources, adding a little dextrose for an early pH drop as well as some starches or complex sugars to let slow, steady fermentation finish the job.

Historically, fermented and dried sausages were only made in temperate parts of the world, usually during cooler times of the year. The seasonal approach was prevalent because, during fermentation, the ambient temperature must remain at 15–25 °C / 59–77 °F. This temperature range promotes the growth of beneficial bacteria, which stops at lower temperatures, and suppresses the growth of spoilage bacteria.

Creating good fermented sausage thus requires a temperature- and humidity-controlled space for fermenting and drying during many months of the year. Today, you can either improvise a fermentation cabinet or buy one made for the purpose.

A variation on traditional, slow-fermented, dry sausage is fast-fermented, semidry sausage made with cultures that ferment at higher temperatures for much shorter times. This approach was traditionally used during warmer seasons. Fast-fermented sausages are much quicker to make, and the incubation can be done sous vide in a water bath at 30–45 °C / 86–113 °F. The exact time-and-temperature combination depends on the particular sausage, culture, and recipe involved. Fast-fermented sausages are not fully dried and must be refrigerated to prevent spoilage.

Semidry sausages have a much higher moisture content and a much lower concentration of salt

The powdery white coating present on some fermented sausages comes from a mold that is applied to the sausage exterior. Metabolic products of the mold also contribute flavor.

EXAMPLE RECIPE

SAUCISSON SEC

Yields 1.5 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pork shoulder, cubed and chilled to -1 °C / 30 °F	1 kg	100%	① Chill grinder extruder bowl, coarse die, and 3 mm / ⅛ in fine die. ② Grind pork shoulder and fatback separately through chilled coarse die into chilled bowl.
Pork fatback, cubed and frozen	250 g	25%	③ Grind both separately through chilled fine die into chilled bowl. ④ Fold ground meat and fat together, and reserve chilled.
Garlic	13 g	1.3%	⑤ Blanch once in boiling water, drain, and mince. Reserve.
Pork fatback	100 g	10%	⑥ Freeze, and cut into small dice. Reserve frozen.
Hazelnuts, roasted, peeled, and chopped	90 g	9%	⑦ Fold minced garlic, nuts, dextrose, pepper, and Insta Cure into chilled ground pork to make forcemeat.
Dextrose	10 g	1%	
Black pepper, coarsely ground	7 g	0.7%	
Insta Cure No. 2	2.5 g	0.25%	
Bactoferm F-RM 52 (Christian Hansen brand)	11.25 g	1.125% *(0.7%)**	⑧ Whisk bacterial culture into water at **20** °C / **68** °F to make slurry. ⑨ Fold into forcemeat, and mix thoroughly to evenly distribute slurry.
Distilled water	35 g	3.5%	⑩ Fold in frozen fat and salt.
Salt	35 g	3.5%	
Synthetic casings, 3 cm by 61 cm / 1¼ in by 24 in	as needed		⑪ Stuff meat into casings, then twist into 25 cm / 10 in links; tie ends with butcher's twine. ⑫ Dip sausages into distilled water to moisten surface, and immediately hang in fermentation chamber or other controlled-atmosphere chamber. ⑬ Ferment at **22** °C / **72** °F and 90% relative humidity for 3 days. A thin film of bacterial growth may form on the surface of the sausage casing. ⑭ Hang sausages in cool room at **12** °C / **54** °F to dry for 3–4 wk, until sausages have lost 25%–40% of their original weight. The more water weight sausages lose, the denser they become.

(2008)

(% of total weight of meat and fat*)

EXAMPLE RECIPE

FAST CURED PEPPERONI

Yields 1.5 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Bactoferm F-LC (Christian Hansen brand)	0.85 g	0.085% *(0.05%)**	① Whisk bacterial culture into water at **20** °C / **68** °F to make slurry. Reserve.
Distilled water	10 g	1%	
Pork shoulder, cubed and chilled to -1 °C / 30 °F	1 kg	100%	② Chill grinder extruder bowl and 3 mm / ⅛ in fine die. ③ Dry-blend seasonings except salt.
Beef chuck, cubed and frozen	425 g	42.5%	④ Toss the cubed meat with seasoning powder.
Pork backfat, cubed and frozen	400 g	40%	⑤ Cover, and refrigerate for 3 h. ⑥ Grind seasoned meat and fat separately into chilled bowl.
Salt	51 g	5.1%	⑦ Stir culture slurry into meat until evenly distributed, and fold in fat and salt.
Dextrose	17 g	1.7%	⑧ Vacuum seal mixture, and hold at **38** °C / **100** °F for 24 h.
Sugar	17 g	1.7%	⑨ Optionally, to make pepperoni sheets, add 0.25% Activa RM to weight of meat, and roll the mixture in a sous vide bag into a sheet 1 mm / 1/32 in thick (see page 2·208).
Red chili powder	12.5 g	1.25%	
Smoked paprika	11 g	1.1%	⑩ Cook sous vide in **55** °C / **131** °F bath for 10 min.
Lactic acid	8.5 g	0.85% *(0.5%)**	⑪ To make quick-dried pepperoni stick, form the forcemeat into 1 cm / ⅜ in diameter sticks.
Allspice, powder	7.5 g	0.75%	⑫ Cook sous vide in **55** °C / **131** °F bath for 25 min.
Black pepper, powder	5 g	0.5%	⑬ Vacuum dry for 8–24 h (see page 2·433) or air dry refrigerated for 2–3 days until desired texture is achieved.
Cayenne	5 g	0.5%	
Insta Cure No. 1	3.5 g	0.35% *(0.2%)**	

(2010)

(% of total weight of meat*)

MODERNIST SAUSAGES

In sausage making, tradition reigns supreme. But with Modernist techniques, you can make sausages that are not possible when using an "old school" approach. The recipes here use gels to stabilize fat, create emulsified sausage with oils or rendered fats, make low-fat sausage, and even produce sausages that have the flavor of rare beef or fried chicken.

EXAMPLE RECIPE

COARSE FAT-GEL SAUSAGE

Yields 420 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pork fatback	70 g	100%	① Cut into medium-size cubes. ② Vacuum seal, and heat to 70 °C / 158 °F.
Sodium caseinate	5 g	7%	③ Disperse gellan and sodium caseinate in water, and blend.
Water	70 g	100%	④ Bring to simmer.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	0.7 g	1%	⑤ Blend in warm fat cubes until fully emulsified. ⑥ Continue blending for 3 min until mixture forms bright-white fat gel. ⑦ Pour into container, cover, and refrigerate for 24 h.
Pork shoulder, chilled	280 g	400%	⑧ Cube pork, and mix with Nutrifos and salt.
Salt	8.4 g	12%	⑨ Mix with fat gel, and grind through coarse 5 mm / ¼ in die.
Nutrifos 088	0.28 g	0.4%	⑩ Stuff or shape, and cook in 63 °C / 145 °F bath to core temperature of 62 °C / 144 °F.

(2010)

You can add the spice mix for any coarse sausage to the recipe above as a flavoring, and similarly use any spice mix for emulsified sausage in the recipe below.

EXAMPLE RECIPE

EMULSIFIED SAUSAGE WITH FAT GEL

Yields 600 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	100 g	100%	① Disperse alginate in water, and blend until fully hydrated.
Sodium alginate (Manugel DMF, FMC BioPolymer brand)	10 g	10% *(5%)**	
Rendered fat or oil (liquid)	100 g	100%	② Blend in until emulsified. ③ Chill to 0 °C / 32 °F.
Meat	500 g	500%	④ Grind meat in fine 3mm / ⅛ in die. ⑤ Place all ingredients in food processor, and puree until emulsified. ⑥ Form in mold, and cook in 62 °C / 144 °F bath to core temperature of 61 °C / 142 °F.
Salt	12 g	12%	

(2010)

**(% of total weight of water and fat)*

EXAMPLE RECIPE

LOW-FAT CHICKEN SAUSAGE

Yields 450 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	138 g	46%	① Blend together until fully hydrated.
Xanthan gum	0.45 g	0.15%	
Guar gum	0.18 g	0.06%	
Salt	6.9 g	2.3%	
Rendered chicken fat or oil	4.5 g	1.5%	② Combine meat and fat, and blend with gum mixture, from above, until smooth.
Chicken breast	300 g	100%	③ Form sausages, and cook in 74 °C / 165 °F bath to core temperature of 73 °C / 163 °F. ④ Chill. Reheat to serve.

(2010)

EXAMPLE RECIPE

RARE BEEF SAUSAGE

Yields 1.8 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Beef chuck	1 kg	100%	① Cut meats into 12.5 mm / ½ in cubes, and combine.
Beef sirloin	500 g	50%	② Freeze meat until semifirm, −1 °C / 30 °F.
Beef short rib	300 g	30%	③ Chill grinder dies and parts, as well as extruder bowl.
			④ Grind beef mixture once through chilled 3 mm / ⅛ in die.
Activa RM	4.5 g	0.45% *(0.25%)**	⑤ Dry blend.
			⑥ Fold seasoning mixture into chilled ground beef mixture until evenly distributed.
Salt	36 g	3.6% *(2%)**	⑦ Roll in plastic wrap to form cylinder 4 cm / 1½ in thick, and tie ends tightly.
			⑧ Refrigerate for 3 h.
Insta Cure No. 1	3.6 g	0.36% *(0.2%)**	⑨ Cook in 55 °C / 131 °F bath to core temperature of 54 °C / 129 °F, about 35 min.
Nutrifos 088	1.8 g	0.18% *(0.1%)**	⑩ Slice to desired thickness.
N-Zorbit M (National Starch brand)	36 g	3.6% *(2%)**	
Black pepper, coarsely ground	9 g	0.9%	
Flat leaf parsley, minced	36 g	3.6%	
Alsatian mustard, optional see page 5·37	as needed		⑪ Serve with mustard if desired.

(2010)

(% of total weight of meat*)

This temperatures given here will cook the sausage beef to medium rare.

EXAMPLE RECIPE

FRIED CHICKEN SAUSAGE

Yields 1.5 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chicken thighs, skinless and boneless, cubed	1 kg	100%	① Chill grinder dies and parts, as well as extruder bowl.
			② Combine chicken pieces with salt and Nutrifos 088.
Salt	26 g	26%	③ Grind chicken mixture once through chilled fine die.
Nutrifos 088	2.5 g	0.25%	
Activa RM	2.5 g	0.25%	④ Fold in Activa.
Ice, crushed	200 g	20%	⑤ Combine with ground chicken in food processor, and puree until smooth and ice is melted.
			⑥ Reserve.
Pressure rendered chicken fat see page 144	400 g	9%	⑦ Heat fat to 65 °C / 149 °F, and whisk in glyceride flakes until fully dissolved.
			⑧ Cool fat mixture to 40 °C / 104 °F.
Mono- and diglycerides (Glice, Texturas brand)	28 g	2.8% *(7%)**	⑨ Slowly drizzle fat into running food processor until fully emulsified.
Synthetic casing, 4 cm / 1½ in. in diameter	as needed		⑩ Stuff forcemeat into casings to make 30 cm / 12 in lengths. Tie off ends.
			⑪ Poach in 60 °C / 140 °F bath for 1 h.
			⑫ Peel casing from cooked sausages, and cut into four 7.5 cm / 3 in portions.
			⑬ Reserve.
Chicken skin, frozen and finely ground	2 kg	200%	⑭ Wet-render over medium low heat until all water has evaporated and skin pieces have fried in their own fat, about 30 min.
Water	400 g	40%	⑮ Remove from heat, and blend with immersion blender until all skin is finely ground.
			⑯ Drain skin, and reserve fat.
			⑰ Dry skin between paper towels in 93 °C / 200 °F oven, about 20 min.
Salt	as needed		⑱ Season powdered skin with 1% of its weight in salt.
			⑲ Roll sausage portions in seasoned powder just before serving.

(2010)

(% of total weight of fat*)

than dried sausages do. To suppress the growth of pathogens, at least 2%–3% salt (sodium chloride) should be added to all fermented sausages when they are made. But dried fermented sausages lose 25%–50% of their weight in water, so their final salt concentration is much higher than that: as much as 8% in some hard salamis. Most don't taste intolerably salty because the majority of the salt is chemically bound to meat proteins.

The Miracle of Meat Glue

Sausage is a dramatic but ultimately fairly crude way to create an idealized meat product. Yes, you can create a blend of different meats (different cuts or different species). You can spice it as you like and decide how much fat to add. It can be tender, tasty, and conveniently portioned.

But nobody is going to mistake a sausage for real meat—i.e., muscle flesh. The same flexibility that we exploit in creating sausages comes at the cost of doing such violent restructuring to the meat that it loses its original identity.

What if we could create restructured meat products that look, feel, and even taste as though they were intact muscle? It turns out there are several ways to do exactly that, by using some of the amazing new tools available to Modernist chefs.

The oldest approach to gluing meat together is one familiar from traditional sausage making. Muscle meats are salted (and, ideally, tumbled) to extract myosin protein, and then assembled and cooked. When the myosin is heated, it gels and glues the meat together. This works best with meats that exude plenty of myosin.

In other cases, where there isn't a lot of myosin, the forcemeat is often cooled to solidify fat and gelatin to hold the mixture together before slicing and serving. An example is a simple *terrine de foie gras*, which is typically made by pressing whole (or largely whole) lobes of foie gras together, weighting them down, and cooking them. In a sense, this is a type of sausage—albeit one in which the "casing" is the terrine pan and the grinding step isn't done at all.

Another traditional example occurs when a butcher ties up a roast (as when folding over the thin "tail" end of a whole beef tenderloin) or reassembles a boned leg of lamb. The point of this tying and reassembling is to hold the pieces together until myosin binds them. The main problem with this approach is that the bond is never very strong.

The bond strength can be increased by using additional proteins such as egg white to supplement the myosin, just as you would in a sausage that is not bound tightly enough. This supplementation works after a fashion and is popular in traditional terrines that mix forcemeat with intact pieces of meat (foie gras, duck breast, braised and reassembled pig's feet).

A different approach is to embed the meat in a gel other than that formed by myosin. One classic example is called *fromage de tête* by the French, brawn or head cheese by the English. A source of meat—such as the head of a cow, a pig, or a sheep—is cooked, and then the deboned pieces are set in a concentrated gelatin solution made by boiling down collagen-rich meats. When the gelatin sets, the various meat chunks are bound together in a sort of culinary conglomerate. It is a bit like the way a terrazzo floor is made by embedding pieces of rock in cement.

This kind of gel embedding is very successful as long as you are willing to live with the constraint that gelatin melts at body temperature, so the dish must be served cold. Carême, Escoffier, and their colleagues in classical French cuisine (see page 1·18) created many elaborate dishes in this fashion, such as galantines assembled with aspic.

Modernist chefs have more options, thanks to hydrocolloid gels (see page 4·124), which have the advantage that they remain gelled at much higher temperatures and thus can be served hot. By gluing meat together with agar, alginate, gellan, carrageenan, or other gels, you can create hot aspics and other seemingly contradictory creations that Escoffier could only dream about. The drawback of gel embedding is that the focal point of the dish becomes the gel, not the meat.

Which brings us to one of Modernist cuisine's most magical ingredients: a family of enzymes, collectively called **transglutaminase**, that form chemical cross-links between muscle proteins so that they bind to one another. Activa is the brand name of the single commercial source of these enzymes; many cooks just call it "meat glue."

Transglutaminase enzymes are found in cells throughout the bodies of all animals, as well as in

Activa TI, also known outside of the U.S. as Activa WM, is recommended for forcemeats. Unlike other versions of Activa that contain added protein sources such as sodium caseinate or gelatin, it contains only the transglutaminase enzyme and a bulking agent (maltodextrin). This version is also recommended for enhancing the texture of other high-protein foods such as noodles.

Activa comes in many grades developed for specific applications (see page 353).

Ballotines and other classic dishes are simpler to make and perform better when they are made with Activa.

plants and microbes. They are involved in blood clotting and many other functions and have been known to science since 1959. Some people view transglutaminase as something artificial or "unnatural." The enzyme is rather daunting to pronounce, much less to ingest. It is manufactured commercially by using bacterial fermentation, and thus is no more (and no less) artificial than yeast-raised bread, sauerkraut, vinegar, wine, and fermented sausages, all of which use fermentation by-products.

Activa is made by the Ajinomoto Company of Japan, the same firm that pioneered the commercial production of monosodium glutamate (MSG) more than a century ago. The company developed a process to manufacture the enzyme on a large scale by fermentation and launched the product in 1992. One of the original motivations for making Activa was to facilitate the production of surimi, a Japanese faux crab meat made from fish. Activa assists the gelling of the myosin in the fish meat, strengthening the texture so that it more closely resembles that of a crustacean.

Since that simple beginning, Activa has proven useful for many other purposes. It strengthens protein gels, so is widely used in commercial yogurt (see page 4·116) or to raise the melting temperature of gelatin (see page 4·70). It can also increase the gel strength in sausages, as discussed earlier in this chapter (see page 241).

The really unique thing about Activa is that it can "glue" nearly any two protein-rich foods together. A fine dusting of Activa powder (or a coating of a slurry of the powder mixed with water) can glue meat and seafood together in a very convincing manner. Meats reformed in this way hold up extremely well to cooking and appear for all intents and purposes to be a single piece of meat.

With Activa, for example, you can take several separate pieces of steak and glue them together to make a piece of meat that looks as if it were cut from an intact muscle. That's a handy trick in situations where you want to create equal-sized portions from what are inherently unequal-sized cuts of meat. Activa also allows you to cut bone, sinew, silverskin, or fat out of a piece of meat, and then reassemble what's left into a monolithic slab.

Just don't expect to take a multitude of tiny trimmings and glue them into a filet mignon. The pieces will stick together all right, but the result will have a composite texture. You can, however, Activa's ability to cross-link proteins also has uses in making or enhancing protein gels (see page 4·74).

glue the tenderloin "tails" together to make a portion that looks for all the world like a single, thicker tenderloin.

Heston Blumenthal is generally credited with introducing Activa to Western fine-dining cuisine in 2003. At The Fat Duck, Blumenthal uses this enzyme to make a dish called "mackerel invertebrate," for example, in which a mackerel is filleted, and then reassembled without its bones.

An even more whimsical application of Activa is to take fish of two different colors—say, tuna and escolar, or salmon and hamachi—and glue their meat together into a checkerboard, striped, or laminated arrangement. (For specific instructions on making one such dish, see page 256.)

Do not confuse Activa with the similarly named Activia, a brand of probiotic yogurt marketed in the United States.

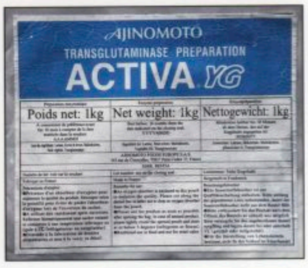
Activa is capable of joining completely dissimilar kinds of meat, such as beef and tuna, but doing that is usually counterproductive because the cooking temperatures for the meats are so different. In some special cases, however, this disparity can be exploited effectively. Activa can be used, for example, to glue skin onto meat because both are composed of protein. Chefs Aki Kamozawa and Alex Talbot like to glue chicken skin to scallops this way. Their notion sounds bizarre but works well because the chicken skin gets much crispier than the scallops and at the same time protects them from high cooking temperatures.

Activa can even be used to glue together meat that has already been cooked. But it generally forms a weaker bond in that application because intact proteins are relatively scarce in cooked meat, so there are fewer opportunities to form protein cross-links.

Activa FP is a general-purpose binder in which the milk protein is hydrolyzed, making it safe for people allergic to dairy.

This enzyme comes in various grades designed for specific purposes, so you need to be sure you have the right one for the job. The most popular version is Activa RM. It includes sodium caseinate (concentrated milk protein), which helps bind things together. You can either sprinkle it on straight or apply it as a slurry by mixing one part Activa to three to five parts water by weight.

Activa YG is widely used in yogurt and other dairy gels.



Another popular formulation is called Activa GS, which contains polyphosphates that help extract myosin from meat for a stronger bond. It is preferable to apply Activa GS as a slurry because phosphates are difficult to dissolve when dusted onto a cold and wet surface.

Activa goes bad very quickly if it gets wet—or even if it's exposed to air—because any humidity degrades it. The most obvious symptom that it has "turned" is that it fails to work. Experienced cooks can also detect a subtle change in its aroma: a slurry of fresh Activa should smell something like a wet dog. Because it loses its effectiveness so quickly once the package is opened, it is best kept in the freezer when not in use. Vacuum packing also helps preserve it, as does a nitrogen flush such as you might use to keep wine in opened bottles fresh.

As with any bonding task, gluing with Activa requires that the surfaces be pressed together for good contact. Applying weights and rolling the meat snugly in plastic wrap are two strategies for holding things tightly together until a strong bond forms. If the option is available, vacuum packing is ideal because it eliminates any air pockets and uses atmospheric pressure, which exerts force in all directions equally, to press the surfaces together until they bond.

The bonding reaction takes place slowly: at typical refrigeration temperatures, about five hours are required to get about 80% of the maximum bond strength. Consequently, most Activa applications entail bonding the meat and letting it sit in a refrigerator for 6–12 hours.

The cross-linking reaction, like most chemical reactions, speeds up with increasing temperature. At 55 °C / 130 °F, the bonding can take as little as five minutes. This so-called "heat-set" method of Activa bonding is ideal for meats that are going to be cooked sous vide to core temperatures of 60 °C / 140 °F and lower. Simply apply Activa to the meat, vacuum pack it, and cook. The Activa will be bonded by the time the meat is done.

Subsequent heating above this temperature will not break the bond once it has formed, but the enzyme will break down if it is heated above about 58 °C / 135 °F. So don't let that happen before bonding has occurred. This limitation means you generally cannot use the heat-set method for meat cooked with a high-temperature source. The sous vide example we describe above works because the slow temperature rise gives the enzyme plenty of time below 58 °C / 135 °F to bond.

Activa has no flavor of its own, but the cross-linking reaction it fosters creates a slight smell of ammonia. Unless you use an excessive amount, there are no bad odors or off-putting tastes associated with its use.

Properties and Uses of Activa

Activa comes in various grades, and each one is optimized for a different use. Depending on the task, Activa can be applied to foods either by dusting the surfaces being bound together, by brushing them with a slurry of Activa and water, or by directly mixing the ingredients with Activa. Not all grades of Activa are suitable for all methods, however. In general, the quantity of Activa used is 0.5%–1.0% relative to the weight of the meat or seafood. Smaller quantities will suffice for other tasks, such as making forcemeats and dairy gels. For most types of Activa, complete bonding occurs in 18–24 h at 3–5 °C / 37–41 °F, except for Activa GS, which typically bonds within 3 h. All Activa products are active from 3–60 °C / 37–140 °F, but they are most active at temperatures from 50–55 °C / 122–131 °F. The table below summarizes the choices available.

Product name			Method of application					
North American	Global	Ingredients	Sprinkling	Slurry	Direct mixing	Dilution or scaling*	Note	Example use
Activa FP	Activa PB	hydrolyzed skim milk protein, transglutaminase	✓	✓	✓	1:3 with ice-cold water	use slurry within 30 min; allergen free	most meat and seafood binding tasks
Activa GS	Activa GS	sodium chloride, gelatin, trisodium phosphate, maltodextrin, safflower oil (antidusting agent), transglutaminase	sometimes	✓	✓	1:4 to 1:6 with water at 10–25 °C / 50–77 °F	use slurry within 6 h; slurry pH is 11 (very alkaline); fast, strong bond with longer working time	seafood
Activa RM	Activa EB	sodium caseinate, maltodextrin, transglutaminase	✓	✓	✓	1:4 or 1:5 with ice-cold water	use slurry within 30 min	most meat and seafood binding tasks
Activa TI	Activa WM	maltodextrin, transglutaminase			✓	0.25%–1.0%		forcemeats, noodles, and tofu gels
Activa YG	Activa YG	maltodextrin, lactose, yeast extract, safflower oil (antidusting agent), transglutaminase	sometimes	sometimes	✓	0.008%–0.01% for yogurts, ≤0.35% for cheese	active pH is 5.5–8, optimum pH is 6–7	yogurt, restructured cheese, and other dairy gels

*(*set weight of food to 100%*)

HOW TO Choose and Use Activa

A transglutaminase enzyme is the key ingredient in Activa, but there are several formulations of this product, and each is tailored to different applications. For meat reconstruction, we recommend either Activa RM, FP, or GS. RM and FP are general-purpose and can be applied as a sprinkle coating or slurry, or tumbled together with chunks of meat or seafood. The only difference between the two is that the milk protein in FP has been hydrolyzed, unlike that in RM, so FP is suitable for people with dairy allergies. GS works best when applied as a slurry or tumbled together with the meat. It forms a stronger bond and works faster, but it also tends to toughen delicate cuts of meat and seafood.

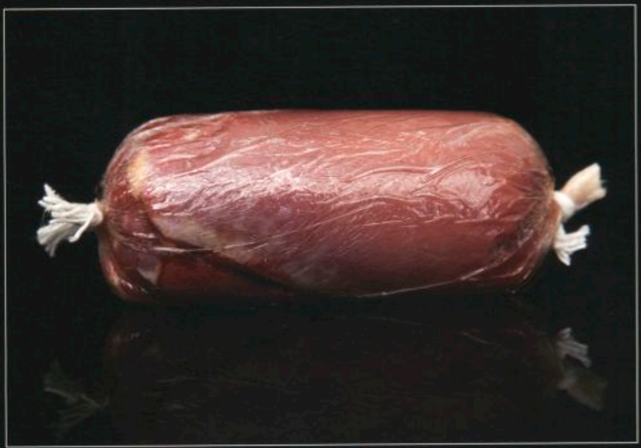
Ideally, the amount of Activa used should be about 1% of the total weight of the meat being bonded together. In practice, evenly dusting the surface of the food and knocking off the excess, or painting the food surface with a slurry, works fine.

Each of these approaches has particular advantages. We present the sprinkle-coating method here for restructuring a pigeon breast and a leg of lamb; we use the slurry method to construct an escolar-and-tuna checkerboard on page 356. A slurry often yields a better bond. Activa RM, FP, or GS can all be blended with three to five parts water to make a slurry. Be aware that Activa RM and FP lose their potency within 20 minutes, whereas Activa GS will continue to work for several hours.

However you apply Activa, always press out any air pockets, and tightly wrap or package the pieces you are binding. Allow up to 12 hours for pieces to bond fully before cooking.

1 **Sift a suitable grade of Activa (such as RM or FP) over the surfaces to be bonded.** Once generously coated, knock away excess.

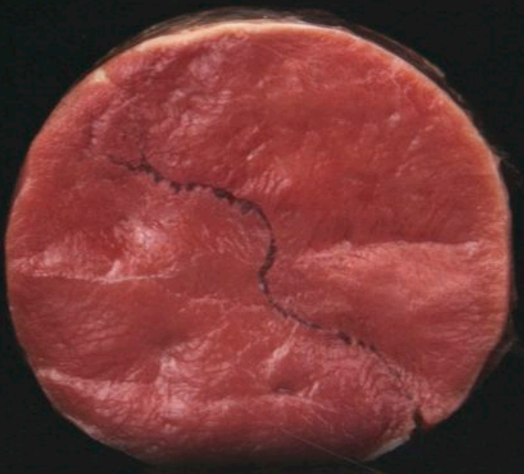
2 **Lay the prepared surfaces against each other.** Carefully press out any air pockets.



3 **Use plastic wrap to form a cylinder.** The wrap keeps the bonding surfaces tightly pressed together.

4 **Chill for at least 5 h.**

5 **Cook.** The meat can be unwrapped if necessary.



VARIATION: Rejoining Seam-Boned Cuts

To improve tenderness, master carvers cut each slice from a leg of lamb at a particular angle, making the cut as far against the grain as possible. The complexity of the musculature in a leg makes this procedure difficult and awkward. But there's another approach: you can seam-bone the lamb (see page 46), separating out each individual muscle, and then use Activa to bond the muscles together again with the grain of every muscle running in the same direction. If the restructured meat is then cooked sous vide and quickly seared, this technique ensures that every slice of the lamb leg is perfectly cooked and as tender as possible.

1 **Seam-bone a leg of lamb (as shown on page 46).**

2 **Sift Activa RM over the surfaces of the prepared muscles.** Use a strainer, and use FP instead of RM if dairy allergies are a concern.

3 **Layer the muscle into a cylinder on a sheet of plastic wrap.** Arrange the muscles so that their grains all run in the same direction.

4 **Force out any large gaps between the muscles.** Then fold the plastic wrap over the meat.

5 **Roll the plastic wrap tightly to pack the muscles together into a cylinder.** Refrigerate for at least 5 h before cooking.

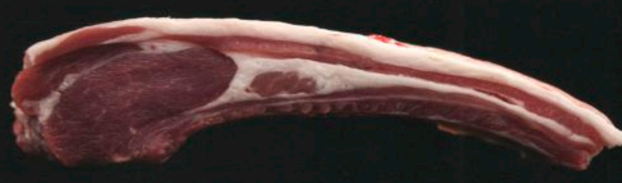
VARIATION: Making a Leaner Rack of Lamb

The combination of seam-boning with Activa is also useful for making a rack of lamb that is free of intramuscular fat and silverskin.

1 **Cut away the fatty surface layer of the rack of lamb, and reserve it.** Or, for a very low-fat rack of lamb, discard the fat layer.

2 **Carve out the intramuscular fat.** Trim away any unwanted silverskin and connective tissue that is found on the shoulder side of the rack. Several flaps of meat will remain.

3 **Follow steps 1, 2, and 4 on the previous page to bond the meat to itself.** Optionally, bond the fat cap back on to the meat.



VARIATION: Bonding with the Slurry Method

The slurry method of applying Activa tends to form bonds that are stronger and more consistent than those that form when the powder is just dusted on. Both Activa RM and FP should be mixed with ice-cold water and used within 20 min; GS should be mixed with lukewarm water and can be used for up to 6 h. The table on page 353 lists suitable mixing ratios for each kind of Activa. For delicate seafood, we prefer either RM or FP because they give the bonded pieces a better texture. GS is best suited to large pieces of meat and seafood that require a very sturdy bond.

1. **Cut tuna and escolar into short strips.** The lengths should be 1.5 cm / ¾ in. Prepare a slurry of one part Activa RM to four parts ice cold water (or 1:3 if using Activa FP because dairy allergies are a concern).

2. **Brush the sides of each strip with the slurry, and press them together firmly.** Alternate between tuna and escolar as shown.

3. **Build up a block one layer at a time.** Use layers five strips by five strips in size. Brush each layer with slurry before adding the next one.

4. **Vacuum seal the block, and refrigerate.** Vacuum-packing preserves the shape. Bonds take at least 5 h to set.

5. **Unpackage, cut slices 1 cm / ½ in thick, garnish, and serve raw.**

VARIATION: Reconstructing a Whole Fish

Butterfly the fish, and cut out the spine and bones. Carefully remove any pin bones. Follow the procedure described above for applying the Activa slurry.

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12 PLANT FOODS

12

PLANT FOODS

Poor, defenseless plants. Anchored in soil and without hides or bones for fortification, they seem no match for those of us who would make their tender shoots into a light lunch. But because they're so vulnerable, plants have evolved elaborate physical and chemical blockades to dissuade us and other fauna from serving ourselves. The bitter taste of many plants signals that poisonous compounds may be present. Even some of the plants in our markets, like potatoes and parsnips, can accumulate toxins in their peels if mishandled. Some plants sport sharp spikes. They say it was a brave man who tried the first oyster, but who do you suppose first tried an artichoke? Or cyanide-laced cassava root? The very cells of most plants—bolstered by stiff, indigestible fiber or by protective toxins—put up a fight.

Fruits are the exception. There's a reason they're sweet and ready to eat: they evolved so that animals would eat them and then disperse their undigested seeds. But we usually alter any foods classified as vegetables, starches, or grains before we serve them. Sometimes, we use chemistry by salting or pickling plants so that they last longer in our larders or become more palatable, or perhaps more nutritious, than they are raw. Other times, we must process the plants by cooking or another method, lest they poison us. Ask anyone who has suffered a long night after a dinner of undercooked kidney beans. In all these cases, we're using chemistry to overcome plants' defenses.

Fortunately, humans and plants have had a long time to negotiate their relationship. After 10,000 years of domestication, most of the plants we eat today have been modified to grow softer, milder in taste, more colorful, bigger, or more amenable in a host of other ways to our notions of pleasure and convenience.

And we can choose one or the other among many effective methods of preparation. Because the flesh of plants, unlike the delicate muscle fibers of animals, tolerates a relatively wide range of cooking temperatures while retaining palatability, you can enjoy a sense of play when using traditional and Modernist techniques alike. See what new "risotto" you can generate with grains or seeds and a pressure cooker, for example. Or explore the texture of vegetables cooked sous vide or of fruits flash-frozen in liquid nitrogen.

You may have been taught a set of rules that dictate how to prepare certain plants as food. Indeed, the laws of nature do set some limitations. But with enough knowledge of the physical and chemical properties of a plant, along with the physical and chemical changes induced by different preparation methods, you can achieve nearly any outcome you like.

Humans eat a tremendous range of plant foods: tubers and roots; leaves and shoots; legumes and seeds; herbs and spices; and even fungi and occasional molds—although neither of the last are technically plants—but only the fruit of a plant has actually evolved to be eaten. Most other parts of a plant's anatomy require the ingenuity of a cook to make them suitable for eating.

PLANTS AS FOOD

Plants are one of our most important and diverse sources of food. Humans eat relatively few varieties of meat by comparison. So it is no surprise that many aspects of the culinary arts focus on exploring the myriad ways to turn plants into food.

Botanists categorize plants according to their biology and physiology; cooks more often classify them based on custom and cooking practice. For our practical purposes, we divide plant-derived foods into fruits and vegetables (including legumes, such as beans, and edible fungi, such as mushrooms), tubers and edible roots, edible seeds (including nuts and grains), and herbs and spices.

Of the many parts of plants that humans eat, only fruits, by and large, actually evolved to be consumed by animals. The delectable sweetness most fruits take on as they ripen is no accident; plants load their fruits with sugar—a compound humans and other animals are born with the ability to recognize and desire—as a way to attract predators. The succulent flavors of fruits are an advance payment—a "cab fare" of sorts that the plant offers so that animals will ingest its seeds (usually buried deep in the fruit) and disperse them far and wide.

When murder mysteries mention the scent of bitter almonds rising from a victim of cyanide poisoning, they're referring to the characteristic odor of some forms of cyanide. The presence of cyanide isn't the only reason bitter almonds smell the way they do—they also have other aroma compounds, such as benzaldehyde—but cyanide is one contributor to their characteristic scent.

Many fruits are unappealing for consumption before reaching that sugary ripe phase. For example, the Hachiya variety of persimmon is intolerably astringent when unripe, more unpleasantly tannic than a cheap red wine. But these persimmons lose their astringency and sweeten as they ripen, just like other fruits do. The lure of sugar is a powerful bribe for seed distribution.

For seeds to propagate a species effectively, they must serve essentially as a packed lunch that is sufficiently nutritious to support the embryonic plants as they travel from the parent plant and then grow tall enough to photosynthesize on their own. The seeds' nutrient stores are typically rich in carbohydrates, fats, or proteins, with the exact mix varying among species.

A fully digested seed is usually a dead seed, so although many plants form fruit to entice seed ingestion, many fruit-bearing species have also evolved seeds that contain some form of toxin and thus encourage the fruit-eater to excrete the seed rapidly—and intact. The seeds of almond trees, for example, contain traces of cyanide. Cyanide toxins have been bred out of the common varieties of seeds and nuts we eat today, but ancestral varieties were more potent.

To keep hungry animals focused on the fruit, plants often lace their leaves and stalks—and sometimes their tubers—with toxic compounds. An extreme example is cassava, which makes its own cyanide. Only labor-intensive processing renders it edible. Potatoes, a close botanical cousin to the assassin's tool belladonna, or deadly nightshade, contain a variety of bitter-tasting, poisonous alkaloids. Harvested potatoes that have turned green from exposure to the sun are known to sicken animals that eat them raw.

Not all plant species benefit, evolutionarily speaking, from being eaten, and many have developed defense mechanisms to deter grazers. Some encase their fruit in spiky or prickly shields. Others deploy a sort of chemical weapons system, exuding bitter or even toxic compounds that repel the local fauna. Plants such as grasses, which don't gain from being eaten but cannot avoid it, have simply developed a tolerance to the regular loss of their tissue. Most plants can't withstand an attack that destroys their leaves and shoots, but grasses can recover and thrive after a cow grazes them down to the roots.

Most plants don't benefit from being eaten—at least not by all animals. The spiny husk of the durian (left) protects the fruit from being eaten before the seeds mature. The spines of an artichoke (next page) ward off herbivores in a different way.

THE MANY KINDS OF

Plant Foods

Cooks categorize plants differently from the way a botanist might. We find it convenient to think of produce as falling into divisions you might find in a grocery store. Fruits, such as pears and tomatoes, are sweet offerings that evolved to entice animals to distribute the seeds contained within. Roots and tubers, such as ginger and potatoes, are starchy underground energy vaults that tide plants over during cold or dry seasons. Although truffles and mushrooms are the fruiting bodies of fungi and are thus technically not plants at all, chefs have historically classified them with the plant foods. Vegetables often comprise the stems or leaves of the plant, or sometimes (as in broccoli and cauliflower) their edible flowers. Finally, edible seeds and nuts, such as grains and candlenuts, store food energy to nurture seedlings during their first spurts of growth.









THE ECOLOGY OF

Strange Distributors

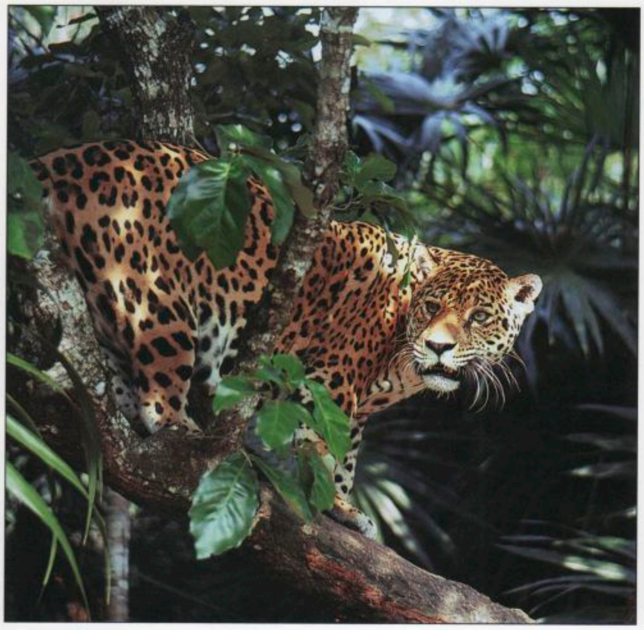
Most fruit seeds are dispersed when animals eat the fruits and deposit the seeds far from the original source when they defecate. This helps the plants disperse their seeds far and wide—along with a convenient fertilizer payload.

Large fruits with large seeds would not have evolved without very large animals to eat them. You need a big mouth and gut to pass a large, undigested seed. But what happens when the mega-animals die off?

The avocado, for example, with its sizable fruit and pit, would have relied on mammoths and ground sloths, extinct in North and Central America for some 10,000 years now. Other large North American seeds—those of the papaw and the Kentucky coffeetree, with pods up to 25 cm / 10 in long—were distributed similarly.

Generally, when a seed distributor goes extinct, the plant soon follows. It's hard for a plant species to survive without seed distribution. The avocado has a surprising savior: jaguars. The felines are large enough to swallow the fruit whole, and the fruit is rich and oily enough to attract their attention as a food source. Dispersion by jaguars kept the avocado viable until its domestication by humans.

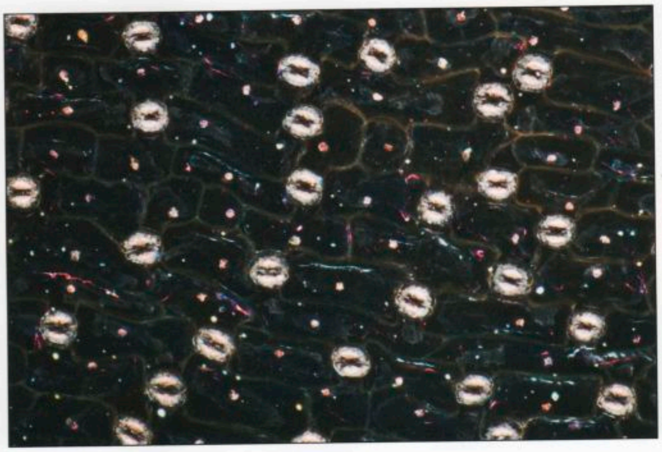
Another interesting and early example is the ginkgo, an ancient tree with an oily fruit that smells like rancid fat. Ginkgos thrived in the time of the dinosaurs, and some paleontologists believe that meat-eating dinosaurs were among the animals that distributed ginkgo seeds.



THE PHYSICS OF

What Plants Are Made Of

Plants are made of gas! Just two things contribute to a plant's weight. A huge fraction is water drawn up by the roots of the plant. Most of a plant's dry matter comes from the air, more specifically from carbon dioxide absorbed by the leaves through intake ports called stomata (right). Fertilizer companies' claims that plants need rich nutrients from soil are true but misleading. Soil nutrients are like vitamins—necessary for good health but only a very small contributor to plant mass. No more than a tiny percentage of the dry weight of a plant comes from the soil. By mass, a plant is primarily carbon, oxygen, and hydrogen.



THE TOXICITY OF

Botanical Self-Defense

Although most fruits evolved to be eaten, some plants, such as red kidney beans and candlenuts (right), are toxic to humans when raw. The persimmon (below center) should never be eaten unripe, because it contains tannins that can clog the digestive system; these chemicals lose their astringency during the ripening process. Apricot pits (below left), like the seeds of most stone fruit, contain compounds that can decompose to form cyanide—a strong incentive for animals that eat the fruits to excrete the seed intact. Many wood sorrels (bottom right) contain oxalic acid, which is mildly toxic in large amounts.

Defeating Plant Defenses

When cooks prepare plants as food, they often must overcome the plants' natural defenses against predation, dehydration, infection, or other threats to botanical life. Kidney beans contain a powerful toxin that can lead to serious illness. It is destroyed by heat but can be dangerous if the beans are raw or undercooked. Kidney bean plants evolved this toxin for the same reason that cassavas and almonds (and the seeds of related stone fruits like peaches or cherries) evolved cyanide—the plants are more likely to propagate if their seeds are not digested.

In addition to disarming the chemical defenses of plants, cooks have to defeat the strong physical structures these organisms have erected to stand upright, retain water, and stave off infection. These structures are microscopic. Unlike animals, which either encase their entire body in a hard exoskeleton or drape it over a scaffolding of bones or cartilage, plants become strong and stiff by erecting a tough wall around each one of their cells. Animal cells, by comparison, have a soft, flexible cell membrane. Generally speaking, there are no equivalents of skeletons or exoskeletons for plants—instead, they have solved the stiffness problem by distributing it to each of their cells.

The rigid cell wall is composed of cellulose and other compounds. Each cell is glued to its neighbors by pectin and hemicellulose. In edible plants, cooking softens the cell walls. It does this mostly by dissolving the pectin and hemicellulose that bind rigid cells together, so they can easily be pushed apart by our teeth. In most cases, the cell walls never become fully digestible—a fair fraction of the material in them passes through us undigested, as **dietary fiber**.

Some edible plant parts, such as tomatoes and lettuce leaves, have softer cell walls. People easily eat these raw. In general, however, the purpose of cooking plant foods is to dissolve enough of the molecular "glue" that binds cells together for them to become soft enough to be appetizing. Unless browning and caramelizing are involved, a change in flavor is usually not the main goal. Potatoes cooked at a wide range of temperatures, for example, have much the same taste.

Cooking has an additional benefit for some plant foods: it actually makes them more nutritious. Take carrots; they are rich in beta-carotene, from which the body synthesizes vitamin A (essential for good vision and other processes). In a recent study, participants absorbed only 3% of the beta-carotene in raw carrots, compared with 6% of that in cooked carrots. When the carrots were pulped to break down the cell walls, absorption increased to 21% for raw carrots and 27% for cooked ones. When the carrots were pulped and cooked in oil to further soften their cell walls, 39% of the beta-carotene was absorbed. Raw carrots may be more "natural," but they're not necessarily best for us.

Spinach, nutritionally speaking, is also best cooked. Cooking diminishes the plant's stores of oxalate salt, a sharp-tasting compound that deters consumption and also binds to iron, calcium, and other minerals, thus preventing the body from absorbing them. Food writer Jeffrey Steingarten (see page 1·65) noted in an entertaining and factual essay, "Salad, the Silent Killer," that despite

A commonly heard argument for buying "natural" foods is that they are free of toxins. In reality, they're free only of added toxins. Plants contain plenty of natural poisons of their own.

Tubers like these crosnes are an interesting intermediate form between seeds and ordinary plant tissue. The tuber stores energy for the plant in the form of carbohydrates. Often, as with potatoes and other root vegetables, the energy that the plant stored underground sustains it through the winter. Once a plant species has invested its energy in a fancy root system like a tuber, it requires a defense (like the cyanide found in cassava) so that animals don't harvest it and make off with the rewards.

THE HISTORY OF

The Internationalization of Plant Foods

Agriculture helped humans develop stable societies. In turn, many plants we eat today evolved because of the cultivation practices made possible by that stability.

Early hunter-gatherers had to move seasonally to find new sources of plant foods and game. As agriculture arose, it allowed people to stay in one place, and as it became more efficient, it supported increasing populations, from cities to societies to civilizations. The plants we eat developed along this route of efficiency. Few modern plant foods resemble the wild versions they were bred from, and surprisingly few plant foods are native to the areas we think of as their birthplaces.

Many "traditional" plant foods aren't traditional at all. Wheat developed in the Fertile Crescent before spreading across the globe. Polenta is not Italian but South American—as are tomatoes. (The number of Italian plant foods that originated in Italy is surprisingly small: white truffles are the shining exception.) Imagine Chinese food without chili peppers, which originated in South America. The Sichuan province does have native Sichuan pepper plants (not to be confused with chili peppers), which lend a trademark buzzing, numbing quality to dishes like mapo tofu, but the dishes we now think of as traditionally Sichuan—loaded up with hot chilies—did not exist until chiles were imported from South America.

Throughout history, traveling humans brought worthwhile plants along to new homes. The discovery of the New World infused Europe with new plant foods. From the 14th to the 16th century, much exploration was driven by the hunt for spices. Prized spices like clove and nutmeg are native to equatorial climates and could not be cultivated in Europe. Plants tend to move most successfully through "horizontal" transport to the same latitude (i.e., east to west and the reverse) and climate, as Jared Diamond noted in *Guns, Germs, and Steel*. Changes in latitude (i.e., north to south or vice versa) are more difficult because of differences in climate and length of growing season.

Many plants that we think of as wild aren't as genetically unmodified as we think. Although so-called wild strawberries aren't as domesticated as hothouse varieties, most come from a strain that humans deliberately cultivated.

Teosinte (above) is a grass found in Mexico that is the original source of corn or maize. Selective breeding by human farmers has changed it almost beyond recognition to its modern form (below).

THE BIOLOGY OF

Digesting Raw Plant Foods

Advocates of raw foods argue that plant foods are nutritionally superior before they are cooked. The human digestive system, however, isn't adequately equipped to draw sufficient nutrition from an all-raw diet. Animal guts do a much better job.

Ruminants, the animal family that includes cows, get enough food value from grasses, which are nearly entirely made up of cell walls toughened by cellulose. Their meals are processed multiple times through a four-chambered stomach, they enlist microorganisms to ferment the cellulose, and they can regurgitate food and rechew it to further break it down.

Elephants deal with the relatively low nutrient value of raw plants by eating as much as 180 kg / 400 lb of food per day. Their bodies can make use of only a fraction of the plant matter, but the quantity makes up for the lack of quality.

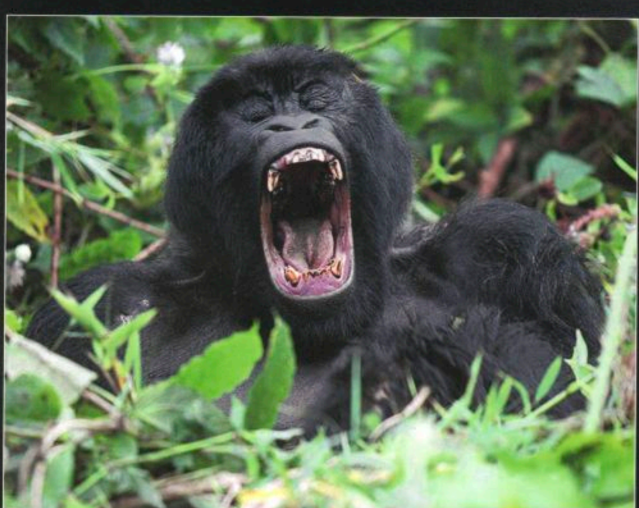
A more efficient strategy is to seek raw foods that have higher nutrient values. Many small plant-eating animals feed on nuts, seeds, and fruits, thus ingesting large doses of calories and nutrients in relatively small packages.

Chimpanzees, our close relatives, eat a diet thought to be similar to that of the predecessors of early humans: mostly fruit, along with some raw meat. Gorillas, on the other hand, primarily eat plant foods that are low in nutrients, including bamboo and wild celery. The prominent ridge, or sagittal crest, along the top midline of gorillas' skulls anchors the powerful jaw muscles they need to spend the bulk of each day chewing such low-value plant foods.

We can be distinguished from both these primates by our ability to cook food. Richard Wrangham, a professor at Harvard University, argues in his book *Catching Fire* that cooking isn't a human invention but rather is what actually drove our evolution from early hominids to *Homo sapiens*. Although it's labor intensive, cooking food makes it easier to extract nutrients from the food. According to Wrangham, every ounce of effort we spend preparing cooked food is paid back with food-derived energy to support the development of our fuel-hogging, oversized brains.

Although advocates of eating raw food claim that their approach is more natural than consuming cooked food, humans lack the jaw muscles and large molars of the other great apes, so we have a hard time masticating raw vegetables adequately.

Fortunately, we have something gorillas do not: blenders and juicers. When raw food and health food advocates prepare smoothies, juices, and other blended foods, they do with spinning blades what gorillas do with gnashing teeth. The blender smashes tough cell walls. Juicers go one better and remove most of the hard-to-digest vegetable pulp.



The huge teeth and massive jaw muscles of a gorilla have evolved to process a largely vegetarian diet.

Human raw food enthusiasts, lacking the gorilla's teeth and jaws, need blenders and juicers to mechanically process food for them.

THE SCIENCE OF

Rating Chili Peppers

Whether you love or hate it, the fiery heat of chili peppers provides some of life's most memorable culinary experiences. Some peppers are hotter than others, and this leads to a question: is there a way to rate the heat?

In 1912 Wilbur Scoville, a pharmaceutical chemist, devised a system for ranking the heat of chili peppers based on taste and dilution. In the modern version of the test, endorsed by the American Spice Trade Association, one gram of chili is finely ground and then put in 95% ethanol at room temperature for 24 hours. This extract is then diluted with a 3% solution of sugar (dextrose) in water until people tasting it can just barely detect the sensation of heat. The dilution ratio corresponds to the hotness of the chili.

This procedure is known as the Scoville Heat Test, and the resulting units are called Scoville Heat Units (SHU). The most extreme chilies ever measured rank up to one million SHU, which means that the chili extract had to be diluted by a factor of one million to one. That is pretty potent stuff—it means that you can still taste one gram of the chili diluted in one ton of water.

Since the 19th century, we have known that the hotness of chili peppers comes from a compound called capsaicin, along with closely related capsaicinoid compounds such as dihydrocapsaicin. In Scoville's era, there was no good way to test for these directly, but more recently, high-performance liquid chromatography and other methods have been developed that can measure capsaicin compounds. They reveal that a 1% solution of capsaicin generally corresponds to an SHU of 150,000.

This all sounds very scientific, and it suggests a way to standardize chilies: just consult the SHU values for the type of chili you are using to determine how much of it you need.

Unfortunately, there are several factors that confound this approach. The first is that the capsaicin content of a chili depends on its ripeness when picked and the conditions under which it was grown. Just as one peach may be far sweeter than another, the heat of chili peppers can vary markedly from batch to batch and even between individual chili peppers.

The next source of variation is the food that the chili is going into. Tests have shown, for example, that it takes about 30 times more capsaicin to register the same level of heat in a neutral oil as it does in water. Tests done in other foods suggest that the perception of chili heat intensity can vary depending on the fat content of food and other factors, and there is no simple rule of thumb to predict it.

Chili peppers, or powders and purees derived from them, can also give different results depending on how finely they are pureed and how much capsaicin has been extracted by cooking. Most chilies used in cooking do not have their capsaicin carefully extracted in 95% ethanol for 24 hours.

Finally, people have different opinions about what constitutes a desirable degree of chili pungency. This perception changes with repeated exposure: you are likely to rate their heat differently if you have eaten chili peppers within the past 15 minutes.

The intense heat of a chili can vary enormously from one pepper to the next. The average hotness is rated on the Scoville scale, but it is only an average; a painfully hot chili often lurks within a group of seemingly identical peppers.

THE BIOLOGY OF

Capsaicin, the Heat of the Chili

Chili peppers, which are technically fruits, seem to violate the rule that fruits are sweet. Bite into a habanero pepper, and you'll doubt that it evolved to be cab fare for its seeds.

The capsaicin that causes the fiery burn of chili peppers has a benefit, however: it kills microbes. Joshua Tewksbury of the University of Washington discovered that nonpungent chilies, such as bell peppers, are far more likely than hot peppers are to suffer fungal attacks, which can destroy their seeds. Pungent, capsaicin-rich chilies such as cayenne peppers help their parent plants resist the fungus.

But how can chili seeds be dispersed if capsaicin burns the animals that eat peppers? Tewksbury found that mammals have a receptor in one of the sensory nerves of the face that is required to taste capsaicins. Birds lack that receptor.

In effect, the capsaicin stops most mammals from eating the chilies—which may be why pepper plants have chilies in the first place. Chili seeds eaten by mammals tend to get crushed and rendered incapable of reproducing. Those eaten by birds, on the other hand, typically remain viable.

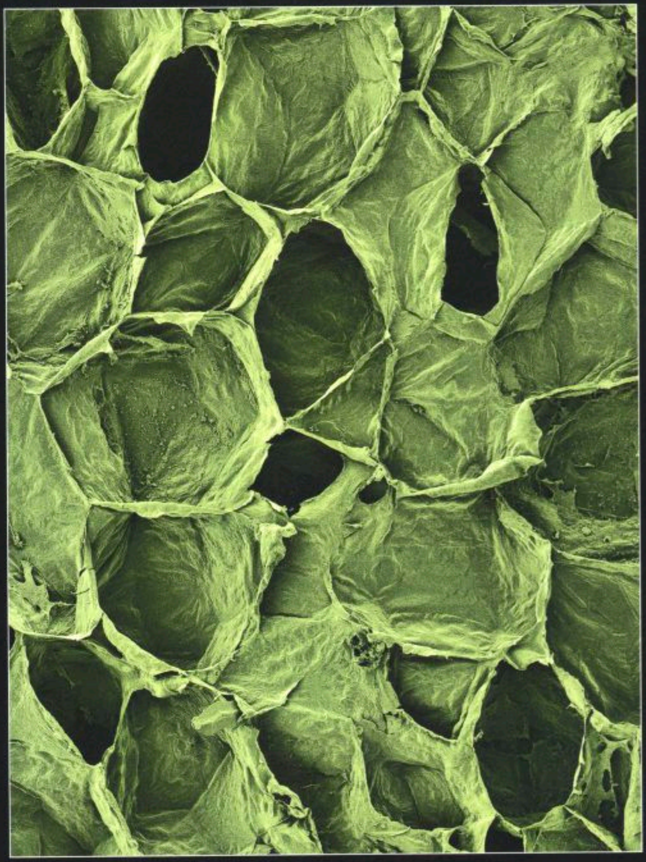
Humans are the exception to the general aversion of mammals to chilies. Our "hurts so good" philosophy drives us to actively seek out hot chilies like those listed in the table below.

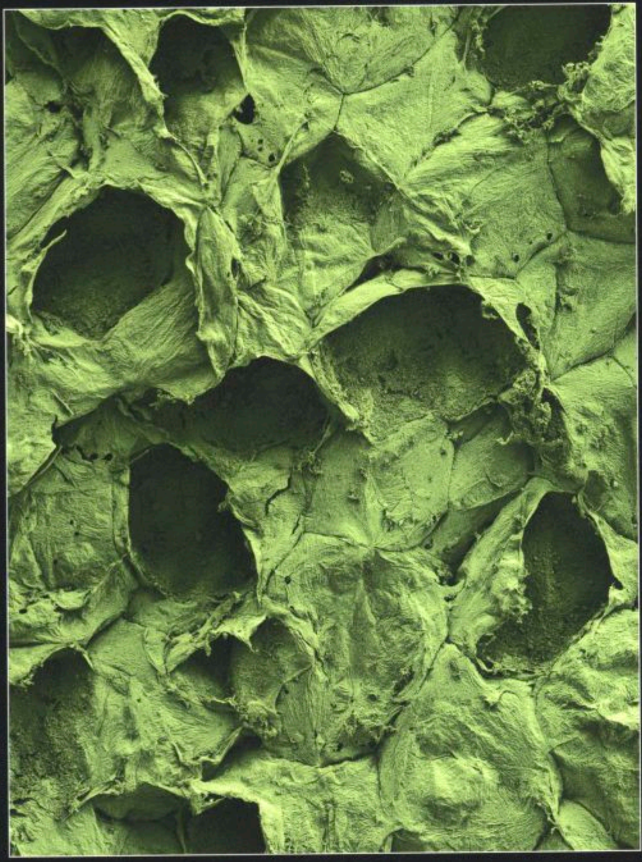
Choosing a Chili

"Spicy" is always relative. Many people around the world find the heat of chilies very pleasurable; to others, this is utterly incomprehensible. As for us, we like spicy heat—so we love chilies, as evidenced by our American barbecue sauce recipes on page 5·66.

Pepper	Hotness (Scoville units)	Example use	Origin
Sweet bell	0	stuffed	Central America
Shishito (fresh)	50–200	grilling	Japan
Pepperoncini (pickled)	100–500	salads	Italy
Hungarian cherry (dried)	100–500	goulash	Hungary
Poblano (fresh)	1,000–2,000	chili relleno	Mexico
Ancho (dried poblano)	1,000–2,000	mole	Mexico
Pasilla (dried)	1,000–2,000	roasted, salsas	Mexico
Anaheim (dried)	500–2,500	salsas	California
Piment d'Espelette (dried)	1,000–2,500	fish	France
Jalapeño (fresh)	2,500–8,000	salsas, pickles	Mexico
Chipotle (dried, smoked jalapeño)	5,000–8,000	mole	Mexico
New Mexico (dried)	6,000–8,500	chili con carne	United States
Serrano (fresh)	8,000–22,000	salsas	Mexico
Japanese (dried)	15,000–35,000	stir-fries	China
Aleppo (dried)	10,000–50,000	stews	Syria
Ají (dried)	30,000–50,000	curries	Peru
Cayenne (dried)	30,000–50,000	American BBQ	United States
Thai (fresh)	50,000–100,000	curries, fish	Thailand
Pequin (dried)	100,000–125,000	rubs	United States
Tepin (wild pequin)	100,000–265,000	stews, salsas	Mexico
Scotch bonnet (fresh)	150,000–325,000	Jamaican jerk	Caribbean
Naga Jolokia or "ghost pepper" (dried)	800,000–1,041,000	curries	India, Sri Lanka
pure capsaicin	16,000,000	self-defense	laboratories

All chilies are native to South America. The plants were brought to the rest of the world by Spanish colonists from the 16th century onward. By now, they have been cultivated in various parts of the globe and have been the subject of selective breeding by farmers, so it is reasonable to describe varieties as Thai, Japanese, or Hungarian peppers.





An electron microscope reveals how the hexagonal cell walls of plants such as broccoli (above left) break down during cooking (above right). The heat swells the intracellular water, which eventually breaks its barriers and leaches out (shown below in tomatoes). Once broken, the softened cell walls collapse.

With enough heat and time, the cells in a tomato completely come apart, reducing what was once a firm fruit into a sweet and savory puree.

its reputation as a rich source of iron, the oxalic acid in raw spinach renders it relatively nonnutritious. In principle, eating vast quantities of raw spinach could actually make you anemic!

Breaking Down the Walls

For all their intricacies, plant tissues are vastly simpler to cook than animal tissues. With animal proteins, just a couple degrees of difference in cooking temperature can yield dramatically different results. Cook a piece of meat to 100 °C / 212 °F or higher, and you're very likely to have a gray, dry disaster on your hands. Cooking vegetables is a more relaxed process—and heat is not the only option. Any method that overcomes the glue that binds their strong cell walls can work.

Some of the approaches cooks use to prepare vegetables mimic those used in the wild by other plant-eating animals. We chop, grind, puree, and juice produce, just as grazers do with their large molars and heavy jaw muscles. We ferment cabbage and other vegetables by co-opting microorganisms to soften the cell walls. Cows do something quite similar in their four-chambered stomachs, in which symbiotic bacteria cope with the strong cell walls of the hard-to-digest cellulose.

Human cooks, however, have a more nuanced tool that other animals lack: heat. In hot water or steam, the cell walls of plants start to break apart from each other between 88 °C and 92 °C / 190 °F and 198 °F—a broad temperature range compared with the tight tolerances that meat cookery demands. The first thing that occurs is that the pectin and hemicellulose that bind the cells start to dissolve. As cooking progresses, the cell walls gradually lose their integrity and become more permeable to water, which leaks out of watery produce, such as carrots, but can also leak into drier foods, such as rice. The spinach leaf wilts and shrivels; the carrot softens from snappy to bendy to mushy. This process occurs even faster in the higher temperatures inside a pressure cooker; see Pressure-Cooking, page 298, for more on that approach.

Effective as heat is, it suffers one major drawback when applied to plant foods: heat sometimes alters or destroys flavor compounds. In peas, corn, citrus fruits, berries, and other heat-sensitive produce, flavor-changing reactions occur at temperatures well below those at which cells come apart. Sometimes enzymes that create flavor are destroyed; in other cases, delicate aromatic compounds are changed or degrade. Whatever the chemistry at work, cooks who prefer the taste of fresh corn need to serve it within a narrow range of temperatures. Corn that is too cool will still have a characteristic raw flavor that few people enjoy; too hot, and the nuanced taste of fresh sweet corn vanishes, leaving the vegetable tasting dull by comparison. The trick is to find a cooking method that balances temperature with flavor and that perhaps incorporates additional processing to optimize the texture.

Water Matters

The water content in vegetables influences how they behave when cooked. When we talk about adding heat to dissolve the glue that binds rigid cells together, note that we don't usually have to add water to the mix. Many plants—usually those that aren't high in starch—contain enough water for effective cooking. When you heat the vegetable, the cell walls spring leaks, flooding the outside of the cell with water that dissolves the molecules binding plant cells together.

Consider lettuce. Containing 98% water by weight, lettuce can be thought of as crunchy water or as a particularly fancy water bottle. When romaine lettuce is dehydrated, it comes out of

Within the rigid walls of most plant cells lies a watery vacuole that takes up most of the cell's volume. The vacuole is a structure that provides rigidity and contains nutrients, wastes, and other materials. Vacuoles can collapse during cooking, and when they do, the food often softens dramatically.

Once broken, the soft cell walls collapse, as seen in the Swiss chard below.

THE CHEMISTRY OF

Color Changes in Cooking

Most cooks have had the experience, sometimes to their delight but more likely to their dismay, of seeing plant foods change color while cooking. Several kinds of chemical reactions can cause shifts in color. The natural pigments in some plants (red cabbage being the best known) respond to changes in pH: add a dash of vinegar to red cabbage as it cooks, and its anthocyanin pigments go pinkish; a sprinkle of baking soda will shift their hue toward blue.

Although people often think of water as being a neutral cooking liquid, its mineral content varies quite markedly from region to region and from tap to tap. Water rich in minerals (also called "hard water") can affect the color and texture of vegetables, for example, by altering **chlorophyll** in ways that dull naturally vibrant greens. If you are making a dish that is very sensitive to minerals, use water that has been purified by **distillation**, **deionization**, or **reverse osmosis**.

acidic

neutral

alkaline

Red cabbage juice contains anthocyanins, a family of pigments that make it an excellent natural indicator of pH and that illustrate how acidity and alkalinity can affect the natural color of foods. All of the solutions below started with the same juice, which is purple when mixed with neutral water. Of the acidic and alkaline solutions shown below, only the middle four are palatable.

The heat of cooking itself alters the chemical components of some fruits and thereby changes their color. One dramatic example is the quince, a hard fruit with yellow skin and white flesh that looks like a cross between a pear and a Golden Delicious apple. (Quinces are relatives of apples.) Eating a quince poses two problems: first, its cell walls are so strong that it is simply too hard to eat uncooked unless the fruit was grown in a hot climate where the fruit sheds its rind and softens naturally. Second, tannic acids in the raw fruit give it a bitter, astringent taste.

So people usually slow-boil or pressure-cook quinces to destroy the tannins and soften the fruit before eating. This process transforms the color of the flesh from off-white to a deep red.

raw peeled pressure-cooked

Boiled potatoes are often not as sweet as they could be, because many of the natural sugars dissolve into the water during cooking. Add 1 g of sugar for every 100 g of water before cooking to establish equilibrium between the sugar content of the food and that of the water around it. This step will keep the natural sugars where they belong—in the potatoes.

For more on how boiling is often a faster way to cook vegetables than steaming, see page 2·72.

Some people say that you can't make as good a sauce from fresh tomatoes as you can from canned tomatoes. The reasoning is that tomatoes change flavor at the temperatures required for canning. It isn't necessarily a better taste, but it's the taste people associate with "tomato sauce" flavor. That flavor can be duplicated by pressure-cooking tomatoes—a process that canned tomatoes go through during the manufacturing process.

the dryer feather-light, revealing a sweet flavor that you normally miss because it is so diluted. Surprisingly, carrots are 88% water by weight, despite their very stiff, solid form. There is as much water in 100 g of carrots as there is in 100 g of whole milk (see photo on page 1·294).

Managing how all that water in vegetables behaves during cooking can be quite a challenge. Leafy plants evolved with elaborate mechanisms to keep water inside during the heat of the day, but the floodgates open when the leaves hit a hot pan. An attempt to sauté greens, even on a professional stove, often results in what is technically a stew. A good solution is to stir-fry leafy vegetables in a wok powered by enough kilowatts or BTUs per hour to convert the released water into steam as fast as it accumulates.

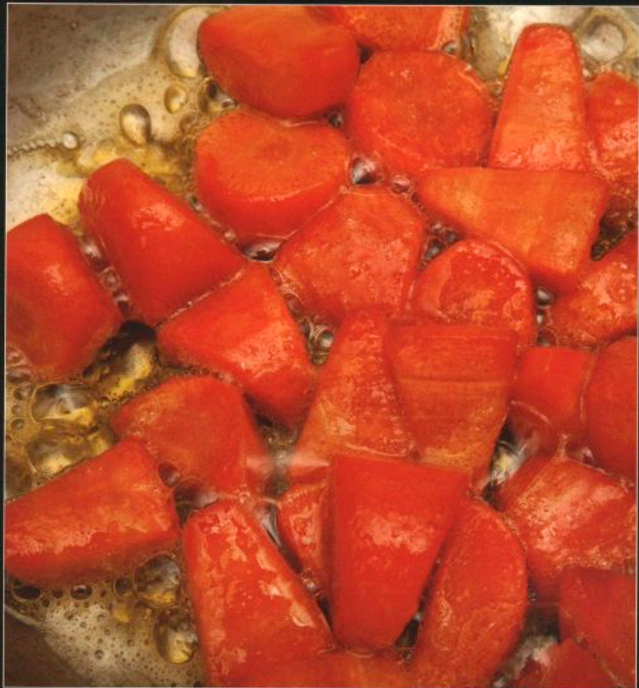
If you'll be cooking a plant food without adding any water to it, remember to take into account how much water the vegetable will release, and think about how to control it. To avoid trouble when sautéing or stir-frying produce, don't put more food into the pan than the burner can heat quickly.

In theory, steaming should be a great way to cook vegetables. But it has two problems. First, condensed steam is slightly acidic, which makes it less effective at dissolving the molecules that bind cells together than boiling is. Second, in most steamers, steam condenses as a thin film of water on the vegetables, which insulates them from heat. In this way, steaming becomes self-limiting—it can take longer to steam a vegetable than to boil it.

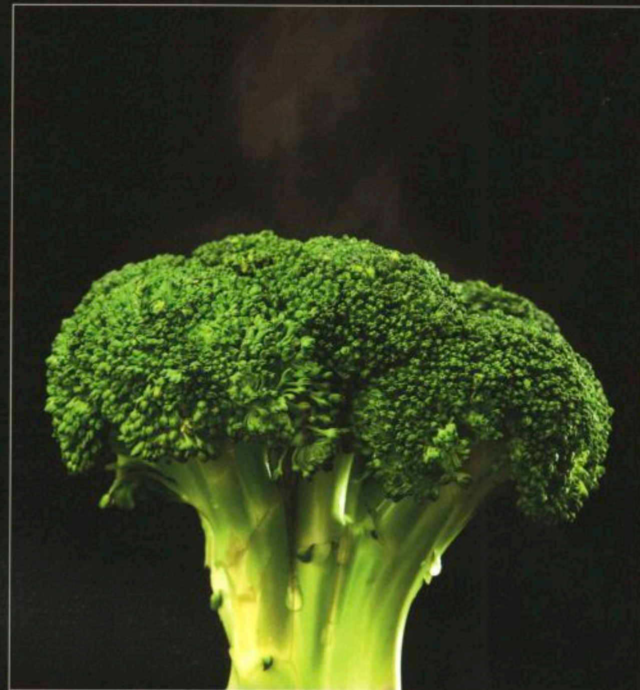
It's not just how you use the water that matters when cooking vegetables—it's also what's in it. The pH, salt, and mineral content of water can all dramatically affect the way plant foods cook.

Here's a simple experiment to demonstrate the effect. Set up three pots of dried beans in water. Add tap water and a touch of baking soda to the first pot, tap water and a slug of vinegar to the second, and distilled water to the third. Now, cook them at the same temperature and for the same amount of time.

The beans cooked with baking soda quickly turn into mush. The beans with vinegar are



Vegetables remain sweeter after cooking in butter than after cooking in water because their natural sugars cannot dissolve in fat the way they can in water and, as a result, do not leach out of the food and into the cooking water.



Broccoli doesn't leach colors, nutrients, or sugars when it is steamed rather than boiled. Steaming is nearly (but not quite) as fast as boiling (see page 2·72), and it adds no fat to the food. When steaming vegetables, be sure to keep the food close to the boiling water in the (invisible) steam and not in the cooler fog (shown in background).

The transmutation of an onion from pungent and crisp to silky, sweet, and golden brown is almost magical and is a crucial contributor to the flavor and color of many savory dishes. The browning is caused by the Maillard reaction, which involves sugars, amino acids, and sulfur compounds (see page 89). Because onions are high in natural sugars, they also caramelize—a related but different phenomenon that requires sugars.

unlikely to soften properly. The beans in distilled water cook properly. Why?

The pectin and hemicellulose that bind rigid plant cells together are more soluble and thus dissolve faster under alkaline (baking soda) than neutral (distilled water) conditions. Acidic conditions (vinegar) actually reinforce the molecules that cement cells together. (Classic Vichy carrots, cooked in true Vichy water from France, are particularly soft because the Vichy water is alkaline and quickly breaks down the cell walls.)

Like vinegar, a high–concentration of salts in the water throttles the speed at which cell walls fall apart. Very hard water contains a lot of dissolved mineral salts, some of which can actually reinforce the mortar between cells. Conversely, if your water is very soft, vegetables will cook faster—perhaps too fast.

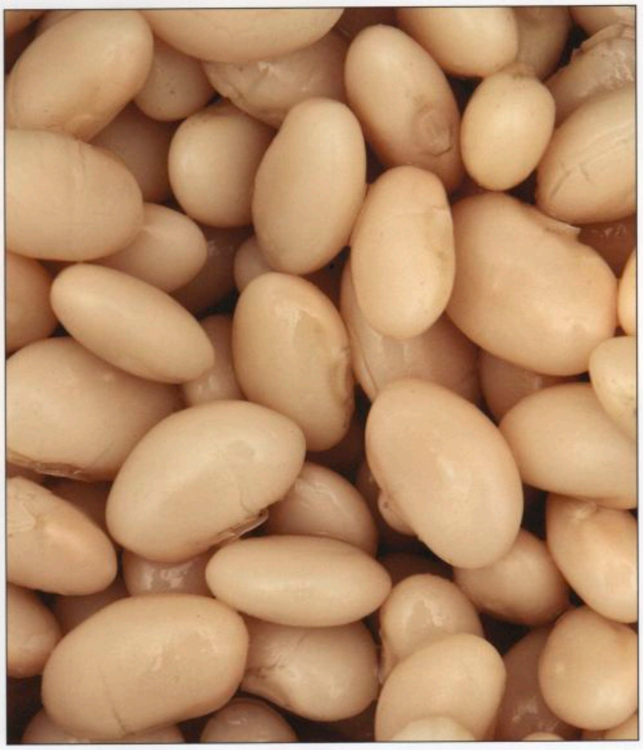
Hard water poses a particular problem when cooking green vegetables. Dissolved mineral salts (carbonate **ions**) can react with **chlorophyll** and turn vibrant chard a dull Army green—rarely the effect you want.

You can solve this problem by cooking in deionized water. Although it's not pleasant to drink, **deionized (DI) water** is essential in chemistry and useful for working around cooking challenges such as this one. If you add the right amount of pure table salt (not sea salt, which typically contains magnesium and calcium or iodized salt) to deionized water, cells come apart faster. You can also add sugar to the water to prevent natural sugars from diffusing out of the vegetables you are cooking.

More generally, understanding whether the flavors you want to preserve or extract are water-soluble or fat-soluble will help you choose the best cooking method. For sugary produce, such as carrots and other root vegetables, steaming or cooking in fat helps keep the natural sugars in the food, which in turn intensifies their flavor.

Broccoli, cabbage, and other cruciferous vegetables, on the other hand, are frequently cooked in water precisely because it helps to leach potent and unpleasant sulfurous aromas from the cooking vegetables. Garlic and chilies are frequently cooked in fat because their fat-soluble flavor compounds are easily extracted this way and give rise to flavored oils (see page 2·328).

Beans often burst after being cooked in ordinary tap water (left). To avoid this, borrow a technique used in commercially prepared, pressure-canned beans. Add 1 g of calcium chloride for every 100 g of water to gently firm the outside of the beans, which prevents them from splitting but does not make them tough (right). If you have very hard, mineral-rich water, you may need to cook your beans in bottled water, or they will never really soften.



THE MECHANICS OF

Vegetable Purees

The goal in making a vegetable puree is usually to reduce it to a fine enough grain that the tongue perceives it as smooth. That means reducing particle sizes to less than about 7 microns / 0.0003 in, which is the limit of human perception.

Typically, you do this by first cooking the food to weaken the cell walls of the plant tissue. You then apply some form of mechanical force—with a blender, a ricer, or a food processor—to shred the cellular structure. Adding fat often helps the pulverization along by enhancing lubrication; fat also helps to create a smoother mouthfeel.

Certain vegetables have ultrahard components that make producing smooth purees a particular challenge. The classic examples are chestnuts and garbanzo beans, or the chickpeas used to make the Middle Eastern dip hummus. Most attempts at making hummus or chestnut purees turn out gritty products. Both chestnuts and chickpeas are hard because they have extra reserves of cellulose and lignin, the main compounds that give wood its strength.

Of course, there are times when grittiness is precisely what you do want in your puree. The same is true for grainy or rough textures; some chefs like the rustic style. A roughly mashed potato, for example, has quite a different texture from a crushed potato or a smooth blend.

It's treacherously easy to overmanipulate the starches in potatoes so much that they become elastic and gummy, some recipes actually encourage the development of that rubbery quality. In the French potato dish aligot, for example, the taffy-like consistency is considered part of its appeal. Mostly, that consistency comes from the cheese, but the overworked starch assists.

Starches

Just as fat stores energy for animals, starch stores energy for plants. Plants also make and store fat, but starches are their principal form of stored energy. Different species of animals have varying amounts of fat depending on the demands of their surroundings, and in the same way, a plant's starch content depends on how that type of plant has evolved to meet the rigors of its environment. Ducks need large stores of fat to prepare them for migration, for example, while chickens have no such requirements. Similarly, plants that create starchy tubers, like potatoes or cassava, do so because they need to store energy safely underground—usually because of winter or some other difficult-to-survive season.

Most people think of stale bread as bread that has dried out, but drying isn't responsible for staleness. A more important effect is the recrystallization of starch granules in the bread. Reheating stale bread in an oven set to 90 °C / 195 °F or higher melts some of the crystals and refreshes and softens the bread's texture. It won't make the bread as good as new, but it will make it better than stale.

Starch exists in plants as small granules inside cells. The sheer number and average size of starch granules varies among different plant types. These characteristics distinguish even varieties of the same plant species, causing significant differences in texture and in the applications for which each variety is best suited. Potatoes are a classic example of such a difference, existing as either floury or waxy varieties. Floury potatoes, like Russet Burbanks or Maris Pipers, are dense with starch granules, while waxy potatoes, such as Charlottes or La Rattes, have a lower starch content. Varieties like the Yukon Gold are in between and act as jack-of-all-trades potatoes.

When cooked, the starch granules of floury potatoes readily swell with water—a process called **gelatinization**—and individual cells easily separate from one another; with just a little bit of mashing, the cooked potatoes yield a light and fluffy texture. This also makes these kinds of potatoes the ideal choice for baked potatoes or French fries.

The enzyme pectin methylesterase (PME) is present in most plant foods, and the heat treatment described at right thus works even for plant foods that aren't starchy. Heat-treating vegetables to stimulate PME is a common processing technique for foods that are later cooked in ways that would otherwise turn them mushy—such as canning. PME can also be purchased in a purified form and used to treat soft and delicate plant foods, such as berries, so that they remain firm even when heated. We explore the use of this enzyme on page 353.

Waxy potatoes behave differently: their starch granules are slower to swell, and their cells tend to adhere despite thorough cooking. In some applications, such as gratins or salads, this tendency to remain cohesive and resist crumbling is precisely what a cook wants from a potato. Mashing these kinds of potatoes requires a lot of effort to force individual cells apart, which tends to cause swollen granules to rupture and releases free starch into the puree. The result is a very sticky potato puree unless the cook intervenes by adding a lot of liquid or, ideally, plenty of fat.

Adding liquid dilutes the free starch just enough that the texture of the potato puree becomes dense and unctuous rather than stodgy and sticky. Unfortunately, if the puree is cooled, the starch molecules rearrange themselves into a mesh that ultimately causes that puree to gel. As the gelatinization happens, some of the molecules interact to create very stable, semicrystalline regions through a process known as retrogradation, which cannot be undone entirely by reheating the puree. This transformation is the reason that cooled and reheated potato purees tend to be gummy.

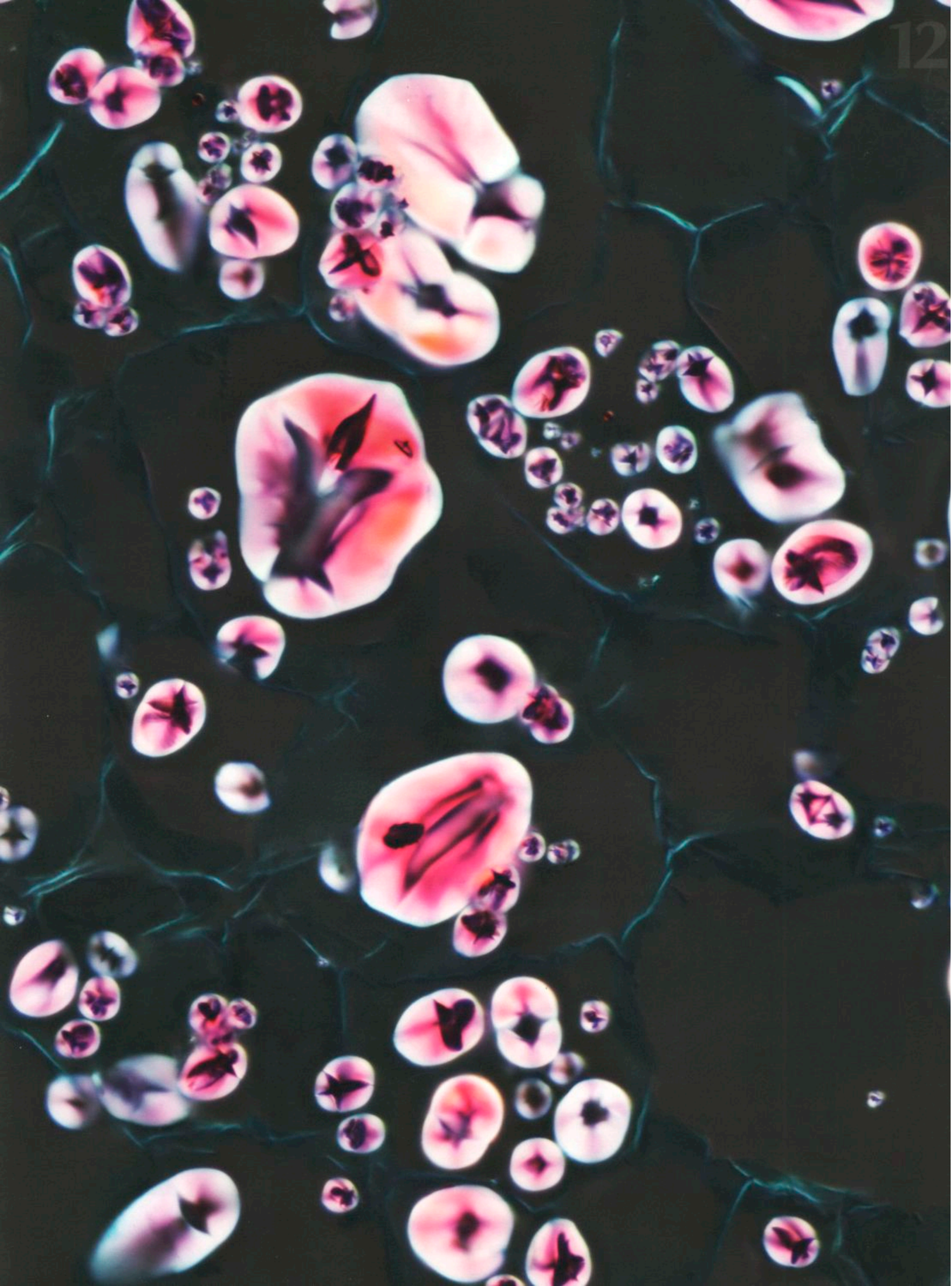
To minimize the problem, incorporate a lot of fat, traditionally butter, and as little liquid as possible. The fat molecules get in the way of the starch molecules and prevent them from gelling and firming when the puree is cooled. Puree prepared this way can be refrigerated until needed and then reheated with the addition of some liquid, such as milk or cream, until it has the desired consistency.

Sometimes, retrograding starch serves a cook's purpose. A heating and cooling treatment makes any potato or otherwise starchy produce more firm, less prone to crumble with cooking, and less likely to have its starch granules ruptured if mashed or pureed. Heat the starchy plant food to a core temperature of 60–65 °C / 140–150 °F, and then hold it at this temperature for an hour before cooling to refrigerator temperature. The heat treatment stimulates an enzyme known as pectin methylesterase, which firms cells so that the vegetable is less prone to become mushy with further cooking. Simultaneously, the heat causes starch granules to gelatinize. The subsequent cooling causes the swollen starch to retrograde, and when that is complete, the food can be reheated and mashed or pureed with much less risk of rupturing granules and releasing thickening starch.

This heating and cooling strategy can be used to prepare a *pomme puree* that, when mashed and mixed with plenty of fat, reheats very well after being kept refrigerated.

Another application of cooling after cooking

Starch granules in potato (next page) are stained red by iodine vapor; cell walls are stained blue. Each cell is packed with the starch granules, which are released when heat or mechanical mashing ruptures cell walls.



Citrus and other fruits can be peeled with enzymes, such as Peelzyme, that dissolve cellulose.

is useful when puffing starchy plant food, such as a blistery potato chip or a starch-based cracker. Thorough cooking ensures that the starch in the food is fully gelatinized, but cooling is the critical step, because it creates a firm gel from the starch. This stiff gel becomes soft and elastic when hot but remains durable enough to stretch and contain expanding steam bubbles when the food is fried or otherwise rapidly reheated.

In some situations, setting starch free is exactly the effect a cook wants. Consider risotto: the long, slow cooking process and the mechanical agitation from constant stirring release quite a bit of the grain's starch, which is necessary to attain the thick, smooth texture characteristic of the dish. Indeed, the varieties of short-grained rice favored for risotto are essential to this process precisely because of the quantity and quality of the starch they leak into the surrounding liquid. When we want to make a risotto-like dish using plant foods with less starch, we can attain the same sort of sauce only by adding a thickener: either starch itself or another hydrocolloid (see page 4·18).

Incidentally, the process of starch retrogradation is why a fully cooked risotto isn't very good when cooled and then reheated. The surrounding starchy liquid doesn't melt back into a smooth, unctuous liquid that envelops the tender grains of rice. On the other hand, parcooking the rice itself is analogous to the heating and cooling treatment used for potatoes. Doing this provides a way to make it easy to quickly finish a risotto for a faster service. Parcooked risotto will be slightly more al dente than is the norm from this treatment but will still release enough starch to adequately thicken the added liquid and finish the risotto for service.

Enzymes

When you drop an apple, it bruises, and the bruised spot soon turns brown. This blemishing seems contrary to the biological imperative of fruit, which is to use both flavor and beauty to entice eaters. Yet browning is one of the chemical reactions in a plant's protective arsenal.

Browning is caused by **enzymes**—proteins that control chemical reactions—called **polyphenol oxidases**. In unblemished fruit, these enzymes are sequestered outside the **vacuole**, the big, sloshy compartment that helps give a plant cell its rigidity. When trauma disrupts a fruit's cells and ruptures the vacuole, the tissue softens, and the enzymes mix with oxygen from the vacuole to cause a chemical reaction that creates brown pigments. These pigments have antimicrobial and insecticidal properties. When they are released from the cells in damaged areas, they provide protection against insects, fungi, bacteria, and molds that could invade the compromised tissue. Browning, for a plant, is a defense mechanism to limit further damage. In this respect, browning is much like blood clotting in humans.

When cooking, we usually wish to avoid unsightly browning. Because oxygen is essential to the browning reaction, antioxidants like ascorbic acid (vitamin C) inhibit it. Lowering the pH, with lemon juice, for example, also slows the various reactions involved in browning. Acid washes are less necessary in foods naturally high in antioxidants, because they tend to brown slowly. Foods with a darker background color are also of less concern, because they won't show the browning effects so vividly.

Another simple way to prevent browning is to cook the plant at a temperature high enough to destroy the relevant enzymes. To halt browning in an apple, for example, remove the peel and give it a quick blanch. The fruit needn't be cooked through, because browning occurs only at the surface, where the damage has been done.

Industrial food producers commonly use this method to discourage browning and to preserve color and flavor. Peas, for example, are generally blanched and frozen in the field just after harvest to destroy their polyphenol oxidases and to preserve their vibrant green color, which would otherwise quickly turn dull. Field-blanching also destroys a separate enzyme that converts the natural sugars of ripe peas into starches immediately after harvest. This is why industrially produced frozen peas generally taste sweeter and better than so-called farm-fresh peas. It sounds like heresy, but it's quantifiably true, as measurement of sugar content proves.

You can also use heat to encourage fruit to ripen, a process that involves a large cast of enzymes. Enzymes convert starches to sugars, trigger color changes, and prompt certain parts of cells to degrade into fragments that produce the aromatic compounds we associate with ripeness. As with most chemical reactions, enzymes work faster at higher temperatures—up to the point where the heat is enough to destroy them. Fruits that evolved in tropical conditions tend to have enzymes that operate at higher temperatures, and higher temperatures are required to destroy those enzymes. Likewise, fruits that evolved to function in cooler temperatures have enzymes that are destroyed at lower temperatures.

Fruits ripen in two distinct ways, and heat accelerates only one of those. **Climacteric** fruits, such as apples, pears, and bananas, continue to ripen after being picked. These fruits also ripen faster in the presence of ethylene, a gas that plants produce as a natural trigger for ripening. You can use ethylene or heat to hasten ripening in climacteric fruits (although in most cases they taste better if allowed to ripen on the plant). **Nonclimacteric** fruits, such as grapes and pineapple, on the other hand, do not ripen once picked. Neither heat-

The medlar, a small, brown fruit related to pears, is seldom seen today but was grown throughout the Mediterranean and Europe 1,000 years ago and served as an accompaniment to wine. Because the ripening cascade in medlars does not make them palatable until long after they are picked, you have to "blet" them before eating. Bletting involves storing the fruit in a cool place for several weeks until the flesh softens to the consistency of applesauce. You then puncture the thick skin and suck out the pulp.

For more on using ethylene to ripen fruit, see How to Ripen on Command, page 285.

The ripening of bananas results when enzymes are triggered by the presence of ethylene gas. In a high enough concentration, ethylene gas smells sweet—a bit like perfume. At very high concentrations, it causes euphoria, and breathing 20% ethylene or more can render you unconscious. Fortunately, ripening fruit emits such low levels of ethylene that your fruit bowl won't make you swoon.

The oracle at Delphi was an important institution in ancient Greece. A woman known as the Pythia would become entranced and issue predictions about the future. Recent geologic evidence suggests that the Pythia may have been entranced by natural emissions of ethylene gas. The theory is controversial but is consistent with ancient accounts of "sweet vapors" during the trance of the Pythia.

ripening nor ethylene-ripening works on them.

There are no hard-and-fast rules for this technique, and the guidelines are different for nearly every fruit. You can seal a cantaloupe in an air-free package with a little alcohol, and then heat it in a water bath at 45 °C / 113 °F. Avocados respond well to a short heat treatment combined with ethylene gas (see next page).

You can use heat to manipulate enzyme activity in ways that delay certain spoilage processes. Blanching vegetables at a fairly low temperature—say, 40 °C / 104 °F—for a few minutes can shut down enzymatic activity and delay wilting, browning, and rotting. Heat-treated iceberg lettuce retains its crisp texture; a similar procedure helps delay the softening of stored carrots. The mechanism of action is not completely understood but probably includes the deactivation of some surface contaminants like molds and bacteria.

THE CHEMISTRY OF

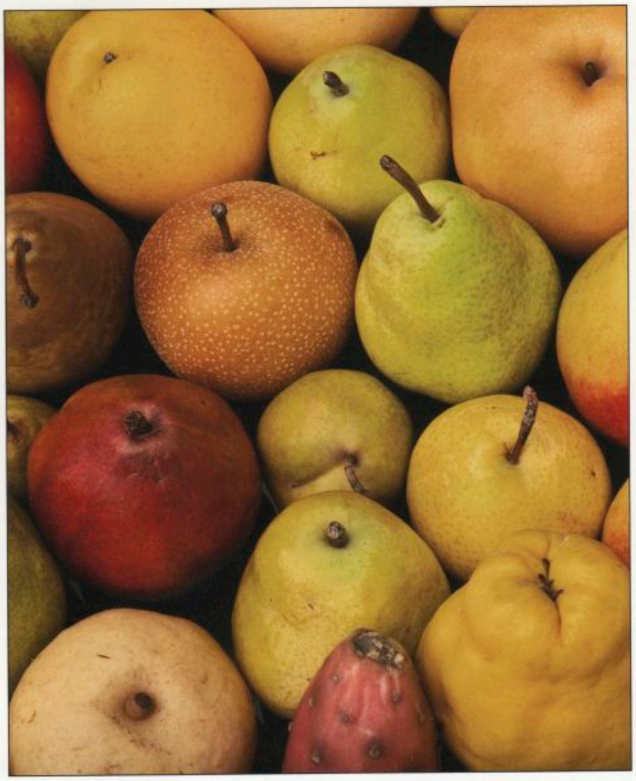
Synchronized Ripening

If you visit the plains of the Serengeti during the right time of year, you'll see an amazing thing: all of the wildebeests and zebras in a herd, sometimes numbering more than a million, will give birth to their babies within a two-day period. This phenomenon, called predator satiation, or saturation, ensures that lions, hyenas, and other predators will kill fewer of the babies than they would if the young were born one at a time over a longer period. Predators can eat only so much in the course of a couple of days; meanwhile, the lucky babies that aren't eaten have time to grow stronger, faster, and less vulnerable.

Many plants also coordinate when they present their seeds or fruit in a process called "masting." Synchronized ripening accomplishes different objectives for different kinds of plants. Seed- or nut-producing plants do it for the same reason that wildebeests do: to minimize the number of offspring that get eaten. Fruit-producing plants, on the other hand, coordinate the ripening of fruit to attract animals en masse. Those plants need animals to eat their fruit and distribute their seeds, and they need a grand presentation to draw animals from a long way away.

Plants coordinate masting with a gas called ethylene, which is released by most ripening fruit. Ethylene is, in effect, a way that fruit can communicate when it is time to ripen. Thus, the ethylene from one ripe apple (or other ethylene-rich fruit) can trigger the ripening of the rest. People can use ethylene to send the same message; the ancient Egyptians and Chinese did so, and we can, too.

The simplest way to ripen with ethylene is to put an apple in a paper bag with the fruits you want to ripen. Make sure the bag is closed but not airtight. You want to concentrate enough ethylene gas to encourage ripening but still allow the flow of oxygen the fruits need to make the enzymes that turn them ripe. This method will also brighten the peels of citrus fruits. If ripe trigger fruits aren't available, you can duplicate the process by using a tank of compressed ethylene gas.



Note that certain fruits, such as grapes, pineapples, and strawberries, will not ripen further after they are picked no matter how much ethylene they're exposed to. And while "ripeness" is a concept that applies only to fruits, remember that fruits include many plants—pumpkins, zucchini and other squash, tomatoes, and eggplants—that are usually classified as vegetables. They may not be sweet, but they'll respond to ethylene as well as bananas do.

HOW TO Ripen on Command

Ethylene is a naturally occurring plant hormone that stimulates the production of enzymes that catalyze growth and maturation. Fruit exposed to ethylene gas ripens faster than it otherwise would. The old trick of putting hard peaches in a brown bag exploits this effect; the fruits emit ethylene, which builds up in the bag and accelerates the natural ripening process. You can use sous vide bags and a tank of ethylene gas to put the same principle to work on a larger scale.

Growers often ship delicate fruits such as tomatoes and peaches when the fruit is green and hard; this strategy minimizes blemishes and bruises. Melons, berries, bananas, and other fruits that are often shipped great distances are usually picked well before they are ripe so that they can withstand the journey to market. And some fruits, including avocados and pears, will not ripen until they fall from the tree.

These fruits are all good candidates for ripening with ethylene, which is available where other kitchen gases are sold. Contact with ethylene stimulates starch molecules in the fruit to break down into simpler sugars. The gas also softens the cell walls and enhances aromas. There is no substitute for the natural sugars and flavors present in tree- or sun-ripened fruit. But when those aren't options, gas-ripened fruit is often the next best thing.

1. **Seal with air in a sous vide bag.** Arrange the unripe fruit in a single layer in a sous vide bag, and seal with air. Do not use a vacuum.

2. **Fill the bag with gas.** Snip off a corner of the bag, and insert the nozzle of the ethylene tank. Add gas, and then remove the nozzle.

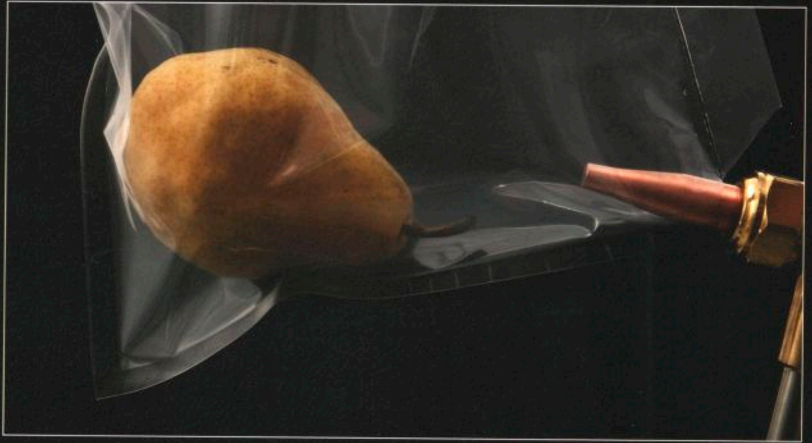
3. **Reseal the bag by heat-sealing.**

4. **Store at room temperature to ripen.** Recommended ripening times are listed in the table below. Avocados require heat treatment for best results.

Best Bets for Gas-Ripened Fruit

Unripe fruit	Time to ripen naturally (h)	Time to ripen with ethylene gas (h)
avocado*	48	3
banana	48	12
berries	72	8
melon	72	24
pear	120	36
tomato	36	10

**(after resealing with ethylene gas in step 3, warm sous vide in a 50 °C / 122 °F bath for 1 h, and then remove from bath, ripen sealed at room temperature for 2 h, and remove from bag)*



COOKING SOUS VIDE

Sous vide packaging equipment opens up new ways to "cook" relatively tender plant foods. A chamber sealer can be used for vacuum compression and infusion, two closely related Modernist techniques that essentially wilt and soften plant foods by rupturing vacuoles inside the plants' cells. See page 390 for a more complete explanation.

The kingdom of plants is replete with biological diversity among its hundreds of thousands of unique species. Even a single species' appearance, texture, and flavor vary from one part of the plant to another, change as the plant matures, and can even be influenced by growth conditions. The complexity of nature's cornucopia is both awesome and mostly impossible to simplify.

Luckily, cooking plant foods is simple. Compared to the cooking of meats or seafood, the way heat tenderizes the cells and structures of plant tissues is straightforward and substantially more forgiving of less-than-exact cooking temperatures.

The texture of plant foods mostly depends on the strength of individual cells and how strongly these cells adhere to each other. How we perceive this texture depends mostly on how easily our teeth can rupture cells and push them apart as they bite through the food. The strength of an individual plant cell is governed by the degree to which its water-filled vacuole inflates the cell and also by the heft and sturdiness of its cell wall. How strongly cells are bound together has to do with how they are packed together and, especially, with the quantity and quality of adhesive molecules embedded in the cell walls.

When plants are cooked above 60 °C / 140 °F, the vacuoles begin to rupture, and the cell walls spring leaks, allowing water to escape into the pot. As the cells empty, their internal pressure falls, and they deflate and pull away from each other. This creates gaps between the cells that weaken the tissue. Tender and delicate plant foods wilt when this happens.

Plant foods that are tough and durable, however, have thick, sturdy cell walls that resist collapsing when water escapes through them. Often they also contain hard starch granules that need to be softened. Although their gritty, raw-tasting starch generally begins to swell and soften at temperatures just slightly above 60 °C / 140 °F, cooking temperatures around 90 °C / 195 °F or hotter are needed to soften these kinds of plant foods. At these temperatures, the adhesive material in cell walls begins to dissolve. That weakens the cells—making it easier for our teeth to break them open—and also loosens their bonds to neighboring cells—making it easier for our teeth to separate them.

When choosing a temperature for cooking plant foods, keep in mind that the higher the temperature, the faster the food softens and thus the more important it is to time cooking just right. Conversely, lower cooking temperatures are more forgiving of timing. But holding plant foods too long at any cooking temperature is a bad idea unless you want to turn them into a puree.

The important role of cooking time is quite unlike what occurs when cooking meats, seafood, and other protein-based foods. The exact cooking *temperature* matters a lot for these foods, but once they reach the target temperature they can be held at it for quite a while without a loss in quality. Indeed, a long holding time at a specific cooking temperature is one of the hallmarks of sous vide cooking, because it tenderizes meat proteins.

With plant foods, the cooking temperature is much less critical as long as it fall within a fairly broad range. We favor cooking many plant foods sous vide at temperatures close to 90 °C / 195 °F, rather than boiling them, because at these lower temperatures, timing needn't be as precise.

Of course, you can cook plant foods at temperatures below the boiling point of water without going to the trouble of vacuum packing the food first. But a sous vide approach makes it easy to measure the ratio of food to cooking liquid and any seasonings. It's also a more frugal way to use valuable broths, stocks, or oils. Compared to boiling in a large amount of water, packaging and sealing the food avoids diluting and dulling the flavor. Better yet, the packaging retains the flavorful juices that escape during cooking.

Finally, vacuum-packed plant foods can be cooked in a water bath, boiled in a pot of water, steamed in a combi oven, pressure-cooked (if suitable packaging is used), or even microwaved. In each case, the food sealed inside the packaging cooks in the same way; only the cooking temperature varies.

Sous vide is an ideal way to cook garden vegetables precisely to the desired texture.

PARAMETRIC RECIPE

FRUITS AND VEGETABLES SOUS VIDE

Cooking plant foods sous vide has several advantages. One is that plant tissue softens more slowly at temperatures below the boiling point of water. This increases the window of ideal doneness, so there is less risk of inadvertently overcooking the food. Packaging the food also makes it easy to add measured amounts of water, fats, oils, and other flavorful liquids, along with any seasonings, to achieve consistent results. Sealing the food in an impermeable bag prevents the natural sweetness and flavor of plant foods from being diluted during cooking. Indeed, the packaging will contain any juices that do leak out, so it is easy to reincorporate them into the final preparation. Finally, in some cases, the exclusion of oxygen while cooking plant foods better preserves their appearance and flavor.

Best Bets for Cooking Fruits Sous Vide Until Tender

		Cut to		Cook			
Ingredient	Prep	(cm)	(in)	(°C)	(°F)	(min)	See page
apricots	peeled, pitted	halves		88	190	15	
apples	peeled, cored	halves		88	190	40	4·276
bananas	skin on	whole		88	190	12	4·166
cantaloupes	peeled, seeded, cubed	2.5	1	53	127	15	
cherries		whole		88	190	7	
cranberries		whole		88	190	45	
grapes		whole		83	181	10	
mangoes	peeled, pitted, cubed	2.5	1	75	167	10	
nectarines	peeled, pitted	halves		88	190	12	
peaches	peeled, pitted	halves		88	190	16	
pears	peeled, cored	whole		88	190	60	
persimmons, soft Hachiya	stemmed	quarters		88	190	20	
pineapples	peeled, cored, cubed	2.5	1	75	167	60	
plums	pitted	halves		75	167	20	

PREPARING VEGETABLES OR FRUITS SOUS VIDE

1 **Select and prep ingredients.** Some of our favorites, along with prep steps, are listed in the tables on these two pages.

2 **Vacuum seal.** See chapter 9 on Cooking Sous Vide, page 2·192, for details.

3 **Cook.** Recommended cooking temperatures and times appear in the tables above, as do references to example recipes elsewhere in the book.

Best Bets for Cooking Vegetables Sous Vide Until Tender

Ingredient	Peel	Cut to (cm)	Cut to (in)	Cook (°C)	Cook (°F)	Cook (min)	See page
asparagus, green or white	yes	15	6	85	185	15	5·147, 2·341
bamboo shoots, fresh	yes	2.5	1	80	176	6 h	5·247
beets, baby	no	whole		85	185	1 h	5·183
beets, large	optional	5	2	82	180	1 h	
carrots, large	yes	15	6	85	185	45	5·164
carrots, young	no	whole		85	185	40	5·32
celery roots	yes	5	2	85	185	1½ h	
chard stems		15	6	88	190	25	
corn, on cob		7.5	3	60	140	15	
daikon radishes	yes	5	2	85	185	25	
endives, Belgian		whole		88	190	50	
fennel bulbs		cut in half		85	185	30	
hearts of palm	yes	whole		85	185	1½ h	
kohlrabi	optional	5	2	88	190	1¼ h	
leeks	root removed	cut in half		85	185	50	
mushrooms (shiitake, crimini, oyster, shimeji, enoki, lobster, porcini)	no	whole		90	194	10	5·187
onions, cipollini	yes	whole		90	194	2 h	5·19
onions, pearl	yes	whole		85	185	50	5·230
onions, sweet	yes	cut in half		88	190	45	
rutabagas	yes	5	2	85	185	1 h	5·53
salsify	yes	5	2	88	190	15	5·205
shallots	yes	whole		85	185	1 h 25	
Jerusalem artichokes (sunchokes)	optional	5	2	85	185	1 h	
squash, summer (zucchini, yellow)	no	5	2	65	149	40	
squash, firm autumn varieties (Hokkaido, kabocha, kuri)	yes	5	2	90	194	15	
squash, tender autumn varieties (acorn, butternut, delicata)	yes	5	2	85	185	25	
turnips	yes	5	2	85	185	35	5·33

VARIATION: Cooking Fruits or Vegetables Sous Vide for Puree

Cooking for a puree requires longer cooking, higher temperatures, or both to soften fruits and vegetables prior to pureeing them.

1 **Select and prep ingredients.** See the table below for recommendations. Peel, stem, or pit the produce to remove coarse or bitter components and to simplify handling after cooking. Cut evenly.

2 **Vacuum seal.** See chapter 9 on Cooking Sous Vide, page 2·192, for details.

3 **Cook.** Recommended cooking temperatures and times appear in the table below, along with references to example recipes elsewhere in the book.

4 **Puree until smooth.** Use a blender or food processor, and then pass through a fine sieve, ricer, or food mill. See page 2·424 for more details.

Best Bets for Cooking Fruits or Vegetables Sous Vide for Purees

	Cut to		Cook			
Ingredient	(cm)	(in)	(°C)	(°F)	(h)	See page
apples, peeled	quarters, cored		88	190	2	5·20
bananas, peel on	whole		88	190	12 min	5·98
blackberries	whole		65	149	1	
dates, pitted	whole		80	176	2	5·122
garlic	cloves, peeled		88	190	1	
kohlrabi	7.5	3	88	190	1½	
mangoes	5	2	75	167	20 min	
mushrooms, dried	whole		90	194	1	
mushrooms, fresh	whole		90	194	2	
nettles	leaves		95	203	10 min	
onions and shallots	7.5	3	88	190	2	
pears, peeled	halves, cored		88	190	1½	
potatoes, peeled	7.5	3	100	212	35 min	296, 5·8
rhubarb	7.5	3	88	190	1	
rutabagas	7.5	3	85	185	2	
spinach	leaves		90	194	7 min	
squash, winter varieties (Hokkaido, kabocha, Kuri)	7.5	3	90	194	45 min	5·63
tomatoes, peeled and seeded	quarters, cored		85	185	25 min	
turnips	7.5	3	85	185	30 min	
watercress	leaves		90	194	10 min	2·426

VARIATION: Cooking Fruits or Vegetables Sous Vide in Sugar Syrup

1 **Make the syrup.** Use equal amounts of water and sugar (sucrose or other, less sweet sugars such as isomalt or glucose syrup), or adjust the sweetness to accommodate your taste and the sweetness of the fruit. Fully dissolve the sugar in the water.

2 **Select and prep ingredients.** The table below offers some good options. For easy handling after cooking, peel away tough skins, remove pits, and cut evenly.

3 **Add syrup, and vacuum seal.** The syrup column in the table below indicates the quantity to use relative to the weight of the fruit. For example, add 20 g of syrup to the sous vide bag for every 100 g of dried apricot.

4 **Cook.** Recommended cooking temperatures and times appear in the table below, along with references to example recipes elsewhere in this book.

Best Bets for Cooking Fruits Sous Vide in Sugar Syrup Until Tender

Ingredient	Prep	Syrup (scaling)*	Cook (°C)	Cook (°F)	Cook (h)	See page
apples	peeled, halved, cored	50%	90	194	3	
apricots, dry	whole	20%	80	176	1	5·173
chestnuts	peeled, whole	100%	90	194	12	
citrus fruits (oranges, limes, lemons, mandarins, kumquats)	whole	100%	90	194	4	
	segments	30%	88	190	40 min	
	quarters	40%	88	190	12	
cranberries	whole	10%	88	190	45 min	
grapes	whole, peeled	10%	83	181	8 min	
grapefruits	peels with pith only	200%	90	194	5	5·226
Buddha's hand lemons	cut into fingers	100%	75	167	2	
quinces	peeled, halved, cored	100%	95	203	8	

*(*set weight of fruit to 100%*)

VARIATION: Cooking Vegetables Sous Vide With Fat

1 **Select and prep.** See the table below for suggestions and prep steps.

2 **Add fat, and vacuum seal.** The fat column in the table indicates the kind and quantity that works best. Proportions are relative to the weight of the vegetable. For example, add 20 g of olive oil to the sous vide bag for every 100 g of trimmed artichokes.

3 **Cook.** Recommended cooking temperatures and times appear in the table below.

Best Bets for Cooking Vegetables Sous Vide with Fat Until Tender

	Cut to				Cook			
Ingredient	(cm)	(in)	Fat	(scaling)*	(°C)	(°F)	(min)	See page
artichokes, baby	whole		olive oil	20%	85	185	1 h	5·244
artichokes, mature	half		olive oil	20%	85	185	1½ h	5·172
carrots, large	7.5	3	butter	30%	83	181	45	
chestnuts, peeled	whole		lard	15%	90	194	12 h	5·18
crosnes (Chinese artichokes)	whole		clarified butter	20%	85	185	35	
Japanese yams	7.5	3	butter	20%	95	203	45	5·35
garlic	whole cloves		olive oil	40%	88	190	7 h	
potatoes	7.5	3	butter	30%	85	185	45	5·195
shallots	whole		neutral oil	15%	85	185	1 h 25 min	
squash, kabocha	7.5	3	olive oil	15%	90	194	1 h	
sweet potatoes	7.5	3	clarified butter	10%	90	194	40	
turnips	7.5	3	butter	10%	85	185	15	

*(*set weight of vegetable to 100%*)

VARIATION: Cooking Heat-Sensitive Vegetables Sous Vide

Some vegetables have delicate flavors that are ruined by high temperatures. Cooking at lower temperature eliminates the raw taste without destroying the desirable fresh flavor.

1 **Select and prep ingredients.**

2 **Vacuum seal.** See chapter 9 on Cooking Sous Vide, page 2·192, for details.

3 **Cook.** Recommended cooking temperatures and times appear in the table below.

Best Bets for Warming Vegetables Sous Vide

		Warm			
Vegetable	Prep	(°C)	(°F)	(min)	See page
asparagus	whole, stalks peeled	70	158	5	
corn	cobb	60	140	15	
		70	158	15	
fava beans	peeled	75	167	25	4·122
green chickpeas	whole	75	167	20	
kohlrabi	thinly sliced	75	167	20	
peas	peeled	70	158	18	4·122
spring turnips	quartered	70	158	15	
young carrots	whole, peeled	75	167	45	
zucchini	thinly sliced	75	167	20	

HOW TO Blanch Sous Vide

Many cooks have noticed that cooking fruits and vegetables in water dulls their taste and sometimes their color. H. Alexander Talbot and Aki Kamozawa of Ideas in Food have proposed that sealing and blanching produce in a sous vide bag prevents various taste, aroma, and nutrient compounds from leaching into the blanching water. Vacuum packing also excludes oxygen before, during, and after blanching that can prevent enzymatic reactions that discolor many plant foods.

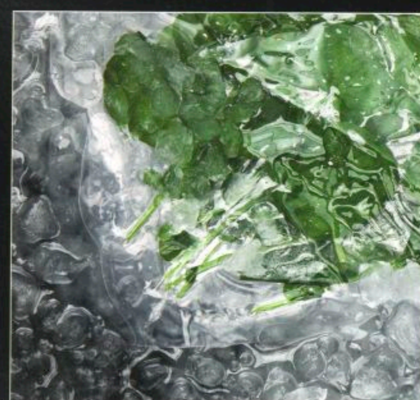
The only significant drawback to this approach is that potent aromas of many plant foods, such as broccoli and other members of the Brassica family, are outgassed when those foods are cooked. The odors are then contained by the packaging. In such cases, open the packaging and remove the food immediately after blanching it to prevent these smells from spoiling the flavor of the food.

Vacuum-sealed parsley oil

1 **Preheat the water bath.**

2 **Vacuum seal.** Trim any leaves so that they lie flat within the sous vide bag in an even layer no more than 2 cm / ¾ in thick and don't get crushed during vacuum sealing.

3 **Cook sous vide.** See the table below for recommended times and temperatures.



4 **Chill the bag in ice water for 30–60 s.** Remove it from the ice bath when it is cool to the touch.

5 **Remove the food from the bag right away.** Refrigerate. Finish by briefly steaming, deep-frying, or otherwise reheating the food.

Best Bets for Blanching Sous Vide

Vegetable	Prep	Cook (°C)	Cook (°F)	Cook (min)
broccoli, florets	cut to 2.5 cm / 1 in thick	85	185	15
Brussels sprouts	leaves	85	185	7
	cut in half	88	190	9
cabbage (all varieties)	leaves, membrane removed	90	194	4
cauliflower	cut to 2.5 cm / 1 in thick	88	190	12
pea vines	vines	90	194	8
spinach	leaves	90	194	7
sweet peas, shelled	whole	90	194	7
watercress	leaves	90	194	10

THE HISTORY OF

Michel Bras and *Le Gargouillou*

Michel Bras, founding chef of the Bras restaurant in France, grew up on the plateau where his restaurant stands. He has spent his life collecting the local herbs, fruits, vegetables, flowers, nuts, and seeds that arrive seasonally. Bras meticulously prepares each ingredient on the very day of its harvest by using the method best suited to it, and then builds an artistic mélange of sometimes 20 different ingredients and textures on each guest's plate. Bras calls his dish *Gargouillou*. His philosophy, presentation, and connection to the seasons mirror in many ways the reverence and aesthetics associated with Japanese kaiseki.

Bras's ability to connect diners with their environment and to encourage appreciation of daily changes in their landscape has inspired other chefs worldwide—such as Andoni Luis Aduriz, Quique Dacosta, David Kinch, and Paul Liebrandt—to combine a kaleidoscope of vibrantly fresh, raw, cooked, or pureed ingredients simply dressed with an aromatic oil or foam into a work they call "Into the Vegetable Garden." Rene Redzepi of Noma in Denmark introduced "edible earth" as another textural element; see page 4·37 for our homage to these chefs.

Let the table below pique your own creative combinations in the style of Michel Bras. This chapter features recipes and cooking techniques for many of the ingredients listed.

A Sampling of Seasonal Flavors

Season	Cooked fruits and vegetables see page 288	Raw fruits and vegetables see pages 269, 390	Grains, nuts, and seeds see pages 303, 304, 376
Summer	blackberry; artichoke, broccoli, eggplant, fennel, fresh seaweed, fresh shelling bean, garlic chive, green bean/haricot vert, leek, pepper, spring carrot, sweet corn, wax bean, zucchini	cherry, grape, melon, peach, plum, summer berries; avocado, cucumber, heirloom tomato, summer lettuce	sprouted grain; pine nut; sunflower seed
Autumn	broccoli rabe, Brussels sprout, cabbage varieties, carrot, cauliflower, chanterelle, chickpea, crosne, endive, hedgehog mushroom, kohlrabi, lobster mushroom, parsnip, porcini, shallot, sunchoke, sweet potato, tender squash, yam	apple, Asian pear, fig, pear, persimmon, pomegranate; radicchio	amaranth, barley, brown rice, buckwheat, quinoa, risotto rice, steel-cut oats, teff; almond, walnut; wild rice
Winter	banana; beet varieties, black trumpet mushroom, celery root, chestnut, collard green, lentil, potato, rutabaga, salsify, spinach, starchy squash, storage onion, Swiss chard, turnip, white bean	all citrus, coconut, mango, pineapple; watercress	cornmeal, kamut, millet, rye berry, spelt, wheat berry; hazelnut; poppy seed, flaxseed
Spring	asparagus (white and green), bamboo shoot, fava bean, fiddlehead fern, garlic scape, green chickpea, green pea, morel, nettle, new potato, pea vine, porcini, ramp, rhubarb, spring garlic, spring onion	miner's lettuce, purslane, radish, sea bean, wild arugula, wild garlic	cashew, macadamia; sesame seed

Purees see page 290	Preserves see pages 348, 362	Dehydrated foods see page 365	Spices and aromatics see pages 2·310, 2·326, 2·328	Herbs and decorations
apricot, blackberry, corn, eggplant, gooseberry, tomato	preserved lychee, smoked corn, tomato confit	leek glass, squash blossom crisps	angelica, dried mango, fresh chili, lavender, lemongrass, myrtle, pink peppercorn, sumac, vanilla bean	anise hyssop, basil varieties, cilantro, lemon verbena, mint, myoga, oregano, salad burnet, summer savory
apple, carrot, cauliflower, cranberry, persimmon, quince, squash, sunchoke	cabbage and rutabaga sauerkraut, cabbage kimchi, garlic confit, lemon confit, marron glacé	apple glass, persimmon leather, squash paper	coriander seed, fennel seed, mustard seed, nigella seed, nutmeg, paprika, saffron, star anise, tamarind	dill, lovage, marjoram, rosemary, sage
date, garlic, onion, potato, rutabaga, turnip	pickled citrus slices, pickled okra, salt-preserved lemon, smoked potato and onion	beet chip, carrot leather, citrus leather, mango paper	allspice berry, caraway, cardamom, clove, cumin, dry chili, fresh horseradish, ginger, juniper berry, licorice, makrud lime, paprika	chive, parsley, perilla, thyme, winter savory
garlic, nettle, pea, rhubarb, spring, sunchoke	pickled ramp, pickled rhubarb, pickled spring garlic, salted radish	green pea wafer, ramp leaf chip, rhubarb glass	curry leaf, fresh wasabi, jasmine, rose, young ginger	borage blossom, chervil, chive blossom, epazote, tarragon

PARAMETRIC RECIPE

POTATO PUREES

The choice of potato is of paramount importance when preparing either light, fluffy mashed potatoes or dense, silky potato puree. A floury potato, such as the Russet Burbank in the U.S. or the Maris Piper in much of Europe, is the perfect choice for mashed potatoes. Cells in these varieties readily split apart with cooking and some mashing. Adding just enough liquid and fat to moisten the mixture is all that is necessary to finish the dish. But if a fluffy texture is really what you are after, the best approach is to make a potato foam—an innovation of Ferran Adrià.

If instead you want a silky texture in the style of the French *pomme puree*, then waxy potatoes are best. The most famous recipe comes from Joël Robuchon, who favors the La Ratte variety, whereas Heston Blumenthal's version uses the Charlotte. The color pigments that lend both varieties their very yellow flesh also imbue a deep, earthy flavor to the puree. But the real secret to a great potato puree, as revealed by food writer Jeffrey Steingarten, is a heat treatment step that gelatinizes the starch and stabilizes granules. Even with this step, it is important to be gentle so as to rupture as few starch granules as possible when making the puree. Gently sieve the potatoes (never use a food processor), and add lots of fat to keep the starch that has been freed from forming a sticky puree.

The very mild flavor of potatoes is often lost to the fat or other ingredients. We have found two approaches to boost the flavor; either works with any of the recipes presented here. The first method makes an infusion (using water or other liquid from the recipe) from the potato skins, which have a more concentrated potato flavor than the flesh does.

The second flavor-enhancing approach is to sauté instant dried potato flakes gently in butter until browned. This produces a roasted potato flavor. Other flavors, such as garlic, can also be infused into the liquids, or garlic (or any other vegetable) can be cooked, pureed (see page 290), and added to the potato mixture at the end. Dried shiitake or cep mushrooms infused in milk or cream lend a wonderful mushroom note (see page 2·310). Adding starch to potatoes may seem like carrying coals to Newcastle, but we find that a small amount makes a big difference.

EXAMPLE RECIPE

POTATO PUREE

Yields 1 kg

INSPIRED BY JOËL ROBUCHON, JEFFREY STEINGARTEN, AND HESTON BLUMENTHAL

INGREDIENT	QUANTITY	SCALING
Yukon Gold potatoes, peeled and skins reserved	500 g	100%
Water	2 kg	400%
Sugar	20 g	4%
Unsalted butter, cubed	250 g	50%
Whole milk	125 g	25%
Crème fraîche	30 g	6%
Salt	to taste	

(original 1981–2005, adapted 2010)

MAKING PUREED POTATOES

1 **Peel and cut potatoes evenly, saving peels, then rinse the potatoes.**

2 **Vacuum seal potatoes with peelings and water (and sugar, if any), then cook sous vide in a 70 °C / 158 °F bath for 35 min.** See the table on the next page for recommended liquids and quantities, which are expressed as a percentage of the weight of the potatoes after cooking. You can substitute the liquid from the bag for liquids in the recipe.

3 **Remove potatoes from bag, drain, and cool completely.**

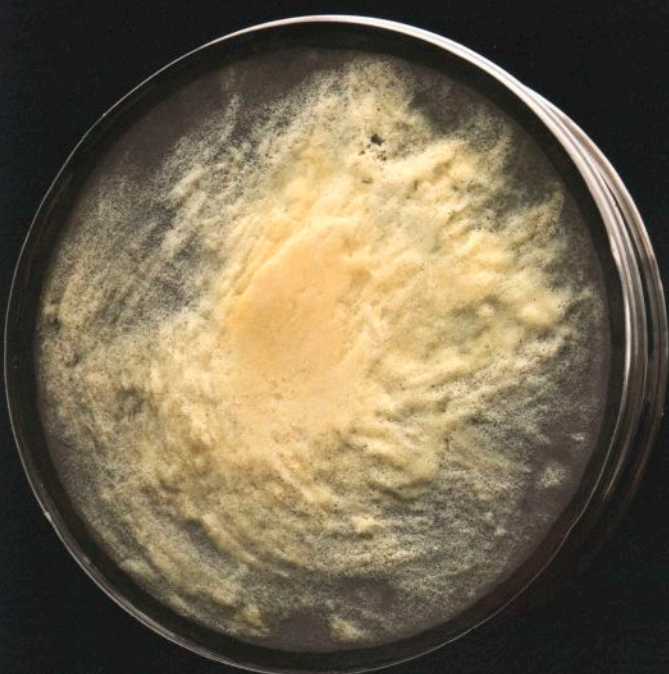
4 **Optionally, sauté instant potato flakes in butter until golden.** Puree them in a mortar and pestle, and reserve for use as a flavor enhancer.

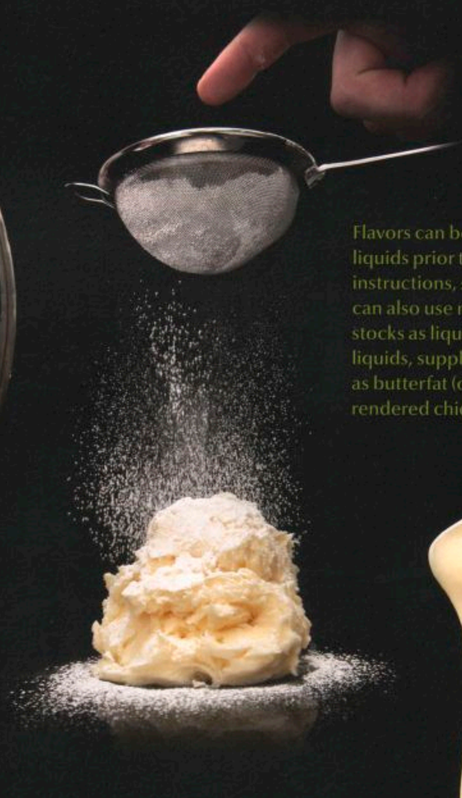
5 **Boil potatoes until tender.** Cooking times vary with the variety of potatoes and thickness of cut, but 15–25 min is typical.

6 **Drain, and then press potatoes through ricer or food mill directly over cubed butter (see photo above).** Then fold the potatoes with the butter.

Best Bets for Potato Purees

Recipe	Potato solid	(scaling)	Liquid	(scaling)	Fat	(scaling)	Other ingredients	(scaling)	See page
Robuchon pommes purée	Ratte or fingerling	100%	whole milk crème fraîche	25% 6%	unsalted butter	50%	salt	2.0%	
Blumenthal puree	Charlotte	100%	whole milk	20%	unsalted butter	30%	salt	2.0%	
fluffy mash	Russet	100%	whole milk	15%	unsalted butter	15%	salt	1.5%	
potato foam	Yukon Gold	100%	vegetable broth or milk heavy cream	60% 50%	olive oil	14%	salt	1.5%	4·281
pommes aligot	Belle de Fontenay or Yukon Gold	100%	crème fraîche	25%	Cantal or Gruyère cheese, grated unsalted butter	80% 10%	salt	1.5%	
roasted potato puree	Yukon Gold dried potato flakes	100% 10%	Yukon Gold potato juice	65%	unsalted butter	73%	salt Ultra-Sperse 3 (National Starch brand)	2.5% 1.0%	5·5





Flavors can be infused into the liquids prior to using them; for instructions, see page 2·310. You can also use meat or vegetable stocks as liquids. If using fat-free liquids, supplement with a fat such as butterfat (one of our favorites), rendered chicken fat, or olive oil.

7 **Pass potatoes through a sieve for a smoother texture.** Robuchon's silky potatoes recipe, for example, calls for three passes through the sieve. We find that one pass through a very fine sieve is enough. At this point, the puree can be refrigerated for later use.

8 **Warm the liquid (including skin infusion, if prepared), and whisk into the potato mixture to the desired consistency.** Add pureed potato flakes if made in step 4.

9 **Season with salt, and gently fold in Ultra-Sperse 3 or any other starch called for in the recipe.**

10 **Optionally, add cheese, and stir until fully melted and incorporated.**

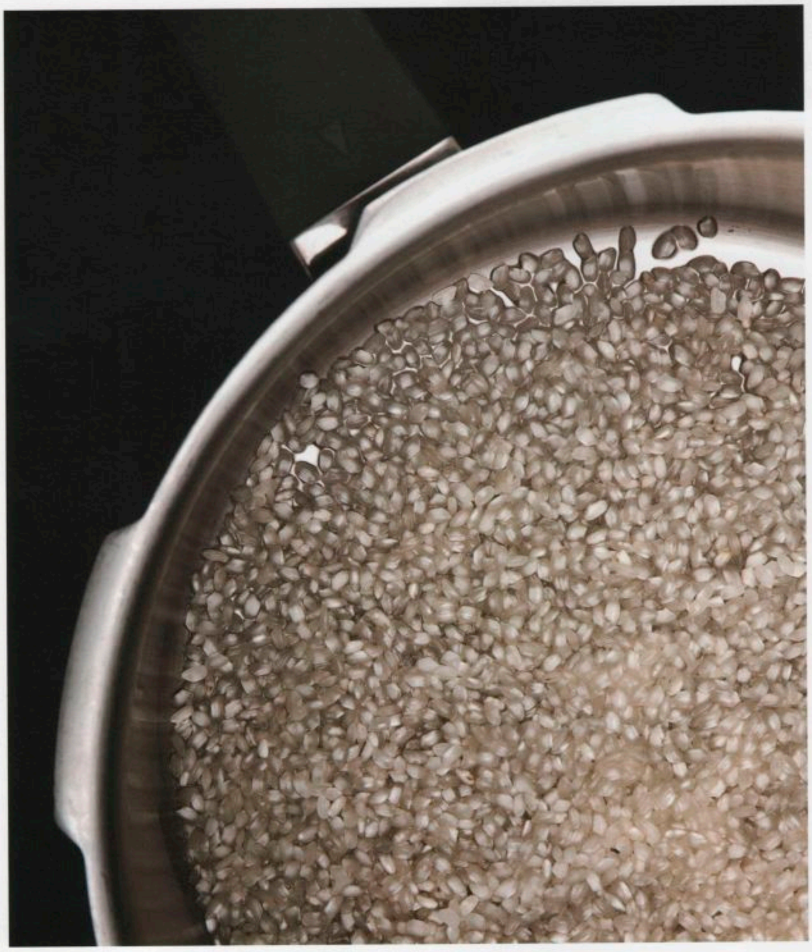
11 **Serve warm.**

PRESSURE-COOKING

If a little heat is good, why not use a lot? We're often better off using high temperatures to cook into submission the cell walls of plant foods, which are less sensitive to temperature than meat cells are. But vegetables are composed mostly of water, and their temperature won't exceed the boiling point of water, 100 °C / 212 °F, until they are dried out.

Cooking at elevated pressures gives us a way around this roadblock. When you use a pressure cooker, it's easy to reach 120 °C / 250 °F. An autoclave (a souped-up pressure cooker) can get even hotter. You shouldn't try this method on any plant food that suffers significant flavor changes from exposure to high temperatures. For beans and most vegetables destined for purees, however, pressure-cooking is a wondrous thing.

For more on anthocyanin, see page 274.



Pressure cookers sometimes have a bad reputation, but we find them fantastic tools. You should feel comfortable using a modern pressure cooker because today's devices are designed and manufactured with safety as the primary concern. Pressure cookers are also very friendly to the environment because they cook quickly and evenly, while using less energy than most other methods.

Pressure cookers are particularly suited for promoting the Maillard reaction (see page 89), which produces flavorful browning in many foods, and for the high temperatures used in caramelization. These two processes are frequently mistaken for each other, but although they are different, they go hand in hand in many practical situations. Elevated temperatures develop their characteristic flavors far more quickly than conventional cooking does, thereby transforming a long, labor-intensive process into one hardly more time-consuming than a casual sauté. The high-pressure heat also deepens the color of tannin-rich foods such as quince by enhancing the formation of anthocyanin pigments.

A prime example is classic French onion soup, in which a combination of caramelization and Maillard reactions produces a rich, browned flavor. With conventional cooking, it can take hours of very slow, careful work to thoroughly brown the onions without burning them. By using an autoclave, you can attain the same results in 20 minutes. It helps to add a bit of baking soda, which further speeds flavor reactions by producing an alkaline pH.

In addition to simplifying such time-consuming tasks, pressure-cooking can soften notoriously hard cell walls enough to make some tough plant foods, such as seeds and nuts, enjoyable in entirely new ways. We can make a faux risotto, for example, from sesame seeds, sunflower seeds, and other ingredients that conventional cooking methods would barely soften past a crunch.

When following a recipe for pressure-cooked food, do not start measuring elapsed time until the cooker reaches full pressure.

COOKING PLANT FOODS UNDER PRESSURE

Pressure-cooking is a convenient, time-efficient way to cook certain plant foods. Under pressure, the cooking temperature can exceed 100 °C / 212 °F, which accelerates the softening process. The speed-up is so dramatic, in fact, that it is easy to overcook delicate foods, so don't use this technique for corn, strawberries, or any other heat-sensitive food that you wouldn't cook aggressively by other means.

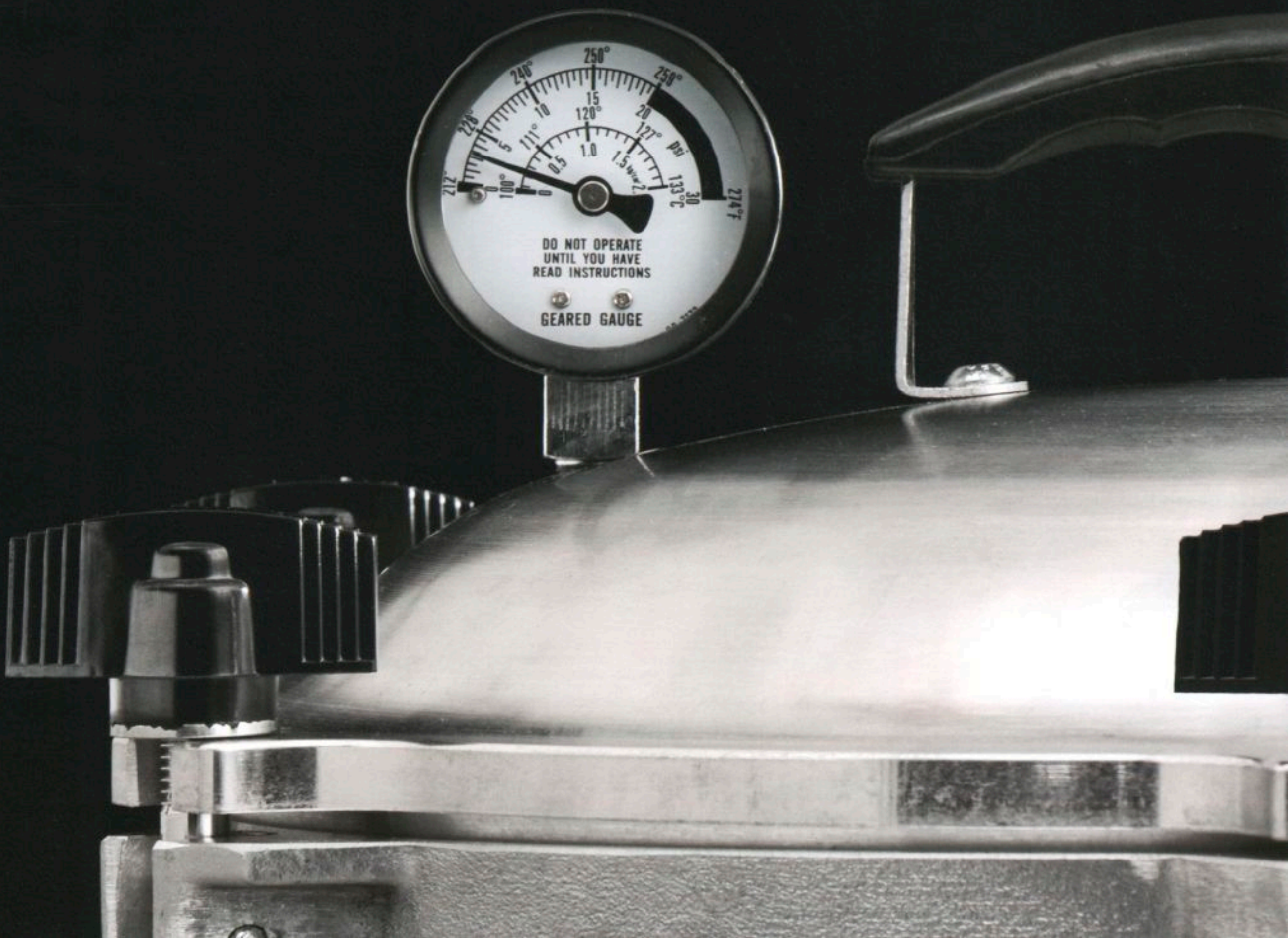
Pressure-cooking is most useful for making tough foods such as artichokes, beans, and seeds extremely soft. A pressure cooker can quickly reduce sesame seeds, sunflower seeds, or rice (which is technically a seed, though it's not often classified as such) to the texture of a risotto, for example.

The high temperatures in a pressure cooker can also create novel flavors that are hard to achieve otherwise. Tomatoes have a different flavor when pressure-cooked, and onions—which are slow to caramelize in a pan and easy to burn—brown quickly if you add a bit of baking soda to the pressure cooker to catalyze the reaction.

The table Best Bets for Pressure-Cooking Plant Foods lists several other good options, along with references to example recipes elsewhere in the book.

Best Bets for Pressure-Cooking Plant Foods

Ingredient	Advantage	See page
Quince, pears	develops flavors and colors	4·167
Caramelized coconut milk, onion soup	browns	4·50
Chickpeas, white beans, other legumes		5·138
Steel-cut oatmeal, pearl barley, other grains	accelerates softening	304
Whole citrus fruits, fresh coconut, nuts, other tough plant foods	softens	
Seeds, including mustard, sesame, sunflower		303



EXAMPLE RECIPE

CARAMELIZED CARROT SOUP

Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Young carrots, peeled and cored	500 g	100%	① Cut into 1.5 cm / ⅝ in pieces.
Unsalted butter	80 g	16%	② Melt butter in pressure cooker.
Salt	7.5 g	1.5%	③ Add carrot slices, salt, and baking soda.
Baking soda	2.5 g	0.5%	④ Pressure-cook at gauge pressure of 1 bar / 15 psi for 50 min to caramelize. ⑤ Pour cold water over cooker to depressurize quickly. ⑥ Blend mixture to smooth puree, and press through fine sieve.
Carrot juice, brought to boil and centrifuged see page 2·360	635 g (from 1.4 kg of carrots)	127%	⑦ Blend with puree, and bring to a simmer.
Water	as needed		⑧ Blend into soup to achieve desired viscosity.
Carotene butter (or unsalted butter) optional, see page 2·365	60 g	12%	⑨ Blend into soup.
Young ginger, finely diced	4 g	1.25%	⑩ Remove from heat, and season with more salt, if desired.
Tarragon, finely minced	2.5 g	0.5%	⑪ Garnish.
Ajowain seed, lightly crushed	0.5 g	0.1%	
Licorice powder, optional	0.5 g	0.1%	

(2009)

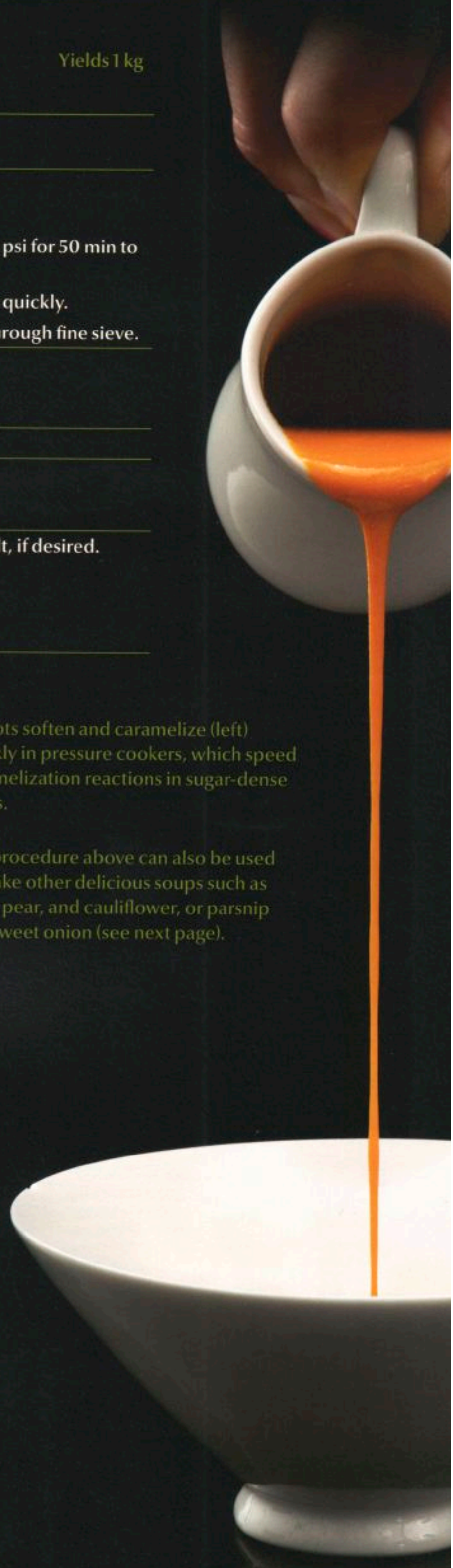
3

4

Carrots soften and caramelize (left) quickly in pressure cookers, which speed caramelization reactions in sugar-dense foods.

The procedure above can also be used to make other delicious soups such as beet, pear, and cauliflower, or parsnip and sweet onion (see next page).

6



AUTOCLAVED ONION SOUP

Yields 700 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sweet onions	1 kg	500%	① Juice 500 g of onions, and reserve 200 g of resulting juice.
			② Slice remaining 500 g of onions thinly.
			③ Pack sliced onions into two 475 ml / 1 pt canning jars, and reserve.
Onion juice, from above	200 g	100%	④ Combine.
Red port (dry)	40 g	20%	⑤ Pour mixture over packed onions, and seal jars. Do not overtighten, or jars may explode.
Unsalted butter, cubed	35 g	17.5%	⑥ Cook in 130 °C / 265 °F autoclave for 20 min. Alternatively, pressure-cook in canner or pressure cooker at a gauge pressure of 1 bar / 15 psi for 40 min.
Sugar	12 g	6%	
Baking soda	1.5 g	0.75%	
Black peppercorns (whole)	1 g	0.5%	
Thyme	0.5 g	0.25%	
Salt	to taste		⑦ Season soup.
Sherry vinegar	to taste		⑧ Portion evenly among four bowls.
Clarified unsalted butter, melted (or rendered veal marrow fat)	28 g	14%	⑨ Spoon thin layer of melted butter over each portion to prevent any cloudiness caused by cheese foam.
Cheese foam optional, see page 4·272	80 g	8%	⑩ Siphon onto soup.

(2009)

3

6

The combination of pressure-cooking and baking soda can also be applied to make a baked-potato consommé. Roast 100 g of russet potato skins until golden, combine with 400 g russet potato juice and 1.6 g of baking soda, and then pressure-cook as described in step 6 above.

EXAMPLE RECIPE

CRISPY BOILED PEANUTS

Yields 120 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	200 g	200%	① Combine, and pressure-cook at gauge pressure of 1 bar / 15 psi for 25 min.
Raw peanuts, shelled	100 g	100%	② Transfer boiled peanuts to dehydrator tray.
			③ Dehydrate at 60 °C / 140 °F for 12 h.
			④ Deep-fry in 190 °C / 375 °F oil for 1 min.
			⑤ Drain on paper towels, cool, and reserve.
Water	100 g	100%	⑥ Combine; let seaweed soak for 30 min at room temperature.
Dried laver (seaweed)	20 g	20%	⑦ Strain to remove excess liquid from seaweed.
Sugar	20 g	20%	⑧ Dehydrate seaweed at 60 °C / 140 °F for 12 h.
Salt	2 g	2%	⑨ Deep-fry in 190 °C / 375 °F oil for about 1 min.
Monosodium glutamate (MSG), optional	1 g	1%	⑩ Drain on paper towels, cool, and measure 25 g.
Demerara sugar	2 g	2.6%	⑪ Grind together.
Chili powder	1 g	1%	⑫ Toss with cooled peanuts and reserved seaweed.
Salt	0.5 g	0.5%	

(2010)

EXAMPLE RECIPE

PRESSURE-COOKED SESAME SEEDS

Yields 125 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	250 g	500%	① Boil seeds in water for 2 min to remove bitterness.
Raw sesame seeds	50 g	100%	② Place blanched seeds and water in pressure cooker.
			③ Pressure-cook at gauge pressure of 1 bar / 15 psi for 1½ h.
			④ Remove mixture from cooker, and cool at room temperature.
			⑤ Strain seeds, and reserve.
Toasted sesame oil	40 g	80%	⑥ Combine.
Salt	to taste		⑦ Toss oil with cooled seeds, and season.

(2008)

The same procedure used to pressure-cook the sesame seeds can also be applied to cook mustard seeds. Simply replace the toasted sesame oil with good-quality olive oil or mustard-seed oil.

PARAMETRIC RECIPE

RISOTTOS

The classic rules for cooking risotto demand ceaseless stirring, meticulous additions of liquid, and a fair amount of mysticism about how the dish must always be made to order. In fact, risotto is not as delicate as popularly supposed. When done properly, partially cooking the rice or other grains in advance will not degrade the quality of the dish. Gualtiero Marchesi, Thomas Keller, and other prominent chefs parcook risotto, and then refrigerate it to firm the starch. Breaking up the cooking process in this way improves both speed and coordination on the line.

It can be challenging to determine how much liquid to use when cooking risotto because absorption varies dramatically according to the variety of rice and the cooking method. A good starting point is to try using twice as much liquid as grain. Expect to experiment a bit before you find the optimal ratio for each recipe.

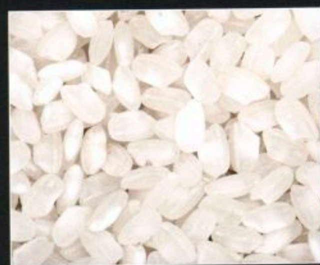
Estimating the final yield of risotto is easier. The "Yield after cooking" column in the table on the next page indicates how much the grain will swell and increase in weight after full absorption of the liquid used. For example, no matter how generous you choose to be with your cooking liquid, 100 g of raw, dried amaranth will produce 190 g of drained, fully cooked amaranth.

After parcooking the risotto and finishing it on the stove top, you can dress the cooked risotto with sauce or, for less starchy grains, add a thickener to yield the traditionally creamy result. Some grains, including bomba rice, barley, and steel-cut oats, have enough natural starch to create a sauce of their own. Others are better if you finish them *mantecato*; that is, enrich the sauce with a dollop of butter and some cheese.

Carnaroli

Sticky rice

Arborio rice



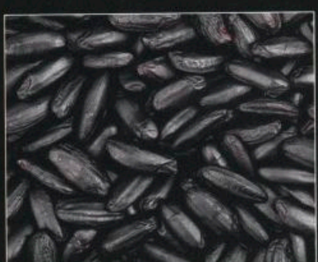
Bomba rice

Bamboo rice

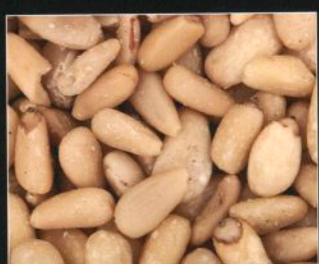
Carrot "rice"

Wild rice

Sunflower seeds



Forbidden rice



Pine nuts

Steel-cut oats

Purple barley

Best Bets for Risotto

Grain	Yield after cooking*	Parcooking time (choose one method) Boil (min)	Pressure-cook (min)	Cook sous vide (min)	Finish on stove top For boiled (min)	For pressure-cooked (min)	For sous vide (min)	Sauce or finish	See page
amaranth, rinsed well	190%	13	4	17	1½	2	2	thicken	5·129
bomba rice	240%	8	4	n/a	4½	3	n/a	mantecato	
brown rice	225%	12	6	30	6	5	4	mantecato	5·241
forbidden rice	150%	17	7	23	3	3	3	integral sauce	
pearl barley	185%	18	12	25	4	4	5	thicken	5·129
pine nuts	110%	9	7	25	1	½	2	thicken	5·65
quinoa	235%	7	2	10	2	3	2	mantecato	5·129
risotto rices (Arborio, carnaroli)	200%	6	3	n/a	3	3	n/a	mantecato	306
short-grain Japanese rice	210%	4	2½	n/a	3	2	n/a	thicken	
spelt, soaked overnight	150%	15	12	25	3	4	3	integral sauce	5·129
steel-cut oats, rinsed	185%	7	5	9	2½	2	2	thicken	308
wild rice	150%	30	25	45	2½	2	4	mantecato	

*(*final cooked weight of each grain—for example, every 100 g of dry bomba rice yields 240 g when cooked*)

PARBOILING RISOTTO

1 **Freeze a sheet tray, and bring a pan of water to a boil.**

2 **Parboil the grains.** See the table above for recommended times.

3 **Drain with a fine sieve.**

4 **Spread the grains evenly in a thin layer on the chilled tray to cool.**

5 **Cover tightly with plastic wrap or vacuum seal.** Refrigerate until needed, but for no more than one week.

6 **Finish cooking for the time recommended in the table.** Follow steps 8–10 on page 307.

7 **Season.** If using a non-starchy grain you may need to thicken (see page 309).

VARIATION: Pressure-cooking Risotto

1 **Freeze a sheet tray.**

2 **Combine grains with twice their weight in water in pressure cooker.** Parcook for time recommended in the table above.

3 **Follow steps 3–7 at left.**

VARIATION: Cooking Risotto Sous Vide

1 **Preheat the water bath to 90 °C / 194 °F.**

2 **Vacuum seal the grains with twice their weight in liquid.**

3 **Parcook.** See the cook sous vide column in the table above for recommended times.

4 **Chill in an ice-water bath.** Refrigerate in the bag until needed.

5 **Follow steps 6 and 7 at left.**

Each of these methods parcooks the rice, but you can also make risotto to order by skipping directly to step 6 after completing step 3. For an example of risotto pressure-cooked directly, see page 308.

Tradition has it that risotto, a classic offering of Italian cuisine, must be made to order with starchy rice from the Po Valley that provides a creamy feel. But you can prepare risotto ahead of time and use a pressure cooker for speedier service, as described on see page 308. You can even make faux risottos with nontraditional rices, root vegetables, or alternate grains—although you may need to add starch or some other thickener to create the characteristic creamy sauce.

RISOTTO MILANESE INSPIRED BY GUALTIERO MARCHESI

Gualtiero Marchesi is usually credited as the originator of parcooked risotto, and he certainly did a lot to popularize it. Risotto Milanese is one of northern Italy's trademark dishes, dating back centuries. Marchesi garnished the classic saffron-tinged dish with gold leaf, making his risotto as sumptuous looking as it is richly flavored.

Food writer Lynne Rossetto Kasper theorized that Milanese risotto was created to showcase affluence by its conspicuous golden hue and its use of an expensive spice. Marchesi's garnish adds to the ornamentation.

Yields 250 g

INGREDIENT	QUANTITY	SCALING
Sous vide vegetable stock see page 2·303	400 g	267%
Olive oil	45 g	30%
Yellow onions, finely minced	50 g	33%
Shallots, finely minced	10 g	6.5%
Carnaroli rice	150 g	100%
Italian white wine (dry)	100 g	67%
Parmigiano Reggiano cheese, finely grated	57 g	38%
Unsalted butter, cubed	30 g	20%
Saffron threads	0.4 g	0.25%
Black pepper, finely ground	to taste	
Salt	to taste	
Gold leaf	four sheets	

(original c. 1986, adapted 2009)

1 **Freeze a sheet tray to use for cooling the rice.**

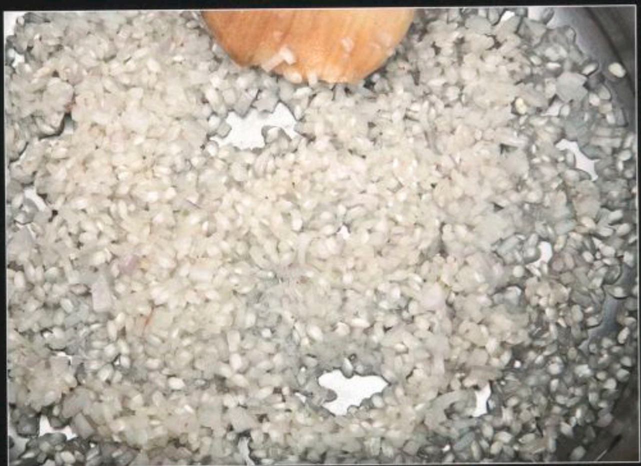
2 **Bring stock to boil.**

3 **Sauté onions and shallots.** When translucent, add rice, and continue sautéing until also translucent, about 5 min.

4 **Deglaze pan with wine.**

5 **Ladle 100 g of stock into pan, and parcook over high heat.** Add two more 100 g ladlefuls of stock, allowing each amount to be fully absorbed before adding another. Parcook for exactly 6 min.

6 **Drain with a fine sieve, reserving any liquid.**



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7 **Spread the risotto in a thin layer on the chilled tray, and cover tray tightly with plastic wrap.** Refrigerate until needed. Up to this point, you can substitute other parcooking techniques such as sous vide or pressure cooking (see page 304).

8 **To finish cooking, put cooled, parcooked risotto in pan, and add remaining stock.** Cook for another 3 min for al dente or until desired texture is achieved.

9 **Remove from heat, and fold in cheese, butter, saffron, and pepper.** Season with salt.

10 **Spoon one portion of risotto onto center of plate or bowl.** Garnish with gold leaf.

8

9a

9b

EXAMPLE RECIPE

SOUS VIDE CLAM AND OAT RISOTTO

Yields 585 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	150 g	150%	① Vacuum seal together.
Steel-cut oats, rinsed with warm water to remove starch	100 g	100%	② Cook sous vide in 90 °C / 194 °F bath for 10 min. ③ Strain, reserving liquid.
Mussel jus see page 2·346	50 g	50%	④ Cool oats, and reserve.
Geoduck clams, belly meat only	100 g	100%	⑤ Vacuum seal. ⑥ Cook sous vide in 50 °C / 122 °F bath for 30 min. ⑦ Slice thinly, and reserve.
Montpellier butter see page 4·220	100 g	100%	⑧ Melt in pan, and then add cooled oats. ⑨ Stir until warmed through, and then add reserved cooking liquid as necessary to achieve desired consistency.
Salt	to taste		⑩ Season oats, and reserve warm.
Wild arugula	25 g	25%	⑪ Combine in small bowl, and toss to coat evenly.
Extra, virgin olive oil	15 g	15%	⑫ Spoon oats in thin layers in warmed bowls.
Leeks, whites only, fine julienne	15 g	15%	⑬ Top each portion with geoduck belly. ⑭ Garnish with salad.
Radishes, fine julienne	15 g	15%	
Champagne vinegar	10 g	10%	
Young ginger, fine julienne	7.5 g	7.5%	

(2010)

EXAMPLE RECIPE

PRESSURE-COOKED VEGETABLE RISOTTO

Yields 600 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Shallots, minced	40 g	20%	① Sauté shallots in uncovered pressure cooker until translucent.
Vegetable oil	20 g	10%	
Carnaroli rice	200 g	100%	② Add to shallots, and sauté until slightly toasted and translucent, about 2 min.
White vegetable stock see page 2·303	180 g	90%	③ Stir liquids into rice mixture. ④ Pressure-cook at gauge pressure of 1 bar / 15 psi for 5½ min.
Carrot juice	110 g	55%	⑤ Pour cold water over pressure cooker to quickly depressurize.
Celery juice	110 g	55%	
Vermouth	50 g	25%	
Aged Gouda cheese, finely grated	100 g	50%	⑥ Mix into hot risotto.
Unsalted butter, cubed	12 g	6%	
Salt	to taste		⑦ Season risotto.

(1994)

EXAMPLE RECIPE

ROOT VEGETABLE RISOTTO

Yields 450 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Shallots, finely minced	60 g	50%	① Sauté shallots until tender.
Olive oil	48 g	40%	
White wine	160 g	133%	② Deglaze shallots, and reduce until dry.
Carrots, cut like rice	120 g	100%	③ Add to shallots.
Potatoes, cut like rice	120 g	100%	④ Cook together until vegetables are al dente, about 7 min.
Turnips, cut like rice	120 g	100%	
Vegetable stock see page 2·296	40 g	33%	⑤ Whisk together in bowl.
Ultra-Sperse 5 (National Starch brand)	2.4 g	2%	⑥ Stir into cooked vegetables. ⑦ Bring mixture to simmer, and remove immediately from heat.
Squash puree, warmed see page 2·424	60 g	50%	⑧ Stir into risotto.
Unsalted butter, cubed	30 g	25%	⑨ Fold into risotto until creamy.
Parmesan cheese, finely grated	24 g	20%	
Salt	to taste		⑩ Season.

(2008)

4

8

MICROWAVING

Microwave cooking gets a bad rap among chefs and foodies, usually for good reason. Microwave ovens cook unevenly, leaving hot and cold spots in food, and their temperatures are hard to control.

None of these issues poses a major problem when cooking vegetables, however. Most vegetables do not require even cooking or exact temperatures, so they make good candidates for cooking in microwaves.

In some cases, microwaving is even the preferred technique, as it is for dehydrating and "frying" herbs. Herbs are small and thin enough that the microwaves uniformly boil away the water in their leaves, dehydrating them to a nice crispness. Dehydration, after all, is what deep-frying mainly accomplishes. The process works so well that we don't deep-fry herbs when we can help it; we rub oil onto the herbs, and then microwave them.

Microwaving is also an effective way to cook food sealed in a sous vide bag, which maintains the humidity around the food. The bag forces steam to stay close to the food, and the circulation of steam helps to even out the irregular heat. Microwave cooking in bags is particularly useful for vegetables that must be kept sealed to prevent oxidation, as well as for vegetables like fennel bulbs and artichokes that take a long time to cook conventionally.

Microwave ovens can be a surprisingly effective tool for cooking some plant foods, such as this Sichuan-style bok choy (see page 313).

PARAMETRIC RECIPE

MICROWAVED VEGETABLES

The microwave oven has been unfairly demonized and banished from gourmet kitchens. Despite its reputation, the microwave oven is the ideal tool for cooking certain foods. Bulbs and leafy green vegetables are particularly good when cooked this way.

Microwaves cook by long-wavelength radiation (see page 2·182), which heats food rapidly but tends to do so unevenly. For delicate foods that are easily overcooked, the inevitable hot spots from microwave heating make it difficult to use. But for plant foods that are less sensitive to cooking temperature, hot spots are less of a problem—as long as they are allowed to even out. The best way to do this is to turn down the microwave's power setting. This lessens the intensity of the hot spots and provides more time for heat to spread evenly throughout the food.

A microwave oven is irrefutably a time-saver. A vacuum-sealed globe artichoke can be microwaved to perfection in less than seven minutes. Often vegetables cooked in microwave ovens have more vivid colors and brighter, fresher flavors. And microwaving techniques make it easy to fry tender herbs or to dry fruit and vegetable juices into perfect powders.

Unfortunately, we cannot give completely accurate times because microwave ovens vary widely in wattage and thus cooking intensity. In general, choose the highest-power microwave you can get—consumer units are typically 600–800 watts, but commercial microwaves are available from 1,000–3,200 watts. This is particularly important if you want to cook a lot of food at once.

Most microwave ovens achieve partial power by turning the oven on and off every second or so, but some have "inverter" technology to directly modulate power. Although direct modulation can be useful for some purposes, it generally offers little advantage when cooking plant foods.

COOKING PLANT FOODS IN A MICROWAVE

1. **Select a technique.** The table below lists our recommendations.
2. **Prepare your ingredients in a uniform size.**
3. **Evenly arrange them on a microwave-safe dish, or seal as specified.**
4. **Microwave at the prescribed power level.**

Best Bets for Microwaving Vegetables

Technique	Best Bets	Prep	Procedure	Time (min)	Power (W)
cooking root vegetables	baby beet, carrot, celery root, potato, turnip	whole	vacuum seal	3–7	800
cooking leafy greens	bok choy, broccoli, cabbage	whole	place in 2 mm / 1/16 in of water in microwave-safe dish, and cover with plastic wrap	3–5	800
cooking bulbs and fibrous vegetables	artichoke, cardoon, celery, fennel, leek, onion, scallions	whole	vacuum seal	2–5	600
frying herbs	basil, carrot top, Italian parsley, sage	leaves	arrange on oiled plastic wrap	3–4	600
dehydrating raw vegetable purees into powders	beet, carrot, mushroom, parsnip, spinach	puree	spread raw puree thinly onto microwave-safe dish	12–20	200

EXAMPLE RECIPE

MICROWAVE-FRIED PARSLEY ADAPTED FROM HESTON BLUMENTHAL

Yields 8 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Frying oil	as needed		① Stretch plastic wrap over microwave-safe plate, ensuring that it is flush with bottom of plate and adheres tightly to plate's edges. ② Brush plastic wrap with thin film of oil.
Flat-leaf Italian parsley, leaves only	30 g	100%	③ Lay parsley across plastic wrap, leaving approximately 2 cm / ¾ in between leaves. ④ Brush tops of leaves thinly with oil. ⑤ Microwave at 600 W (75% power) for 4 min or until crisp, checking leaves every 1½ min to prevent burning.
Salt	to taste		⑥ Transfer fried parsley to paper towel-lined tray. ⑦ Season. ⑧ Reserve in airtight container, preferably lined with silica gel desiccant.

(original 2005)

1

3

Inexpensive PVC-based cling film should not be used for this technique because it poses health hazards. Use polyethylene-based films instead.

EXAMPLE RECIPE

TOMATO POWDER ADAPTED FROM THOMAS KELLER

Yields 15 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Tomato pulp, peeled, seeded, and finely chopped	200 g	100%	① Squeeze tightly in towel to extract excess moisture. ② Spread in thin, even layer on microwave tray lined with parchment paper. ③ Microwave on low power for 30–40 min, or until pulp has dried completely but still retains its color. ④ Cool to room temperature. ⑤ Grind in coffee or spice grinder until as fine as possible. ⑥ If some pieces do not break up during grinding, sift powder through fine mesh strainer while stirring with spoon. ⑦ Store in covered plastic container.

(published 1999)

Microwave ovens can be used for dehydrating fruits, vegetables, and herbs in the same manner as this recipe. Of course, conventional methods of dehydration could also be used (see page 2·428).

EXAMPLE RECIPE

ARTICHOKE AND POTATO CHAAT

Yields 600 g (4 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Artichoke hearts, cleaned	200 g	100%	① Combine and vacuum seal.
Water	100 g	50%	② Microwave at 800 W (full power) for 3 min, and then cool for 2 min in bag.
Extra, virgin olive oil	40 g	20%	③ Remove artichokes very carefully from bag (steam will escape), and cool completely.
Unsalted butter	32 g	16%	④ Cut into small dice, and reserve.
Fingerling potatoes (whole)	200 g	100%	⑤ Combine and vacuum seal.
Brown butter see page 4·213	40 g	20%	⑥ Microwave at 800 W for 3 min, and then cool for 2 min in bag. ⑦ Remove potatoes very carefully from bag, and cool completely.
Water	25 g	12.5%	⑧ Cut into small dice, and reserve.
Saffron threads	0.1 g	0.05%	
Masala Sev (chickpea flour noodles), store-bought	30 g	15%	⑨ Toss with diced artichokes and potatoes.
Cashews, coarsely crushed	10 g	5%	
Cilantro leaves (small)	10 g	5%	
Dates, thinly sliced	10 g	5%	
Mint, fine julienne	5 g	2.5%	
Lime juice	to taste		⑩ Season chaat, and divide into equal portions.
Salt	to taste		
Yogurt foam see page 4·287	100 g	50%	⑪ Garnish chaat generously.
Tamarind paste see page 5·99	40 g	20%	
Chaat masala see page 5·282	to taste		

(2010)

EXAMPLE RECIPE

SICHUAN BOK CHOY

Yields 350 g (4 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Hoisin sauce (store-bought)	20 g	10%	① Combine, and bring to simmer.
Fermented black bean and chili paste (store-bought)	15 g	7.5%	② Cool and reserve.
Shaoxing wine	8 g	4%	
Soy sauce	5 g	2.5%	
Toasted-sesame oil	1 g	0.5%	
Shiitake mushroom caps (smallest possible)	100 g	50%	③ Blanch in boiling water for 2 min. ④ Transfer to bowl, and reserve.
Rice wine vinegar	100 g	50%	⑤ Whisk together until fully dissolved.
Water	50 g	25%	⑥ Bring brine to simmer, and remove from heat.
Sugar	25 g	12.5%	⑦ Pour warm brine over blanched mushrooms.
Salt	3 g	1.5%	⑧ Cool completely to pickle mushrooms, and reserve.
Baby bok choy, cleaned and cut in half	200 g	100%	⑨ Vacuum seal together. ⑩ Microwave at 800 W (full power) for 2 min, and then cool for 2 min in bag.
Water	50 g	25%	⑪ Remove bok choy from bag, and serve immediately.
Pressure-cooked sesame seeds see page 303	50 g	25%	⑫ Garnish bok choy with spicy sauce, pickled mushrooms, sesame seeds, and chili oil. ⑬ Serve with steamed rice.
Dried chili oil see page 2·329	10 g	5%	

(2010)

FRYING

Frying is fast! It's a quicker method than cooking with hot air because oil has much higher heat capacity (see page 1·266) than air does: you can stick your arm in an oven at 200 °C / 390 °F, but even a drop of oil at that temperature will cause a serious burn. It's also faster than cooking in water because oil can be heated well above 100 °C / 212 °F—indeed, you can fry at twice that temperature. Such a high temperature quickly boils water near the surface of the food, which causes furious bubbling as steam strives to escape by rising through the oil. In turn, this also speeds frying because the turbulence of the bubbles stirs the oil surrounding the food, so it never stagnates and cools around the food.

Unlike other high-heat means of cooking, frying cooks very evenly. As a liquid, oil conducts heat much faster than air, which means that any temperature differences within the oil quickly even out. This property makes it simple to control the temperature of cooking oil so that food is evenly heated. Cooking with **radiant heat** also rapidly heats food, but for various reasons, it is difficult to cook food evenly this way. That is true whether we are using the intense glow of a grill or broiler or if we are using microwave energy.

If a cook's goal is to simply remove water, then an oven or a purpose-built dehydrator will do an admirable job. But the crispy and crunchy textures, as well as the richness and flavors that we associate with fried food, are the unique result of rapidly heating and drying the food in oil. We explore the

The deep-fried whole sweet onion, popularly called a "blooming onion," has been a signature dish of the Outback Steakhouse chain of restaurants in the United States since the late 1980s. Despite Outback's Australian theme, the dish is largely unknown on that continent.

science in depth in chapter 7 on Traditional Cooking. Here, we take a more pragmatic look at the strategies available to cooks.

Broadly speaking, there are two: naked and coated frying. Naked means that we put the food directly into the hot oil. Foods that have a high starch content, such as potatoes, respond well to this approach. So do some low-starch plant foods, such as Brussels sprouts and their *Brassica* cousin, the cauliflower. Although they won't crisp as well as starchy foods, the intense heat will turn them golden brown and profoundly flavorful. By using a Modernist vacuum infusion, we can even make crispy chips from watermelon. Blistering-hot frying oil is, perhaps, the perfect way to cook green beans, a technique perfected in traditional Chinese cuisine.

For more on making fruit and vegetable chips, see page 328.

The other main approach to frying is to coat food in a starchy batter or breading. This coating is the only part of the food that is actually exposed to the oil during deep-frying. Under the coating, the food poaches and steams in its own juices while the starch coating fries. Thus, when we make a batch of fried chicken or tempura shrimp, we are frying only the batter—we're actually steaming the chicken or shrimp.

Because so much revolves around the batter or breading, which are nearly always composed of plant foods, we discuss frying both plant and animal foods here. A batter or breading may enclose anything from a pickle to a chicken leg or even a Snickers bar, but the method of frying the coated food remains the same.

Battering and Breading

Batters and breadings serve two purposes. First, they are delicious in their own right (they also offer a wonderfully crunchy texture). Second, they insulate the foods they coat from the hot oil because they transmit only a portion of the heat of the oil.

One reason many batters are foams or contain foams (such as bread crumbs) is that foams make good insulators and help to ensure that delicate foods aren't overcooked. The foaminess of batters also adds to the crispy mouthfeel of fried cuisine.

You can foam a batter in several ways. Traditional approaches include leavening, such as with baking powder or baking soda (to generate carbon dioxide); adding a carbonated liquid like soda water or beer; and folding in a premade foam like beaten egg whites. The Modernist way is to foam the batter directly by using a whipping siphon. This has many advantages, including the fact that nitrous oxide does not acidify the batter the way that carbon dioxide does. Acidic conditions inhibit the Maillard reaction (see page 89) and thus reduce flavor and browning.

Alcohol can be a useful batter ingredient, for several reasons. It evaporates at a lower temperature than water and thus transmits much less heat to the interior. As it evaporates, the batter dries and therefore cooks much faster, which reduces the risk of overcooking the food. As a result, alcohol is a particularly helpful ingredient when frying seafood and other heat-sensitive foods.

Alcohol does have its drawbacks. If the evaporation is too vigorous, it will blow the batter right off the food. Alcohol also tends to make foams collapse quickly, so you must work fast. The silver lining here is that a dying foam has coarse, uneven bubbles that can produce a lacy and extra-crispy texture in the fried coating.

Breading is one step thicker than a batter. It involves affixing solid particles, such as bread crumbs or panko, to the food, often by using a batter as glue. Breaded food is thus coated by a fairly thick conglomerate of breading material and batter.

Like batter, breading provides both insulation and texture. The solid particles in the breading are often either set foams—such as bread crumbs—or ingredients that turn into foams when cooked, such as dried starch gels similar to foamed snacks (see page 4·302). Their foamy characteristics enhance both the insulation and the crunch.

Breading has much more structural integrity than a light batter does. As a result, it can be used to envelop foods that are liquid when hot, such as foie gras, hollandaise (see page 4·228) or even corn pudding (see page 5·104).

A hen-of-the-woods mushroom is transformed by deep-frying into a delicious golden orb.

Naked, Battered, and Breaded

Coating	naked, raw	naked, fried	flour, liquid, and fine crumbs
Texture		thin and crisp	dense and crisp
See page			336

flour, liquid, and coarse crumbs or panko

dense and crunchy

338

alcohol-laced, siphoned batter

lacy and crisp

332

puffed starch pieces

airy and crunchy

THE CHEMISTRY OF

Naked Frying

Frying plant foods "naked" (without a coating) works best when the food either has a high starch content or naturally browns well on its own.

Starch is essential for creating a glassy, crispy texture that we prize in fried potatoes (see page 322) or potato chips/crisps (see page 330). Starchy root vegetables can be fried in the same ways as potatoes. If the fruit or vegetable you want to fry lacks starch, just add it (see page 328). In this way, you can make crisp chips from virtually any fruit or vegetable.

Frying for browning and flavor development is what occurs with cauliflower, Brussels sprouts, green beans, asparagus, and other vegetables. In those cases, crispiness is not the goal, although some develops anyway.

Sugar content affects the ideal frying temperature. The more sugars in the fruit or vegetable being fried, the lower the temperature must be to avoid burning the sugar.

1 **Prep.** Preheat frying oil to 190 °C / 375 °F, and cut vegetables to dimensions indicated. The dried shiitake must be hydrated with warm water for at least 30 min before frying.

2 **Fry for the time indicated in the table.** The vegetables typically turn very dark brown and look almost overcooked.

3 **Drain and season.** Transfer fried vegetables to a tray lined with paper towels. Season with salt.

Best Bets for Naked Frying

Ingredient	Prep (cm)	Prep (in)	Deep-fry (min)
artichokes, baby	quartered		3
asparagus, green and white	whole		3
bok choy	quartered		4
broccoli, florets	2.5	1	3
Brussels sprouts	halved		5
cauliflower, florets	2.5	1	4
cucumber	2.5	1	4
daikon radish	1.25	½	8
eggplant	2.5	1	5
green beans	whole		3
scallions	whole		2
shiitake, fresh	whole		4
shiitake, dried	whole		2
squash, autumn	2.5	1	3
sunchoke	1.25	½	3
zucchini	1.25	½	1½

For frying potatoes, see the suggested strategies on page 322.

EXAMPLE RECIPE

DEEP-FRIED BRUSSELS SPROUTS ADAPTED FROM DAVID CHANG

Yields 350 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Fish sauce	130 g	26%	① Whisk together until sugar dissolves.
Lime juice	70 g	14%	② Reserve sauce.
Sugar	60 g	12%	
Water	55 g	11%	
Rice wine vinegar	25 g	5%	
Garlic clove, minced	5 g	1%	
Bird's eye chili, minced	3 g	0.6%	
Xanthan gum (Keltrol T, CP Kelco brand)	0.53 g	0.1% *(0.15%)**	
Rice puffs	20 g	4%	③ Measure individually, and reserve for garnish.
Cilantro stems, 1 cm / ⅜ in long	10 g	2%	
Small mint leaves	4 g	0.8%	
Brussels sprouts	500 g	100%	④ Peel off tough outer leaves until only cores remain, about 2 cm / ¾ in each in diameter. ⑤ Slice in half.
Frying oil	as needed		⑥ Deep-fry sprouts in 180 °C / 355 °F oil until tender and very dark, about 5 min. ⑦ Drain on paper towels. ⑧ Toss with sauce, arrange on plates, and garnish.

(original 2008)

(% of total weight of first five ingredients*)

HOW TO Make the Ultimate French Fry

Americans call them "French fries," or just fries for short. The French call them *pommes de terre frites*, or *frites* for short, and consider them an essential part of French cuisine. Belgians call them the same thing but argue that *they* invented them, not the French. Finally, the British call them "chips." By any name, they are universally loved, although their recipes are frequently executed badly.

As with many foods, the origin of fries is lost to history. The Belgians claim they originated in about 1680 in the Meuse Valley during the winter months, when freezing weather prevented fishing. Spanish historians claim that a Spaniard first made *patatas fritas,* and the fact that Spanish colonists were the first Europeans to encounter potatoes makes this claim plausible.

Oddly enough, the earliest written evidence of a French origin for French fries is a document written between 1801 and 1809 by American President Thomas Jefferson about a dish he called *"pommes de terre frites à cru, en petites tranches"* (potatoes fried from raw, in thin slices), which was likely prepared for him by his French chef Honoré Julien. The British did not get chips until a Belgian immigrant started making them in London in 1860.

The standard cookbook version of the recipe requires cooking the potatoes twice. The first cooking (parfrying) is done in oil at a low temperature (typically near 150 °C / 300 °F). Then the potatoes are allowed to cool before being fried a second time at a higher temperature (190 °C / 375 °F). This process gives good results, but fanatics around the world have sought to improve on it.

There isn't universal agreement on what an "ideal" fry is, but most believe that it should have a very crisp exterior that stays crisp until eaten. The interior should be soft—even fluffy. Heated arguments can erupt about the best potato to use (most prefer a mealy potato like Russet Burbank or Maris Piper) or the best oil to use (vegetable oil, rendered beef suet, or a mixture). The size of the fries also matters: you can go from thick-cut steak fries to ultrathin shoestring fries.

British Chef Heston Blumenthal went to great effort to optimize his Triple-Cooked Chips by deploying two innovations. First, he boils the raw potatoes until they are almost falling apart, and then he vacuum-dries them. After that, he parfries them at 130 °C / 265 °F, followed by more vacuum desiccation. The final frying is done in 200 °C / 390 °F oil. The result is excellent and has set a new standard in the annals of fried potatoes.

More recently, Dave Arnold and Nils Norén did extensive experimentation with various approaches to parcooking and parfrying. Their ultimate fry uses an idea borrowed from Polish researcher Grażyna Lisińska and colleagues, who found that a pectin-dissolving enzyme creates a great fry texture. Arnold and Norén found it produces results superior to those of Blumenthal's method, thereby crowning a new king of the fried potato. This work inspired the *Modernist Cuisine* team to get creative. We came up with an ultrasonic treatment and starch infusion (a variation on our approach to fried watermelon; see page 328) that produces what we think are the best French fries we've ever made. Until, that is, somebody comes up with something else.

Starch-Infused Ultrasonic Fries, page 325

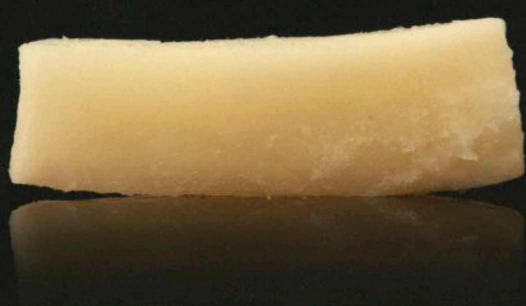
POMMES PONT-NEUF INSPIRED BY HESTON BLUMENTHAL

Yields 350 g

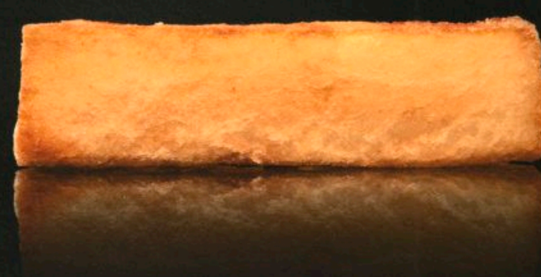
INGREDIENT	QUANTITY	SCALING	PROCEDURE
Russet potatoes	500 g	100%	① Cut into batons 1.5 cm / ⅝ in thick by 1.5 cm / ⅝ in tall.
Water	500 g	100%	② Whisk sugar, salt, and baking soda into water.
Sugar	15 g	3%	③ Add potatoes and water mixture to pot, and boil for about 20 min until very tender and nearly falling apart.
Salt	7.5 g	1.5%	
Baking soda	0.75 g	0.25%	④ Drain, and place warm potatoes on wire rack in vacuum chamber.
			⑤ Pull vacuum until surfaces of chips are dry and chips feel cool, 3–4 min.
			⑥ Optionally, vacuum-cool again, or air-cool in a single layer.
			⑦ Blanch in **150** °C / **300** °F oil until chips are mostly cooked but still pale, about 7 min.
			⑧ Deep-fry in **220** °C / **430** °F oil until crisp, about 2 min.
			⑨ Drain on paper towels.

(2010)

Boiled and vacuum-dried



Parfried and dried



Cooked until golden

A vacuum treatment both cools and dries the exterior of the fries. Heston Blumenthal found that this process produces a thicker, crunchier crust. He does the vacuum-cooling and vacuum-drying step twice: first after boiling, and again after parcooking.

Air-cooling the chips after the boiling step yields a thinner, more delicate crust. To air-cool the fries, place them in a single layer on a wire rack. You can use a household fan to speed the process.

We find that vacuum-cooling and vacuum-drying after parfrying produces a chip that is too dry for our tastes. We prefer to vacuum-cool after boiling, but to air-cool after parfrying.

PECTINASE-STEEPED FRIES

Yields 350 g

ADAPTED FROM NILS NORÉN AND DAVE ARNOLD

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Russet potatoes	500 g	100%	① Cut into batons 1.5 cm / ⅝ in thick by 1.5 cm / ⅝ in tall.
			② Rinse thoroughly to remove surface starch.
Water	500 g	100%	③ Combine with rinsed potatoes.
Pectinex Ultra SP-L (Novozymes brand)	2 g	0.4%	④ Soak for 1 h, and drain.
Water	500 g	100%	⑤ Vacuum seal with potatoes in one even layer.
Salt	10 g	2%	⑥ Steam at 100 °C / 212 °F for 15 min.
			⑦ Drain and cool.
			⑧ Blanch in 170 °C / 340 °F oil for 3 min, and cool.
			⑨ Deep-fry in 190 °C / 375 °F oil until crisp, about 3 min.
			⑩ Drain on paper towels.

(2010)

STARCH-INFUSED FRIES

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Russet potatoes	500 g	100%	① Cut into batons 1.5 cm / ⅝ in thick by 1.5 cm / ⅝ in tall, and rinse thoroughly to remove surface starch.
Water	100 g	20%	② Combine with rinsed potatoes.
Potato starch	50 g	10%	③ Vacuum seal.
			④ Refrigerate for 30 min, and drain.
Water	500 g	100%	⑤ Vacuum seal with potatoes in one even layer.
Salt	10 g	2%	⑥ Steam at 100 °C / 212 °F for 15 min.
			⑦ Drain.
			⑧ Place hot fries on wire rack in vacuum chamber.
			⑨ Pull vacuum until surfaces of fries are dry.
			⑩ Blanch in 170 °C / 340 °F oil for 3 min, and cool.
			⑪ Deep-fry in 190 °C / 375 °F oil until crisp, about 3 min.
			⑫ Drain on paper towels.

(2010)

Starch-Infused Ultrasonic Fries

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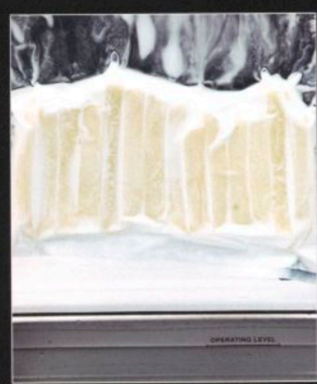

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ULTRASONIC FRIES

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Russet potatoes	500 g	100%	① Cut into batons 1.5 cm / ⅝ in thick by 1.5 cm / ⅝ in tall, and rinse thoroughly to remove surface starch.
Water	500 g	100%	② Vacuum seal with potatoes in one even layer.
Salt	10 g	2%	③ Cook at **100** °C / **212** °F for 15 min.
			④ Transfer to ultrasonic bath, and cavitate for 45 min.
			⑤ Flip bag, and cavitate in ultrasonic bath for another 45 min.
			⑥ Drain.
			⑦ Place hot fries in single layer on wire rack.
			⑧ Cool at room temperature, with or without fan.
			⑨ Blanch in **170** °C / **340** °F oil for 3 min, and cool.
			⑩ Deep-fry in **190** °C / **375** °F oil until golden and very crisp, about 5 min.
			⑪ Drain on paper towels.

(2010)

STARCH-INFUSED ULTRASONIC FRIES

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Russet potatoes	500 g	100%	① Cut into batons 1.5 cm / ⅝ in thick by 1.5 cm / ⅝ in tall, and rinse thoroughly to remove surface starch.
Water	500 g	100%	② Vacuum seal together with potatoes.
Salt	10 g	2%	③ Cook at **100** °C / **212** °F for 15 min.
			④ Drain. Cool and reserve.
Water	100 g	20%	⑤ Whisk together.
Potato starch	50 g	10%	⑥ Vacuum seal carefully with cooked potatoes.
			⑦ Cavitate in ultrasonic bath for 45 min.
			⑧ Flip and cavitate in ultrasonic bath for another 45 min.
			⑨ Drain.
			⑩ Place hot fries on wire rack in vacuum chamber.
			⑪ Pull vacuum until surfaces of fries are dry.
			⑫ Blanch in **170** °C / **340** °F oil for 3 min, and cool.
			⑬ Deep-fry in **190** °C / **375** °F oil until crisp, for 3 min.
			⑭ Drain on paper towels.

(2010)

12

14

The chips must be cooled and dried both after the boiling step and after parfrying. Vacuum cooling and air cooling both work, but yield different textures—see page 322.

We use a 21 l / 5½ gal Branson 8150 ultrasonic bath set at a frequency of 40 kHz for making these fries.

Special Cutting Tools for Frying Fruits and Vegetables

Several tools can cut thin sheets or fine strands which are ideal for frying or cooking like pasta. To fry potatoes prepared this way, heat oil to 190 °C / 375 °F, and fry for 3–5 min. To fry foods that contain more sugar, such as carrot, sweet potato, and squash, heat oil to 165 °C / 330 °F to prevent burning, and fry for 7–10 min.

Alternatively, you can cook potato noodles and sheets as you would pasta. Boil them in seasoned water for 2½ min, and then toss them with oil or sauce. Daikon noodles are best cooked for 2 min; carrot noodles for 3½ min. Most fruit and vegetable noodles crumble if cooked longer.

Japanese Vegetable Sheeter

This style of slicer is versatile and practical. It comes with various blade attachments that can create long, even sheets, thick and fine noodles, and a particularly fun net-like sheet. Use it with vegetables and fruits that are not too brittle or tender, such as potato, sweet potato, daikon, carrot, butternut squash, cucumber, zucchini, large radish, apple, green papaya, and green mango. Of those, the starchier vegetables—such as potato, sweet potato, and carrot—work best for frying; cook the others like pasta or serve them raw in salads.

To prepare vegetables for the slicer, peel and cut them into a cylinder to fit the dimensions of the blade.

Potato sheet, raw

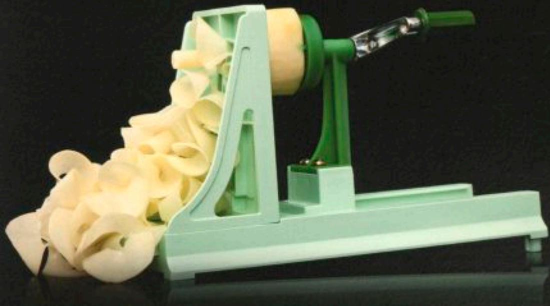
Potato sheet, fried

Fine potato noodles, raw

Fine potato noodles, fried

Potato net, raw

Potato net, fried

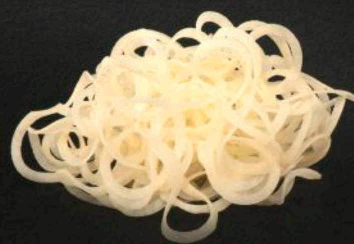


Japanese Rotary Vegetable Slicer

The rotary slicer has most of the same applications as the sheeter, but it does not make flat sheets.

Fine potato noodles, raw

Fine potato noodles, fried



Thick potato noodles, raw

Thick potato noodles, fried

Potato ruffles, raw

Potato ruffles, fried

Microplane grater

Microplaned potatoes and sweet potatoes yield a crunchy texture when fried. The natural starch in them forms delicate little clumps.

Microplane potatoes, fried

PARAMETRIC RECIPE

FRUIT AND VEGETABLE CHIPS

Potatoes get star billing in the world of chips, but we can lend other plant foods the texture needed to challenge the potato's status. The technique below describes how to fill the vacuoles inside the cells of a fruit or vegetable with starch. This approach works well for porous fruits and vegetables, such as cucumbers, apples, Asian pears, watermelon, pineapple, and celery root. Varying the thickness of the chips alters their texture; a thinner chip tends to be shatteringly crisp, while a thicker chip has a crunchy snap.

Best Bets for Fried Fruit and Vegetable Chips

	Slice		Deep-fry		
Ingredient	(mm)	(in)	(°C)	(°F)	(s)
apple	1	1/32	165	330	105
Asian pear	1	1/32	190	375	100
carrot	1	1/32	190	375	40
celery root	1–3	1/32–1/8	165	330	60
cucumber (and pickles)*	1–3	1/32–1/8	165	330	15–25
eggplant*	3	1/8	165	330	90
jalapeño*	3	1/8	165	330	15
lotus root	1–3	1/32–1/8	190	375	15–25
melon	1	1/32	165	330	105
pineapple	1	1/32	165	330	120
potato	1–3	1/32–1/8	190	375	35
strawberry*	3	1/8	165	330	40
tomato*	3	1/8	165	330	15
watermelon	1	1/32	165	330	105

**(dehydrate at 60 °C / 140 °F for 1 h before frying)*

Adding 0.5% of Methocel K100M by weight of slurry can reduce the oil uptake of the chips after frying by up to 20%. For regular potato chips, simply compress the potato slices with a stock solution of 100% water and 0.5% Methocel K100M before frying for similar results. The film-forming properties of methylcellulose prevent the vacuoles from absorbing as much oil upon cooling.

EXAMPLE RECIPE

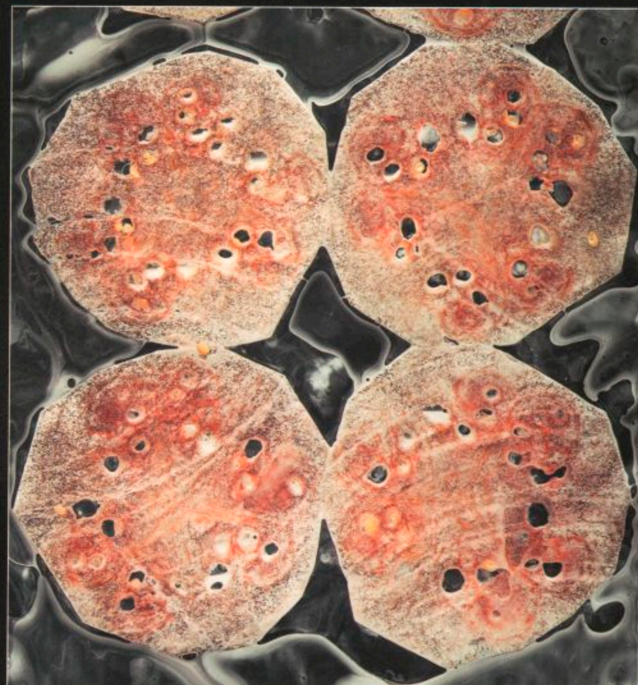
WATERMELON CHIPS

Yields 100 g

INGREDIENT	QUANTITY	SCALING
Seedless watermelon flesh, skin and pith removed	200 g (from one whole)	100%
Water	100 g	50%
Crisp Coat UC (National Starch brand) or raw potato starch	50 g	25%
Salt	to taste	
Neutral oil	as needed	

(2009)

MAKING CRISP CHIPS FROM PRODUCE



1 **Slice evenly.** See the table of Best Bets for Fried Fruit and Vegetable Chips at left for suggested ingredients and thicknesses. Use a meat slicer, if available, to produce slices of uniform thickness.

2 **Mix Crisp Coat UC or potato starch with water to make a slurry (not shown).** Optionally, add Methocel K100M to the slurry to reduce oil.

3 **Dip slices in starch slurry, and arrange them in one layer in a sous vide bag.** Vacuum seal. A full vacuum impregnates the slices with starch, yielding a texture similar to that of a thin potato chip.

4 **Remove slices from bag, and pat dry.**

5 **Dehydrate (optional).** For delicate fruits and vegetables such as tomatoes, cucumbers, and jalapeños, dehydrate the starch-coated slices at **50** °C / **122** °F until completely dry, up to 2 h.

6 **Deep-fry until crisp and golden.** See the table for a recommended oil temperature and frying time.

7 **Drain on absorbent paper towels, and season with salt.**

CHIPS LIKE MOM USED TO BUY

Under ideal conditions, homemade potato chips can be more delicious than any you'll find in a store. Too often, however, varying wetness and starch content of the potatoes available frustrate this goal. That is why, as an homage to the infallible uniformity of Pringles, we have experimented with constructing our own crunchy, salty chips of ground potato.

The basic approach is based on a *tuile*, the thin, delicate wafer of traditional French cooking. The finished "chips" are baked; while they are still hot from the oven, you can form them into whimsical shapes. They turn brittle and crisp as they cool. In a moment of serendipity as we experimented with this technique, we discovered that the addition of modified food starch causes the chips to puff into a form similar to that of *pommes soufflées*.

EXAMPLE RECIPE

RESTRUCTURED POTATO CHIPS

Yields 100 g

INGREDIENT	QUANTITY	SCALING
Water	200 g	400%
Instant potato flakes	50 g	100%
Raw potato starch (or Ultra-Crisp CS or Crisp Coat UC for puffed chips)	18.5 g	37%
Neutral oil	15 g	30%
Salt	1.5 g	3%

(2009)

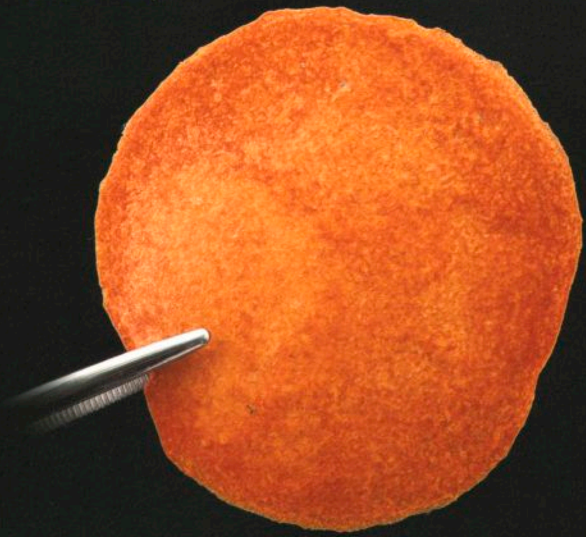
3a

1. **Combine all ingredients.**
2. **Blend (optional).** For puffed chips only, puree with hand blender or blender until smooth, about 1 min.
3. **Cast mixture into circular template, 2 mm / 3⁄32 in thick and 7.5 cm / 3 in.** in diameter.
4. **Bake in 175 °C / 350 °F oven on tray lined with silicone mat until golden and crisp, about 9 min.**
5. **Turn over (optional).** For puffed chips only, flip and bake another 2–3 min to ensure they are completely baked through.

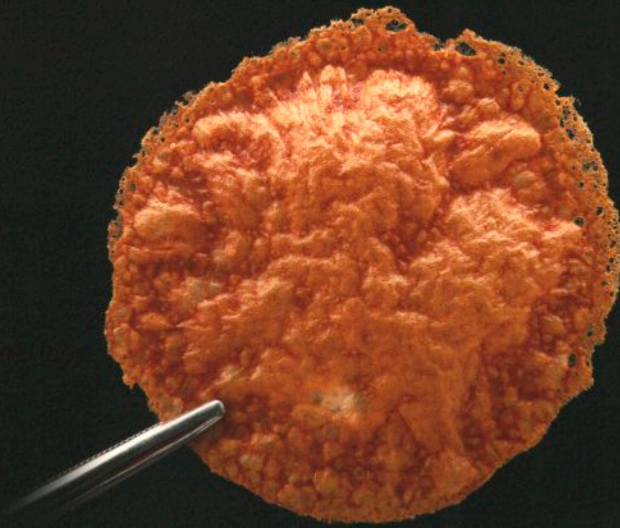
3b

For more on starches, see page 4·20.

Tuile-like chip



Puffed chip



THE HISTORY OF

Pringles

Potato chips are fragile—and therefore a challenge to food packagers. Before the introduction of Pringles in 1968, chips were produced only regionally because their delicate constitution made them impractical to ship long distances. The secret to creating a shippable chip, it turns out, is molding it rather than slicing it from a whole potato. Wavy, saddle-shaped Pringles, which stack perfectly in a pile in their cylindrical cans, soon became an international brand.

Pringles are made by adding starch and seasoning to a potato batter, and then forming the mixture into chip-like shapes that are fried or baked. Both the method of their creation and the various additives in Pringles became targets in more than one pitched legal fight about the true meaning of a potato chip. In the United Kingdom, for example, Pringles maker Procter & Gamble argued that their product was a potato "snack" rather than a crisp (as chips are called there). "Snacks," you see, were exempt from a tax that the U.K. levied on potato crisps.

The High Court agreed with the company's argument, partly on the grounds that Pringles are about 40% potato flour. (Other ingredients include corn and rice flours, and wheat starch.) In 2009, however, an appeals court ruled that Pringles were subject to the tax because "there is more than enough potato content for it to be a reasonable view that [the product] is made from the potato." Whatever conclusions you may draw about this logic, you can call them "chips" with a clear legal conscience.

To make puffed chips, use Ultra-Crisp CS or Crisp Coat UC rather than raw potato starch, and include step 5. For a great flavor addition, replace the water with cheese-infused water (see page 2·310).

PARAMETRIC RECIPE

BATTER-FRYING

A simple cloak of flour or other starch and a short sizzle in oil add a transformative crunch to foods as diverse as zucchini, cod, and Twinkies. The main trick is choosing a batter that sticks to the food and delivers the desired exterior texture, from airy and crispy to dense and crunchy. Whether you use traditional batters or the Modernist versions we recommend in the table on the next page—and whether you are making tempura prawns at a fine restaurant or novelty pickles at the county fair—the basic mechanics of frying are largely the same.

1 **Select a batter.** Use the Batter Textures table at right to choose an option that yields the texture you desire.

2 **Mix flours or starches with seasonings.** Ingredients and proportions are listed in the table on the next page.

3 **Blend liquid with rising agents.**

4 **Whisk liquid into dry mixture.**

5 **Pour batter into siphon (for siphoned batters only).** Charge siphon with the gas listed in the scaling column.

6 **Coat food with an adhesive (optional).** Batters cling better to low-moisture foods if you first dip the food in milk, eggs, or another sticky substance.

7 **Coat evenly in dry starch (see page 338).** Shake off any excess.

Batter Textures

	Crisp	Crunchy	Extra crispy
airy	tempura, whole egg		
lacy	yeast		crispy tempura
thin	cider		
rich		egg yolk	
dense	beignet	cornmeal	

8 **Dispense batter into bowl, and coat the food evenly.**

9 **Fry.** For recommended frying temperatures and times, see individual recipes.

10 **Pat dry, and season.** Salt is appropriate for most foods.

7

8a

Best Bets for Batters

Batter	Flour or starch	(scaling)	Seasoning	(scaling)	Liquid	(scaling)	Rising agent	(scaling)	See page
tempura	flour	67%	n/a		sake	100%	baking powder	2%	5·197
	rice flour	67%			vodka	75%	siphon*	two charges of CO_2	
					malt syrup	8%			
whole-egg	sweet-potato starch	37.5%	salt	2%	blonde ale	100%	dry yeast	0.6%	
	flour	37.5%			egg	15%	siphon*	two charges of N_2O	
yeast	Trisol (Texturas brand)	90%	salt	1%	water	100%	fresh yeast	2%	5·75
	flour	65%							
crispy tempura	flour	28.5%	salt	3%	water	100.0%	baking powder	0.5%	
	cornstarch	12.5%			vodka	12.5%	siphon*	two charges of N_2O	
	Ultra Crisp CS (National Starch brand)	10.0%							
cider	tapioca starch	35%	n/a		hard cider	100%	baking soda	0.75%	5·28
	flour	25%					siphon*	two charges of N_2O	
	xanthan gum	0.15%							
egg yolk	potato starch	50%	salt	2.5%	ice water	100%	thermal shock		
	flour	35%	Old Bay	1.0%	malt vinegar	30%			
	glutinous rice flour	15%	salt		egg yolk	8%			
beignet	flour	33.0%	salt	2%	carbonated water	100%	baking soda	1.5%	next
	tapioca starch	33.0%							
	trehalose	16.5%			vodka	11%			
cornmeal	cornmeal	40.0%	salt	1.5%	buttermilk	100%	Methocel SGA 150	1.25%	
	flour	17.5%	cayenne pepper	0.5%			baking powder	0.60%	

(we use 1 l siphons; fill siphon at least half full, and adjust quantity of charges as needed)

8b

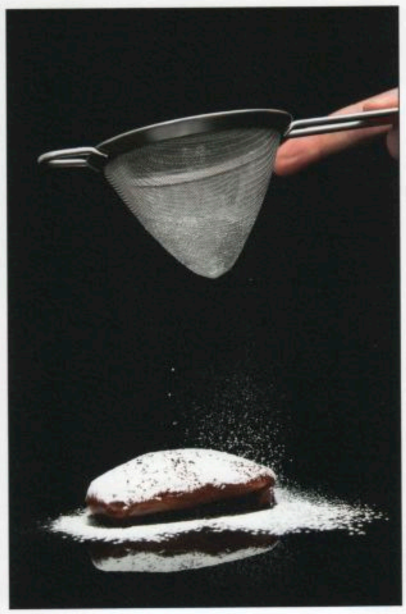
9

CRISPY HALIBUT CHEEK ADAPTED FROM HESTON BLUMENTHAL

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
All-purpose wheat flour	200 g	50%	① Sift together, and reserve.
Rice flour	200 g	50%	
Salt	4 g	1%	
Baking powder	3 g	0.75%	
Vodka	350 g	87.5%	② Blend.
Water	200 g	50%	③ Whisk into dry mixture until completely incorporated.
Malt syrup	12 g	3%	④ Pour into 1 l siphon, and charge with one cartridge of nitrous oxide.
			⑤ Shake vigorously and reserve siphon refrigerated.
Halibut cheeks, cleaned of connective tissue	400 g (four cheeks)	100%	⑥ Dust Trisol evenly over cheeks.
			⑦ Skewer each cheek.
Trisol (Texturas brand)	100 g	25%	⑧ Siphon batter into bowl.
			⑨ Coat cheeks evenly with foam batter.
Neutral oil	as needed		⑩ Fry in 200 °C / 400 °F oil.
			⑪ Lift extra batter from bowl with fork, and drizzle onto cheeks to build lacy surfaces. Make sure to flip cheeks in oil while drizzling batter, to build an even crust.
			⑫ Remove each cheek from oil when its core reaches 50 °C / 122 °F, about 6 min.
			⑬ Drain on paper towels.

(original 2005, adapted 2008)



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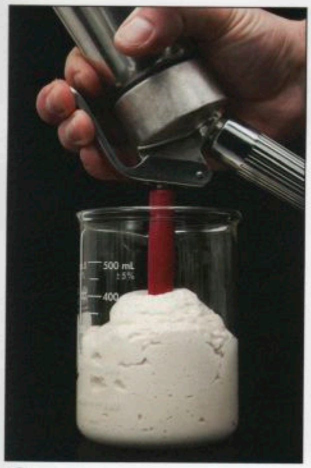

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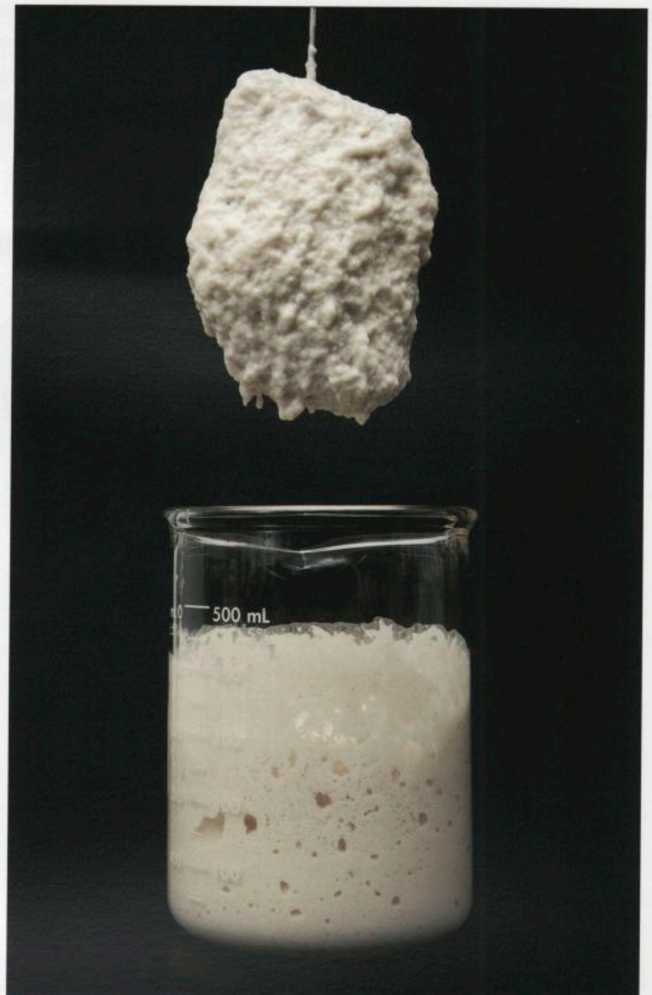

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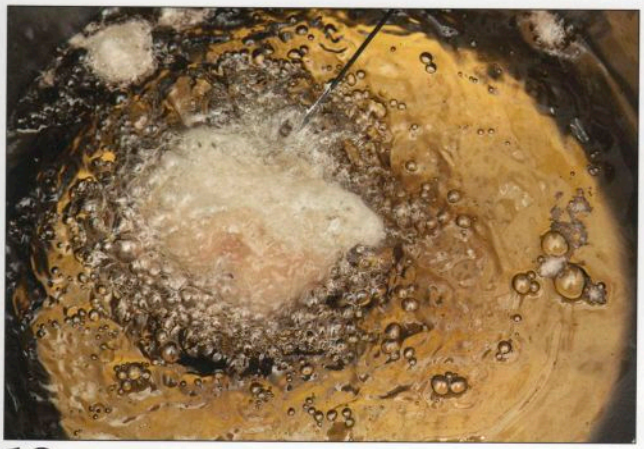

9b

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12

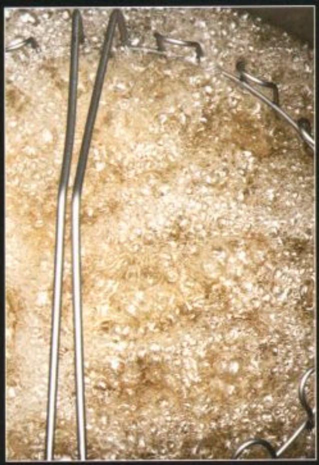
THE COLONEL'S FRIED CHICKEN INSPIRED BY COLONEL HARLAND SANDERS

Yields 800 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chicken, drumsticks	800 g	100%	① Clean, pat dry on paper towels, and reserve.
Cake flour	200 g	25%	② Combine and reserve.
All-purpose bleached wheat flour	160 g	20%	
Whole wheat flour	32 g	4%	
Black peppercorns	10 g	1.25%	③ Grind spices and herbs finely.
White peppercorns	8 g	1%	④ Combine with flour mixture.
Paprika	4.5 g	0.56%	
Onion powder	4 g	0.5%	
Caraway seeds	2.5 g	0.31%	
Nutmeg	1.5 g	0.18%	
Sage, rubbed	0.7 g	0.08%	
Allspice, ground	0.5 g	0.06%	
Thyme	0.5 g	0.06%	
Cayenne pepper	0.3 g	0.03%	
Bay leaf	0.1 g	0.01%	
Salt	24 g	3%	⑤ Combine with seasoned flour mixture, and reserve.
Monosodium glutamate (MSG)	14 g	1.75%	
Whole milk	120 g	15%	⑥ Blend together until smooth.
Eggs	60 g	7.5%	⑦ Dip chicken pieces into egg mixture, and dredge in seasoned flour mixture.
			⑧ Pressure-fry coated chicken in 160 °C / 325 °F oil for 7 min. Alternatively, fry in 180 °C / 360 °F oil until golden and cooked through, about 12 min.

(original 1930, adapted 2010)

For pressure-frying instructions, see page 2·120.



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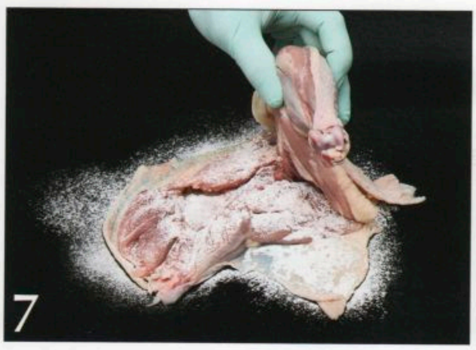
EXAMPLE RECIPE

MODERNIST FRIED CHICKEN

Yields 1 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Chicken legs with skin	1 kg (four legs)	100%	① Remove thigh bones from legs; leave lower leg bones in.
Water	500 g	50%	② Whisk together until salt dissolves to make brine.
Salt	35 g	3.5%	③ Vacuum seal with prepared chicken legs.
			④ Brine in refrigerator for 5 h, or vacuum tumble for 30 min (see page 152), and then drain.
Chicken skin, from whole chicken	20 g	2%	⑤ Cut pieces of skin to match dimensions of exposed thigh meat.
			⑥ Dust Activa over cut skin pieces and exposed, boneless thigh meat.
Activa RM	10 g	1%	⑦ Press matching skin pieces to meat so that no skin remains exposed.
			⑧ Wrap each leg tightly with plastic wrap, and refrigerate 12 h to let proteins bond.
Water	50 g	5%	⑨ Mix until baking soda dissolves.
Baking soda	5 g	0.5%	
Vodka	450 g	45%	⑩ Mix with baking soda solution to make brine.
			⑪ Unwrap chicken legs, and vacuum seal individually with equal portions of brine.
			⑫ Brine, refrigerated, for 3 h, or vacuum tumble for 30 min.
			⑬ Remove from bag, and pat dry.
			⑭ Vacuum seal dry chicken legs.
			⑮ Cook sous vide in 64 °C / 147 °F bath for 2 h.
			⑯ Blot dry.
Spray-dried buttermilk see page 2·443 or store-bought	15 g	1.5%	⑰ Whisk together spice mixture, and reserve.
Cayenne pepper	2 g	0.2%	
Bay leaf, powdered	1 g	0.1%	
Black pepper, coarsely ground	1 g	0.1%	
Frying oil	as needed		⑱ Fry thighs in 225 °C / 435 °F oil for 4 min.
			⑲ Drain on paper towels, and dust with spice mixture.

(2010)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PARAMETIC RECIPE

BREADING

If you want a crisp or crunchy crust on a food, you'll find that breading gives you more control over the texture—and a wider range of options—than a batter can. You can also prepare breaded food in advance and refrigerate it until you're ready to fry.

A breaded crust helps protect the food inside from overcooking, and it securely contains wet contents. The downside to breading is the careful engineering it requires. For many foods, you'll want to use three distinct coatings: a sticky coating to keep the breading from sliding off a dry coating of starch or another hydrocolloid, a liquid coating that swells the dry coating enough to make it tacky, and then the final breading.

You can mix and match coating layers from the three tables below and on the next page. Coatings are listed in order from traditional ingredients to Modernist; the latter often provide a greater variety of textures and a more cohesive crust. Remember that some coatings impart a flavor of their own. We prefer neutral ingredients that allow the flavor of the core foods to stand out.

An age-old trick for frying a liquid is to gel it with gelatin so that it is solid enough to be breaded and fried. If served hot, the gelatin melts to yield a liquid interior. This is a great culinary surprise and can be used to excellent effect (see page 340). Be sure to tell your guests to eat with one bite—or expect them to make a mess!

Adhesives

Coating	Stickiness	Flavor
albumin powder	acceptable	egg
flour	good	raw flour
starch	good	varies, raw starch
modified starch	very good	neutral
Trisol (Texturas brand)	very good	neutral

Liquids

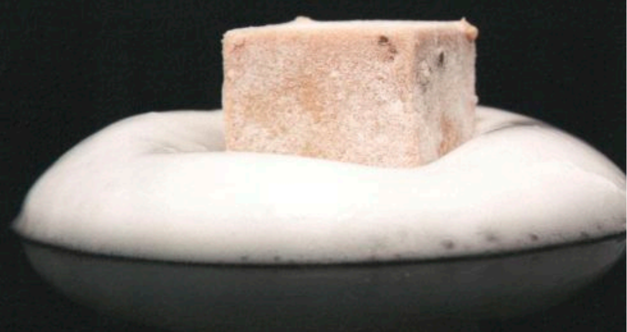
Coating	Film thickness	Film flavor
whole egg	thick	egg
egg yolk	medium	egg
egg white foam	medium	egg
slurry of 100% starch, 30% water	thin	neutral
methylcellulose K100M, slurry, or foam (100% water, 0.5% K100M)	thin	methylcellulose

1 **Prep the core ingredient, if required (optional, not shown).**

2 **Cut into even pieces.** If the food pieces differ greatly in size, some will overcook while others don't cook enough.

4 **Dip in a liquid coating, and drain excess.** See the Liquids table for suggestions; egg yolk (left) and methylcellulose foam (below) are shown.

3 **Dust food evenly with an adhesive coating.** The Adhesives table lists some that we recommend.



Breadings

Coating	Density	Texture	Oil absorption
bread crumbs	heavy	crispy	moderate
processed grain (cream of wheat, rolled oats, instant polenta, pressed rice flakes)	light	crunchy to crispy	moderate
freeze-dried vegetable flakes (carrot, corn, onion, potato)	light	very crispy	high
puffed snacks	varies	crunchy	low

5 **Roll food in breading to cover.** All the options listed in the Breadings table can work well.

6 **Refrigerate breaded food until crust is firm, at least 1 h (not shown).**

7 **Deep-fry until golden.** We fried these in 190 °C / 375 °F oil for about 90 s. For other recommended temperatures and times, see individual recipes.

8 **Drain on paper towels, and season (not shown).**

CROMESQUIS INSPIRED BY MARC MENEAU

Yields 1.5 kg (50 cromesquis)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Red port, chilled	450 g	129%	① Disperse gelatin in port.
160 Bloom gelatin	50 g	14.3%	② Simmer until reduced to 200 g, and reserve warm.
Raw duck foie gras	350 g	100%	③ Cut foie gras into cubes.
			④ Sear until exteriors are golden but centers are still raw, about 1 min, and reserve warm.
Heavy cream	600 g	171%	⑤ Whisk together and season.
Black truffle juice (store-bought) or mushroom jus see page 2·348	50 g	14.3%	
Salt	15 g	4.3%	
Black pepper, ground	0.2 g	0.05%	
Ultra-Sperse 3 (National Starch brand)	6 g	1.7% *(0.5%)**	⑥ Dry blend powders, and disperse into cold cream mixture.
			⑦ Bring to a simmer while blending to hydrate fully.
Iota carrageenan	2.4 g	0.68% *(0.2%)**	⑧ Blend in warm port reduction and foie gras until smooth.
			⑨ Cast mixture in nonstick mold in layer 2 cm / ¾ in thick.
Low-acyl gellan (Kelcogel F, CP Kelco brand)	1.8 g	0.51% *(0.15%)**	⑩ Refrigerate until set, at least 4 h.
			⑪ Cut foie gras gel into 2.5 cm / 1 in cubes.
Black truffle, finely minced	30 g	8.5%	⑫ Fold into hot puree.
Trisol (Texturas brand)	as needed		⑬ Dredge cubes in Trisol.
Eggs	300 g	85%	⑭ Blend until smooth.
Egg yolks	75 g	21.4%	
Fine, dry bread crumbs	150 g	43%	⑮ Coat floured cubes in egg mixture, and then dredge in bread crumbs.
			⑯ Refrigerate cubes for 2 h to harden crusts.
Frying oil	as needed		⑰ Fry cubes in 190 °C / 375 °F oil until golden, about 2 min.
			⑱ Drain on paper towels.

(original c. 1983, adapted 2010)

(% of total weight of first five ingredients)

EXAMPLE RECIPE

CORN CROQUETTA INSPIRED BY DAVID KINCH

Yields 350 g (24 croquettas)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Frozen sweet corn, thawed	200 g	67%	① Combine, and puree until smooth.
Heavy cream	90 g	30%	② Strain through fine sieve, and reserve 300 g of corn puree.
Salt	5 g	1.7%	
Cayenne pepper	3 g	1%	
Vanilla seeds and pulp	1.5 g (from one vanilla bean)	0.5%	
Corn puree, from above	300 g	100%	③ Disperse gelatin in 100 g of reserved corn puree.
160 Bloom gelatin	9 g	3%	④ Warm mixture until gelatin is fully dissolved.
			⑤ Whisk in remaining reserved corn puree.
			⑥ Cast mixture in layer 2.5 cm / 1 in thick in nonstick mold.
			⑦ Refrigerate until set, at least 4 h.
Water	100 g	50%	⑧ Bring water to a simmer.
Methylcellulose E4M	1.5 g	0.75%	⑨ Blend in methylcellulose until fully dissolved, 2–3 min.
			⑩ Refrigerate at least 4 h to hydrate.
Crisp Coat UC (National Starch brand)	5 g	2.5%	⑪ Cut gelled puree into 2.5 cm / 1 in cubes.
			⑫ Dust cubes evenly with Crisp Coat to coat.
			⑬ Whip hydrated methylcellulose with electric whisk to form stiff and foamy peaks.
			⑭ Coat cubes evenly with whisked methylcellulose, and reserve.
Corn powder, freeze-dried see page 372	50 g	25%	⑮ Mix to make breading.
			⑯ Dredge foam-covered cubes in breading mix.
Panko	50 g	25%	⑰ Refrigerate cubes to firm and bind crusts, about 30 min.
Frying oil	as needed		⑱ Fry cubes in 190 °C / 375 °F oil until golden, about 1½ min.
			⑲ Drain on paper towels.
Salt	to taste		⑳ Season.

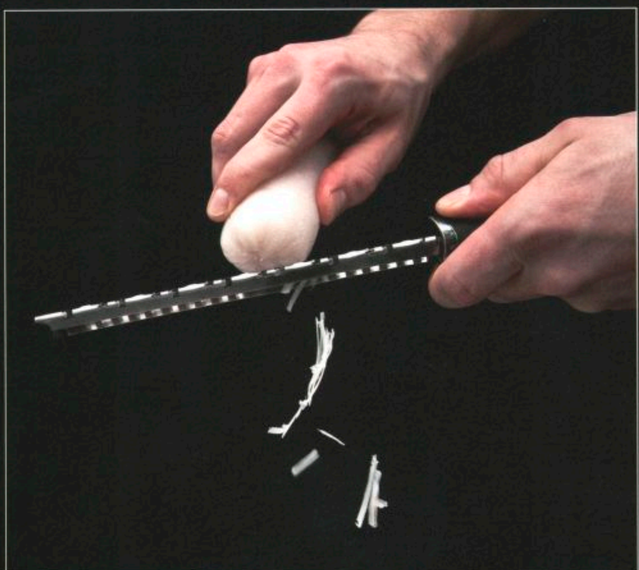
(original 1997–1998, adapted 2010)

ONION RINGS

Yields 250 g (about 10 onion rings)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Onions, thinly sliced	750 g	375%	① Saute until light golden, about 10 min and cool.
Unsalted butter	100 g	50%	② Vacuum seal cooked onions with water.
Water	150 g	75%	③ Cook sous vide in 90 °C / 194 °F bath for 1 h.
Onion stock, cold, from above	45 g	22.5%	④ Strain and cool onion stock. Measure 245 g for recipe.
Methocel A15C (Dow brand)	4 g	2%	⑤ Bring onion stock to simmer, and disperse Methocel A15C and salt.
Salt	1.5 g	0.75%	⑥ Refrigerate Methocel solution for at least 8 h to hydrate fully, and reserve cold.
Onion stock, cold, from above	200 g	100%	⑦ Combine and blend all ingredients in food processor to fine, smooth paste.
Tapioca starch	120 g	60%	⑧ Vacuum seal.
Salt	3 g	1.5%	⑨ Cook sous vide in 93 °C / 200 °F bath for 20 min.
			⑩ Cool completely until hardened, at least 12 h.
			⑪ Remove from bag, and grate with Microplane.
			⑫ Dehydrate at 70 °C / 160 °F until hardened, about 3 h.
			⑬ Reserve breading in airtight container.
Yellow onions, thinly sliced	500 g	250%	⑭ Brown onions over low heat.
Neutral oil	50 g	25%	⑮ Deglaze with water as needed until very tender, about 40 min.
			⑯ Drain excess oil, and blend to smooth puree.
			⑰ Cool completely, and measure 100 g.
			⑱ Blend 100 g of puree with Methocel solution, and transfer mixture to pastry bag.
			⑲ Pipe onion ring shapes onto silicone mat.
			⑳ Freeze.
Tapioca starch	100 g	50%	㉑ Dredge frozen onion rings in tapioca starch, and shake off excess.
Egg, blended	50 g	25%	㉒ Dip rings in egg.
Frying oil	as needed		㉓ Dredge rings in breading until evenly coated, and place on silicone mat.
			㉔ Deep-fry rings in 190 °C / 375 °F oil for 2 min, ensuring that puree stays inside coating.
			㉕ Drain on paper towels.

(2008)



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Here we make a puffed starch snack and grate it to make the breading for the onion ring. The ring itself is made of onion puree.

23

PRESERVING

Food preservation was once a life-or-death necessity for surviving winter and other tough times. Thanks to refrigeration and global shipping, we no longer need to preserve edible plants as a matter of survival, but the techniques and recipes for doing so remain of vital cultural importance. In many regions, people still cherish the unique flavors and the varied textures of preserved produce.

Recently, there has been renewed interest in the culinary traditions of preserving, sparked in part by a proliferation of kitchen gardens. Novice gardeners quickly discover that fruits and vegetables don't keep for long. Fruit evolved to be eaten more or less immediately, not to sit in fruit bowls. It's best for the plant if animals ingest and disperse the plant's seeds quickly so that the seeds can get a start on life during the proper season.

The natural shelf life of vegetables is similarly limited. The moment a vegetable is picked, it starts to become more vulnerable to spoiling agents, including bacteria, mildew, and mold and other fungi. Vegetables that escape these external threats still decay, as natural enzymes in the plant tissue cause destruction from within. Refrigeration forestalls this effect, but more powerful means are needed to stop damaging enzymes and to inhibit the growth of harmful microbes. The most common approach to preservation is to deprive the microbes of the water they need to thrive, either by dehydrating the food (with heat or a vacuum) or by adding salt or sugar, which takes water away from microbes by chemical means.

A second easy way to hinder bacterial growth is to lower the pH of the water in the food by adding vinegar (acetic acid) or some other acid. This is the essence of pickling.

A third, less intuitive, option is to encourage the growth of certain desirable bacteria in food. They can outcompete spoilage-causing microbes and, by secreting acid and other compounds, suppress the growth of pathogenic microbes. That's what happens in fermentation.

Most other methods of preserving, such as smoking and freeze-drying, work by either removing water or adding compounds that directly suppress bacterial growth, or by some combination of both.

Canning and freezing are two methods of preservation that do not work this way. Canning involves sterilizing food so that all enzymatic activity and bacterial growth is forever halted. We explain the details of canning in Traditional Cooking on page 2·75. Freezing doesn't eliminate enzymes or bacteria. Instead, it effectively halts their activity to prevent spoilage. Finally, heat-shocking is a relatively new technique that greatly extends the life of fresh produce, without changing the appearance, texture, or flavor of that produce.

Smoked potatoes (below) and pickles (next page) last longer without spoiling than their fresh counterparts do, in part because their low pH discourages bacterial growth. A dish by Alain Passard inspired the potatoes garnished with hazelnuts.

Drying with Salt and Sugar

Exposing food to high levels of salt or sugar is essentially a method of "drying" food in liquid. It employs a chemical process known as **osmosis**, which works to balance the concentration of dissolved ions or molecules in liquids on either side of a semipermeable membrane. If the concentration is higher on one side than the other, liquid moves by osmosis to the side with a greater concentration of dissolved salt or sugar until the two sides reach **equilibrium**.

So when you place fruits or vegetables in water and add a sufficient amount of salt or sugar, water actually comes out of the plant cells rather than soaking into them. Think of it as the plant tissue's trying to dilute the external liquid using the water sequestered in its own cells.

For more on how bound water helps to preserve food, see Water Activity, page 1·307.

The result is that the plant cells dry out by as much as 50%. This reduces the water activity in the vegetables—that is, the amount of water available to pathogens and chemical reactions.

Two common examples of this technique are brining vegetables in a salt solution and candying fruits in a sugar solution. In both cases, the osmotic movement of water reduces the water content of the plant's cells.

Osmosis, like heating and dehydration, is a diffusion process: the water diffuses through the boundary of the cell walls. So, as with heating and drying, the size of the food affects the time required to dry it osmotically in the same way. Double the thickness of the food pieces, and they will take roughly four times as long to brine. Triple the thickness, and the brining time shoots up by a factor of nine. The time required increases as the thickness squared.

For more on how osmosis works, see page 2·332.

You can see osmosis at work if you salt a few slices of eggplant on a plate. The grains of salt draw water from the plant cells, causing tiny droplets of brine to form on the slices. This creates a feedback loop in which the "localized brine" on the surface draws out more liquid, which in turn dissolves more salt on the surface, thus encouraging still more liquid to migrate from the interior. Conversely, you can substitute a soak in strong brine for direct salting in any recipe that calls for salting in order to preserve food.

Pickling and Fermenting

Many kinds of bacteria secrete acid when food is present. The microbes can tolerate the acid they make better than other species of bacteria can, so the acid gives them a competitive edge. Cooks exploit this Darwinian mechanism whenever they make vinegar. Yeasts make alcohol as they feed on sugar, and then acetobacters consume the alcohol and excrete acetic acid that is strong enough to kill other bacteria. The acetic acid is the key ingredient in vinegar.

Many cultures have preserved vegetables in vinegar or some other acidic solution—or have taken the less direct approach to the same end: **fermentation**. To ferment vegetables, cooks deliberately encourage the growth of bacteria that, while harmless to us, produce an anti-microbial acid (typically lactic acid). Doing this usually involves salting the food to inhibit spoilage-causing bacteria early on, as well as holding the food at just the right temperature to promote the growth of acid-producing bacteria. The ideal temperature range is 18–24 °C / 64–75 °F. Fermentation in a salty brine has a name: pickling.

Acidifying via fermentation yields many of the distinctive flavors of traditional foods. Think of all the ways cabbage is treated, from sauerkraut to kimchi. Fermentation is also the basis for yogurt and fermented sausages, such as summer sausage and salami (see page 220).

A variation on this approach is alcoholic fermentation. Alcohol is noxious to a broad spectrum of microbes. Indeed, that's why yeasts secrete it: to poison other microorganisms that might eat the sugars that the yeast thrives on. This strategy succeeds well for yeast—unless the alcohol-eating, vinegar-making acetobacters are present.

Alcoholic fermentation is used in recipes such as those for brandied fruits, in which the fruit is jarred along with yeast. Brandied cherries, preserved by their alcohol, are among the best-loved examples. Wine is a type of preserved plant food, too: grape juice that is preserved by alcoholic fermentation.

Red pearl onions turn pink when they are pickled because vinegar dissolves and shifts the hue of the anthocyanin pigments in them.

PARAMETRIC RECIPE

SALTING, PICKLING, AND FERMENTING

Preserving food means suppressing the growth of harmful bacteria, and there are several proven ways to do that. The most common approach is to remove water from the food. Heated dehydration is one obvious way; another is to add salt or sugar, which encourages water to pass by osmosis through the semi-permeable walls of plant cells. Adding vinegar or some other acid suppresses microbes by lowering pH. Fermentation changes pH indirectly by nurturing desirable bacteria that secrete acid.

PRESERVING FRUITS AND VEGETABLES

1. **Select an ingredient and a preservation method.** The Best Bets for Preservation table at right suggests many good options.

2. **Mix brine or cure, and combine with aromatics.** Use the table of Formulas for Preserving Produce on the next page to determine quantities. Note that weights are scaled in proportion to the vinegar for vinegar pickles and to the fruit or vegetable for other kinds of preserves.

3. **Cook or ferment.** For sour or sweet vinegar pickles, bring the brine and aromatics to a simmer, and pour over the prepared ingredients. For oil and sugar preserves, cook all ingredients over low heat until they are very tender and their surfaces are nearly dry. Keep fermented pickles or sauerkraut unsealed in a dark, cool place for at least two weeks; check that liquid exuded from the ingredients always covers the solids.

4. **Refrigerate (nonfermented preserves only).** After cooking, cover the ingredients completely with brine or cure, vacuum seal them or place them in an airtight container, and then refrigerate them to pickle or cure.

Keep brined and cured products refrigerated.

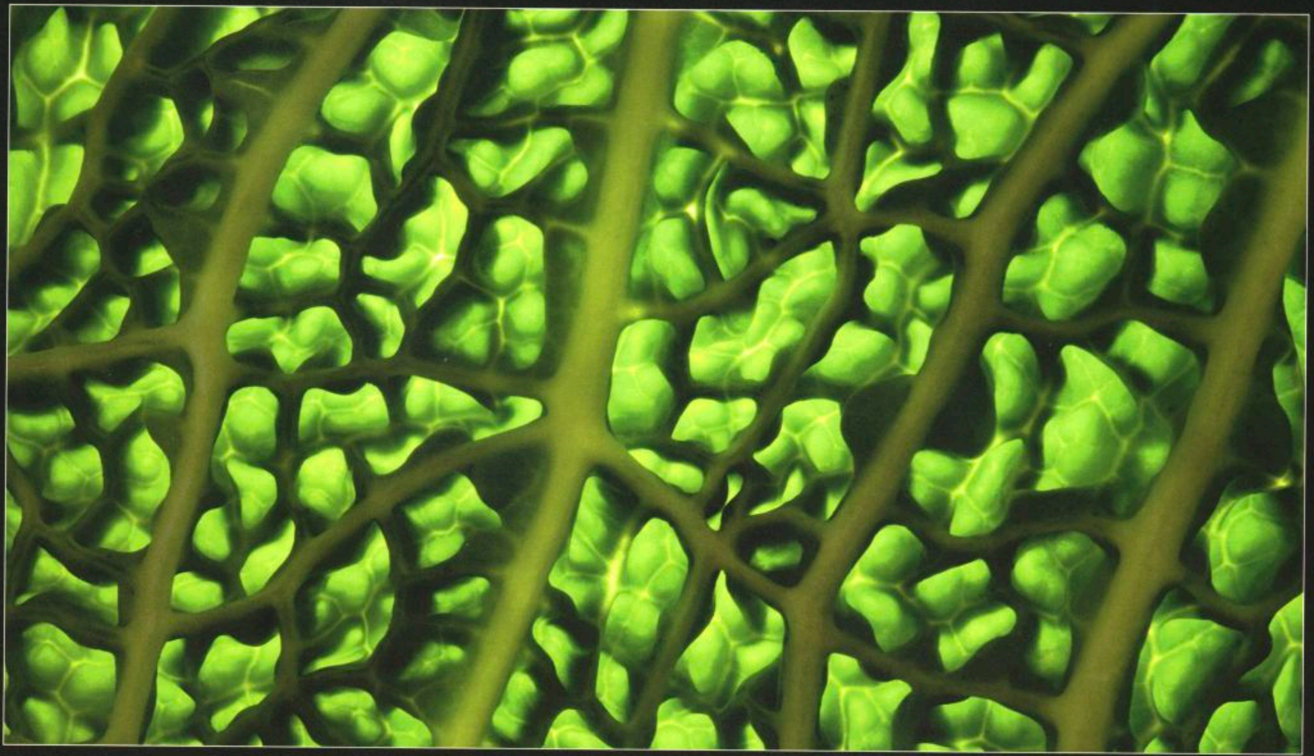
Best Bets for Preservation

Ingredient	Vinegar pickle	Salt pickle	Fermented pickle	Sugar preserve
apple	✓	✓	✓	✓
apricot	✓			✓
bean sprout	✓	✓	✓	
beet	✓			✓
bell pepper	✓		✓	✓
cabbage	✓	✓	✓	
carrot	✓	✓	✓	✓
cauliflower	✓	✓	✓	
cherry	✓	✓		✓
chili	✓	✓	✓	✓
citrus	✓	✓		✓
coconut, young	✓			✓
cucumber	✓	✓	✓	
eggplant	✓			✓
fig	✓			✓
garlic	✓	✓	✓	✓
grape	✓			✓
green bean	✓	✓	✓	
lychee	✓			✓
mango, green	✓			
melon	✓	✓	✓	✓
mustard seeds	✓	✓		✓
mushroom	✓	✓	✓	
okra	✓	✓		
olive	✓	✓		✓
onion	✓		✓	✓
papaya, green	✓	✓	✓	
peach	✓			✓
pear	✓			✓
pineapple	✓			✓
radish	✓	✓	✓	
rhubarb	✓	✓		✓
rutabaga	✓		✓	
seaweed	✓	✓	✓	
tomato	✓			✓
turnip	✓	✓	✓	
zucchini	✓			✓

Formulas for Preserving Produce

Product	Ingredient	(scaling)	Aromatics	(scaling)	See page
sour vinegar pickles	vinegar	100%	garlic	1.5%	353
	water	40%	black peppercorns	0.5%	
	salt	4%	mustard seeds	0.5%	
	calcium lactate (optional, to firm)	1%	red chilies (optional)	0.2%	
sweet vinegar pickles	vinegar	100%	coriander seeds	1.00%	5·118
	water	70%	star anise	1.00%	
	sugar	40%	ginger	1.00%	
	salt	5%	lemon zest	0.40%	
	pectin methylesterase enzyme (NovoShape brand, optional, to firm)	0.4%	white peppercorns	0.25%	
salt pickles	fruit or vegetable	100%	n/a		
	salt	9%			
	sugar	9%			
fermented pickles	fruit or vegetable	100%	n/a		351
	salt	1.5%			
	lactic acid (optional, to enhance flavor)	0.2%			
sugar preserves	fruit or vegetable	100%	lemon zest	0.5%	356
	sugar	100%	vanilla pulp and seeds	0.1%	
	water	100%			

Note that the table above does not include the preparation steps that should be taken to pasteurize the food. Store any unpasteurized foods in the refrigerator as you would fresh foods. Canning and heat preservation require more intense pasteurization; see Canning, page 2·75, for details.



EXAMPLE RECIPE

PRESERVED LEMONS ADAPTED FROM BRADFORD THOMPSON

Yields 2 kg

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Lemons (organic)	3 kg (about 25 large)	100%	① Cut off one slice, 2.5 cm / 1 in thick, from one end of each lemon. ② Cut each lemon as if to quarter, but keep lemon intact by not fully cutting through its flesh and not cutting through its unsliced end. ③ Reserve lemons in large bowl.
Salt	1.5 kg	50%	④ Combine.
Sugar	800 g	26.6%	⑤ Place five 1 l / 2 pt canning jars with lids in boiling water to sterilize.
Black peppercorns	50 g	1.6%	⑥ Air-dry sterilized jars and lids on rack.
Cinnamon sticks, crushed lightly	25 g	0.8%	⑦ Open up each lemon without breaking its unsliced end; lemon should resemble a bloomed flower.
Coriander seeds	25 g	0.8%	⑧ Sprinkle seasoned salt generously inside lemons.
Fennel seeds	20 g	0.6%	⑨ Pack lemons into canning jars, five per jar, covering each layer with remaining salt mixture.
Saffron threads	18 g	0.6%	⑩ Seal jars tightly and refrigerate. Preserved lemons can be used after 4 wk but are best after 3–4 mo. Store refrigerated for up to 1 y.
Star anise, crushed lightly	10 g	0.3%	
Black onion seeds	5 g	0.2%	

(original 2004, adapted 2009)

8a

8b

EXAMPLE RECIPE

SAUERKRAUT

Yields 600 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Savoy cabbage (green cabbage, red cabbage, rutabaga, or turnips may be substituted)	2 kg	100%	① Remove leaves, and cut out and discard their central ribs. ② Slice leaves into fine ribbons.
Salt	30 g	1.5%	③ Toss with cut leaves. ④ Pack salted leaves in crock or other deep, opaque container. ⑤ Cover mouth of container with cheesecloth, and top with clean rock or other heavy, sanitized object. ⑥ Store at **18–24** °C / **64–75** °F for 2–4 wk, or until pH is below 4.0. Cabbage must become fully submerged in its own juices. This should occur by the third day; if not, add 1% salt brine to cover. ⑦ Vacuum seal, and refrigerate sauerkraut with brine until needed.

(2008)

3

4

5

6

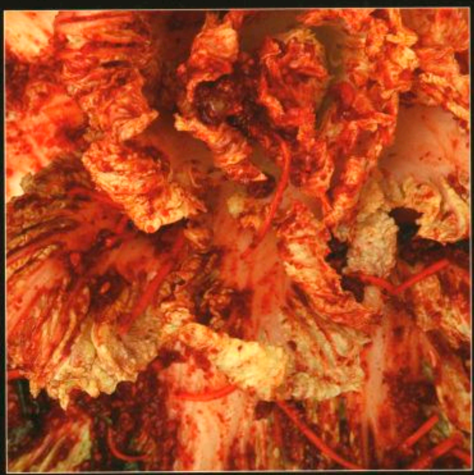
KIMCHI ADAPTED FROM DAVID CHANG

Yields 650 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sugar	75 g	9%	① Combine salt with 30 g of sugar.
Salt	22 g	2.6%	
Napa cabbage head with leaves attached	825 g	100%	② Rub mixture thoroughly into leaves while keeping cabbage head intact. ③ Cover, and refrigerate for 12 h. ④ Drain and reserve.
Garlic, finely minced	100 g	12%	⑤ Combine with remaining 45 g of sugar.
Fish sauce	65 g	8%	⑥ Rub mixture completely into leaves, keeping head intact.
Light soy sauce	62 g	7.5%	⑦ Cover, and store at 18–24 °C / 64–75 °F for 24 wk to ferment. Final pH should be less than 4.0.
Korean chili powder	48 g	6%	⑧ To serve, cut individual leaves away from core.
Scallions, minced	37 g	4.5%	
Ginger, finely minced	35 g	4%	
Carrot, julienne	30 g	4%	
Dried salted shrimp	7 g	1%	

(original 2003)

2



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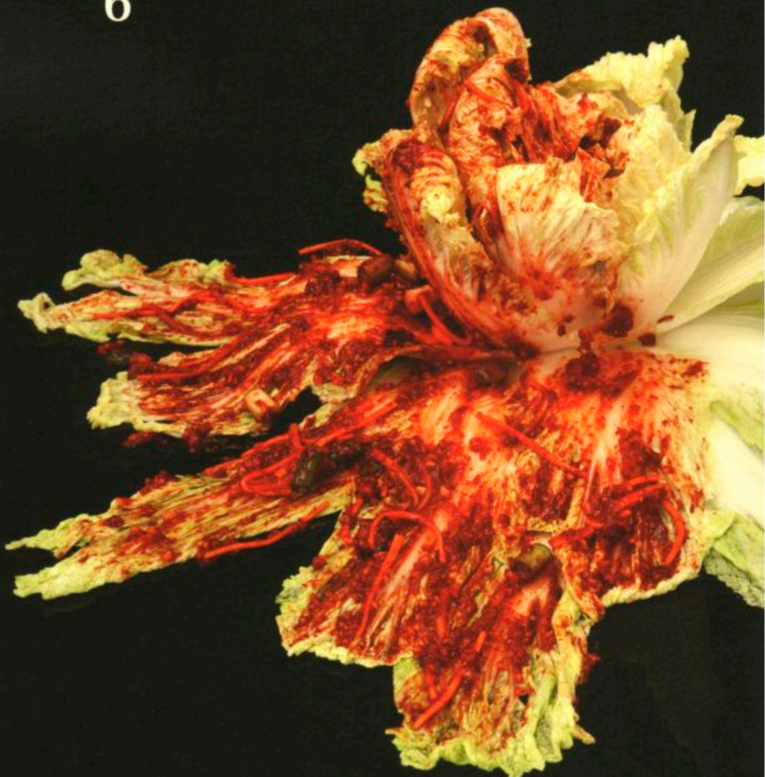
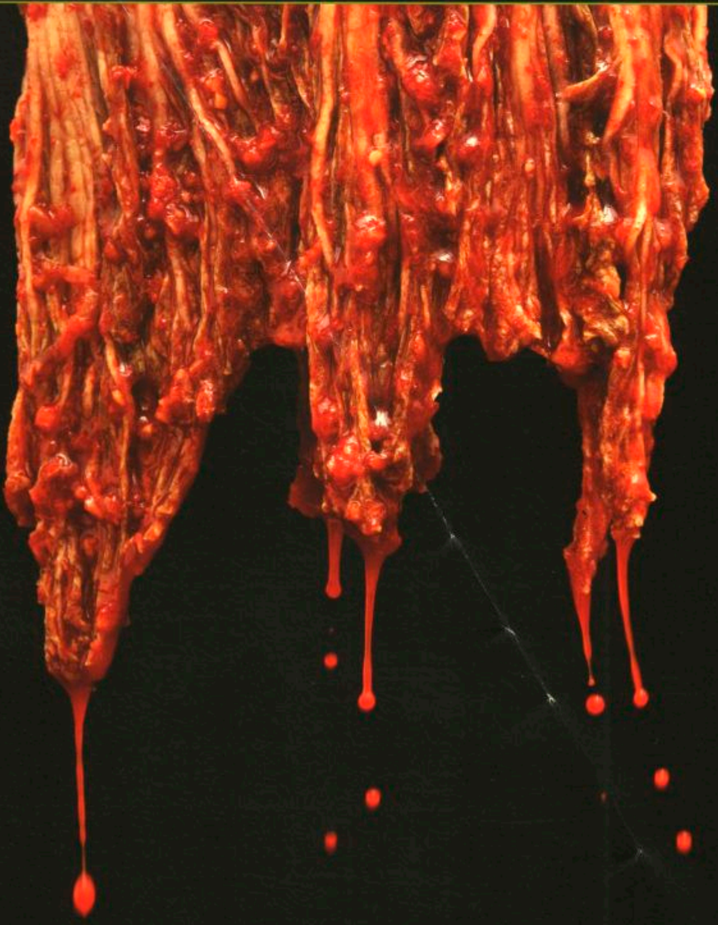




EXAMPLE RECIPE

SOUS VIDE CUCUMBER PICKLES

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Small pickling cucumbers	300 g	100%	① Slice to 4 mm / ¼ in thick, and reserve.
White wine vinegar	350 g	117%	② Combine, and bring to a boil.
Water	150 g	50%	③ Remove brine from heat, and cool.
Sugar	80 g	27%	④ Refrigerate to cool completely.
Salt	8 g	2.7%	
Black peppercorns	1 g	0.3%	
Caraway seeds	1 g	0.3%	
NovoShape PME enzyme (optional, Novozymes brand)	2 g	0.67% (*0.4%*)*	
Fresh dill sprigs	8 g	2.7%	⑤ Add dill and sliced cucumbers to chilled brine. ⑥ Vacuum seal. ⑦ Refrigerate for 1–2 d.

(2010)

(% of total weight of vinegar and water*)

EXAMPLE RECIPE

GARLIC CONFIT

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Olive oil	500 g	200%	① Place garlic cloves and aromatics in mason jars, and cover with oil.
Garlic cloves, peeled	250 g (about 35 cloves)	100%	② Place mason jars in pressure cooker, and pour water halfway up their sides.
Rosemary sprigs	3 g	1.2%	
Thyme sprigs	3 g	1.2%	③ Pressure cook at 1 bar / 15 psi (gauge) for 2 h.
			④ Alternatively, vacuum seal together, and cook sous vide in 88 °C / 190 °F bath for 7 h.
			⑤ Serve, or cool and refrigerate.

(2009)

Pressure-cooked garlic confit has a darker appearance and deeper flavor than sous vide garlic confit does. This recipe can also be made with other typical Provençal aromatics, such as fennel seed, bay leaf, lavender, and sage, instead of—or in addition to—rosemary and thyme.

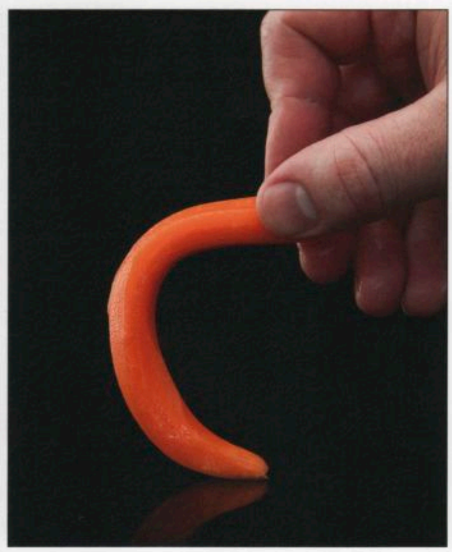
EXAMPLE RECIPE

NUKAZUKE

Yields 350 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	1 kg	100%	① Combine.
Salt	200 g	20%	② Stir until salt is completely dissolved.
Rice bran (nuka)	1 kg	100%	③ Combine.
Ginger, cut into chunks	20 g	2%	④ Add solution from above.
Cabbage leaves	15 g	1.5%	⑤ Cover, and leave at room temperature for 2 wk; stir once daily.
			⑥ Discard cabbage leaves and ginger; reserve rice bran mixture.
Carrots	200 g	20%	⑦ Rub surfaces of vegetables with salt.
Japanese cucumbers (or Persian)	200 g	20%	⑧ Place in deep crock with rice bran mixture; bury vegetables completely in mixture.
			⑨ Cover top of crock tightly with plastic wrap.
Radishes	100 g	10%	⑩ Store in dry place at room temperature until desired texture is achieved, 4–24 h.
Salt	as needed		⑪ To serve, remove vegetables from rice bran mixture, and rinse.
			⑫ Reserve rice bran mixture, refrigerated, for future pickling.

(2010)



This pickling method is most effective when whole vegetables are used.

CRISPY DOSA

Yields 800 g (12 dosas)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Jasmine rice	400 g	100%	① Soak together in water at room temperature for about 3 h.
Whole black gram (urad dal)	200 g	50%	② Drain.
Flattened rice flakes (poha)	25 g	6.25%	
Water	850 g	212.5%	
Water	100 g	25%	③ Combine with soaked grains and soaking liquid, and grind until smooth and fluffy.
Coconut (fresh), grated	30 g	7.5%	④ Add up to 100 g more water, as necessary, to achieve thin pancake-batter consistency.
Salt	10 g	2.5%	⑤ Measure 500 g of batter, and ferment in covered container at room temperature for 2 h. Refrigerate remaining batter.
Lactic acid	2.5 g	0.63%	⑥ Add to batter, and continue to ferment for 30 min.
Ghee see page 4·213	as needed		⑦ Bring nonstick skillet or griddle to medium heat. ⑧ Ladle batter onto skillet. Use an outward spiral motion to spread evenly. ⑨ Drizzle 5 ml / 1 tsp of butter around edges of each dosa. ⑩ Cook until crispy and golden on bottom.
Masala curry sauce see page 5·90	80 g	20%	⑪ Combine potatoes and masala sauce; warm through. ⑫ Warm foam in 60 °C / 140 °F bath for 20 min.
Sous vide cooked potatoes, cubed	120 g	30%	⑬ Fill dosas with potatoes, foam, and puffed lentils; serve on side.
Coconut chutney foam see page 4·282	150 g	37.5%	
Puffed lentils see page 4·302	80 g	20%	

(2010)

YUZU AND KUMQUAT MARMALADE

Yields 475 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Fructose	100 g	40%	① Dry blend.
High-methoxyl pectin (Brown Ribbon HV, Obipektin brand	2.5 g	1%	
Salt	1.5 g	0.6%	
Yuzu juice (fresh or bottled)	55 g	22%	② Reserve 5 g of juice. ③ Blend powder mixture with remaining 50 g. ④ Bring juice to boil to make syrup. ⑤ Remove from heat, and cool completely.
Kumquats, quartered	250 g	100%	⑥ Blanch once in boiling water, and cool completely. ⑦ Combine with cooled yuzu syrup. ⑧ Vacuum seal together. ⑨ Cook sous vide in 80 °C / 176 °F bath until very tender, about 4 h. ⑩ Remove from bag to cool completely, and reserve.
Mandarin juice, freeze-concentrated see page 2·337	70 g	28%	⑪ Combine, and hand-blend until gums are completely incorporated. ⑫ Fold into cooled marmalade base.
Guar gum	0.28 g	0.11% *(0.2%)**	
Xanthan gum	0.2 g	0.08% *(0.16%)**	
Citric acid	2 g	0.8%	⑬ Whisk into marmalade.
Yuzu juice, from above	5 g	2%	⑭ Add to marmalade, and refrigerate.

(2010)

(% of total weight of yuzu and mandarin juices*)

EXAMPLE RECIPE

ENZYME-TREATED PINK GRAPEFRUIT

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pink grapefruit, peeled	300 g	30%	① Separate carefully into segments, leaving membranes intact, and reserve.
Water	1 kg	100%	② Combine, and transfer to sanitized jar.
Pectinex Ultra SP-L (Novozymes brand)	2 g	0.2%	③ Add grapefruit segments.
			④ Seal jar.
Pectinex Smash XXL (Novozymes brand)	1 g	0.1%	⑤ Refrigerate for 12 h to soak.
			⑥ Remove treated segments from water.
			⑦ Brush away any undissolved grapefruit membrane.

(2008)

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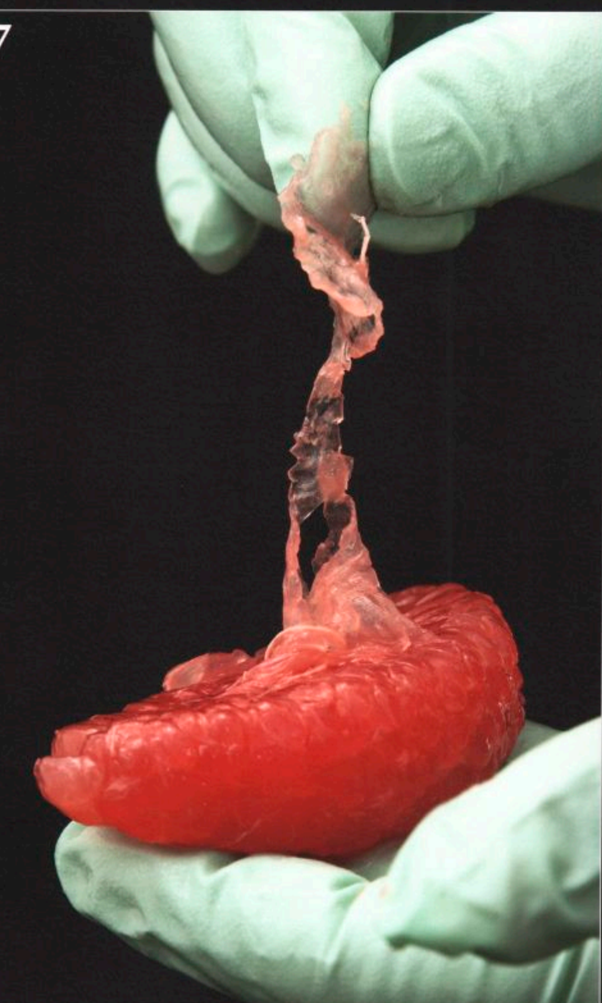


Heat-Shocking

It seems counterintuitive, but you can delay the inevitable decay of fresh produce with the application of heat. Briefly exposing freshly harvested fruits and vegetables to mildly elevated temperatures (typically 37–45 °C / 99–113 °F) helps them retain their crispness and fresh character. This method works on most fruits and vegetables, even fragile ones such as lettuce and grapes. Indeed, commercial processors commonly use it to keep produce from spoiling during distribution. In addition to hot-water dips or blanching, you can heat-shock produce using hot vapor or air.

Heat treatment is a relatively simple way to prevent spoilage and keep fruits and vegetables at their peak quality for longer periods. In one study, researchers immersed lettuce in 50 °C / 122 °F water for 90 seconds and then held it at 5 °C / 41 °F for two weeks. Remarkably, the lettuce showed no signs of browning even at the two-week mark. Heat treatment has also been shown to prevent discoloration in avocados, to delay sprouting in potatoes, and to halt the growth of stems in cut green onions.

It's not entirely clear what heat-shocking does to raw plant foods that extends their shelf life so dramatically. One possibility is that the heat halts the production of enzymes that promote ripening and decay. It may also kill some kinds of microbes and fungal spores.

Grapes can be heat-shocked for preservation and then peeled for presentation.

PARAMETRIC RECIPE

HEAT-TREATED FRUIT

Gently warming certain fresh fruits in a water bath extends their shelf life without affecting the flavor or "cooking" the fruit. The warm soak destroys some of the enzymes that cause ripening, thereby slowing the process. Whenever you use this technique, be sure to closely monitor the temperature of the water bath, leave the fruit in for only the recommended time, and fully dry the produce before storage. Not all fruits benefit from this process, but some, like blueberries and grapes, will keep dramatically longer after a good hot bath.

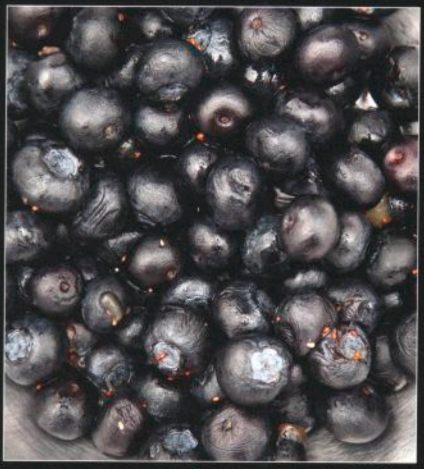
EXTENDING THE SHELF LIFE OF FRUIT

The table at right suggests a number of fruits for which this process works well. Make certain the water bath has reached the temperature indicated before you drop the fruits in whole.

Stir gently and submerge the fruits if necessary. If you remove them after the time indicated and dry them thoroughly, you can expect their shelf life to increase by half or more, as noted in the table.

Best Bets for Heat-treated Fruit

	Warm bath			Shelf life, untreated	Shelf life after treatment
Fruit	(°C)	(°F)	(min)	(d)	(d)
blueberry	60	140	½	7	20
citrus, segments	60	140	20	6	11
grape	55	131	½	5	25
melon	50	122	60	12	15
pear	45	113	40	10	15
strawberry	60	140	¼	9	12
tomato	60	140	½	7	10



Fresh blueberries (left) dipped for 30 seconds in a water bath at 60 °C / 140 °F (middle) come out looking little changed (right) but have nearly twice the shelf life of untreated berries.

Smoking

Smoking has been used primarily as a way to preserve meats and seafood. The heat of the smoke dehydrates the food, while acids and other compounds in smoke offer some protection from spoiling by suppressing bacterial growth.

Although smoking is not usually used on plant foods, there is no reason why it can't be. With vegetables, the goal of smoking is to flavor rather than to preserve (though some preservation does inevitably result from the dehydration that occurs).

Traditionally, cooks have taken advantage of smoking for only a few plant foods. Eggplants acquire a smoky flavor when charred and mashed into Middle Eastern baba ghanouj, and chili peppers (usually jalapeños) in the form of dried and smoked chipotles are popular far beyond Mexico, where they originated.

Cold-smoking, which is done at temperatures as low as those in a refrigerator, will work on nearly any vegetable. Cold smoke deposits a film of condensate from the smoke on the vegetables without significantly altering their texture the way hot smoke does. As with meats, the smoke adheres best if the outside of the vegetable is slightly tacky to the touch.

Hot-smoking requires more finesse because it involves cooking the food as well as flavoring it. Typical hot-smoking temperatures for meats and seafood are too low to cook plant foods; to soften plant tissue, cooking temperatures in the range of 90 °C / 195 °F are needed. That kind of heat is likely to dry out the surface of the vegetable before the interior dries, so you'll need to keep the humidity high, and it may be necessary to occasionally moisten the surface of the food. Or you can precook the vegetable and hot-smoke it briefly for flavor.

Be warned that hot-smoking is not appropriate for all vegetables. Any attempt to hot-smoke lettuce, for example, will result only in wilted leaves. If you are truly committed to trying smoked lettuce, use cold-smoking; it will deliver better results.

If a smoker is unavailable, cook the potatoes sous vide with 2 g (1% total weight of potatoes) of high-quality liquid smoke mixed into the butter.

For more on how to regulate the humidity inside a conventional smoker, see page 2·135.

For more on how cold-smoking and hot-smoking work, see page 2·141.

Fresh pasta (above left) responds well to smoke, taking on both a characteristic color and flavor (above right). Although smoking works with any pasta, those that include egg in the dough tend to absorb more flavor and color because egg proteins react vigorously with compounds in the smoke.

PARAMETRIC RECIPE

SMOKED PLANT FOODS

Smoking is no longer solely a technique for the backyard barbecue or the community pit oven. Nor is it limited to meat and seafood, although smoked sausages and salmon will remain perennial favorites. Modernist cooks have explored smoking as a way to delicately infuse into plant foods flavors that give them a whole new character, much as the addition of oak adds nuance and intrigue to a vintage wine.

Use smoked produce as a featured dish or as a component in a larger recipe. Enliven a cheeseburger with smoked lettuce (see page 5·15). Modernize a classic Greek moussaka with hickory-smoked eggplant. Or add smoked pine nuts to Genoa pesto. The best modern smokers maintain highly controlled smoking environments. If the cooker doesn't do it automatically, it is up to the cook to maintain the right relative humidity so that the food doesn't shrink or dehydrate (see page 2·132).

Each type of wood can be considered an ingredient as well. The choices below each offer a subtle and sweet smoke flavor that works particularly well with each variety of produce.

SMOKING PRODUCE AND PASTA

1 Select and prepare the ingredient. The table Best Bets for Smoked Plant Foods below offers a number of good options.

2 Load the wood mixture into the smoker. Do not soak the wood chips first, because that results in acidic smoke (see page 2·140).

3 Set smoker temperature and relative humidity to the values indicated. For smokers without temperature or humidity controls, place a pan of water on the bottom rack of the smoker, and use a wet-bulb thermometer to monitor the wet-bulb temperature.

4 Smoke for the time indicated in the table.

Best Bets for Smoked Plant Foods

			Smoke								
			Dry-bulb temp.		Wet-bulb temp.		Relative humidity	Time		
Ingredient	Wood	(scaling)	(°C)	(°F)	(°C)	(°F)	(%)	(h)	Note or example use	See page
apple	apple	100%	65	149	46	114	40	24	serve plain, or in tarte tatin	
asparagus	cherry	100%	7	45	4	39	80	24	sauté quickly	
corn, on the cob	oak	100%	10	50	3	37	60	24	cook sous vide, and baste with smoked butter and pimentón	
	maple	25%								
eggplant	hickory	100%	65	149	46	114	40	6	baba ghanouj, moussaka	
fresh pasta	oak	100%	10	50	3	37	60	24	pasta carbonara	
	nectarine	33%								
olive oil (or other oils and fats)	oak	100%	10	50	3	37	60	12	vinaigrette, brushed on grilled bread	
	nectarine	33%								
onion, cooked sous vide	oak	100%	65	149	54	129	60	24	cook sous vide, and finish in a roasting pan with bacon-infused butter	289
	maple	25%								
pecan	apple	100%	65	149	46	114	40	6	briefly roast, and toss with pecan oil, salt	
pineapple	oak	100%	10	50	3	37	60	24	briefly grill, and brush with lime and vanilla syrup	
	maple	25%								
pine nut	hickory	100%	30	86	21	70	60	4	pesto	
potato, cooked sous vide	oak	100%	10	50	3	37	60	24	pulpo a la gallega	next page, 5·193
	nectarine	33%								
rice	oak	100%	10	50	3	37	60	24	paella valenciana	5·239
	nectarine	33%								
soy sauce, dark	oak	100%	50	122	40	104	60	24	shiro dashi or miso soup	
	nectarine	33%								
soy sauce, white	oak	100%	10	50	3	37	60	24	spot prawn tempura	5·201
	nectarine	33%								
watermelon	hickory	100%	65	149	46	114	40	2	dessert for a barbecue	

EXAMPLE RECIPE

SMOKED POTATOES WITH VIN JAUNE SABAYON ADAPTED FROM ALAIN PASSARD Yields 625 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Ratte fingerling potatoes, peeled	100 g	100%	① Vacuum seal together.
			② Cook sous vide in 90 °C / 194 °F bath for 1 h.
Baby Yukon gold potatoes, peeled	100 g	100%	③ Remove potatoes from bag.
			④ Cold-smoke cooked potatoes at 10 °C / 50 °F for 24 h, or hot-smoke in stove-top smoker for 30 min.
			⑤ Cool.
Unsalted butter, melted	50 g	50%	⑥ Vacuum seal potatoes with butter.
Vin jaune	75 g	75%	⑦ Combine vin jaune with shallots.
Shallots, finely minced	50 g	50%	⑧ Reduce to syrup.
			⑨ Strain, and measure 10 g of vin jaune reduction.
White vegetable stock see page 2·303	200 g	200%	⑩ Blend together fully with vin jaune reduction.
			⑪ Cook mixture sous vide in 70 °C / 158 °F bath for 35 min.
Egg yolks	156 g	156%	⑫ Transfer sabayon to 1 l siphon, and charge with two cartridges of nitrous oxide.
Heavy cream	40 g	40%	⑬ Keep siphon warm in 62 °C / 144 °F bath until ready to use.
Lemon juice	5 g	5%	⑭ Warm sealed potatoes in same bath used for sabayon for 10 min.
Salt	to taste		⑮ Remove potatoes from bath and bag; divide equally among four bowls.
			⑯ Dispense warm sabayon around potatoes.
Roasted hazelnut oil	20 g	20%	⑰ Garnish potatoes.
Toasted hazelnuts, quartered	20 g	20%	
Ginger, finely diced	7 g	7%	
Chives, finely minced	to taste		
Salt	to taste		

(published 1997, adapted 2010)

If smoking is not an option, vacuum seal raw potatoes with a mixture of water and good-quality liquid smoke in step 1. Use 2 g of liquid smoke for every 100 g of water, and include enough smoke-water mixture to equal the weight of the potatoes.


4a


4b

Dehydrating

Prior to the advent of freezing and refrigeration, dehydration was one of the simplest ways to preserve plant foods. If we remove enough liquid from fruits and vegetables, we rob microbes of the medium they need to flourish, thus protecting food from spoiling.

Traditional methods use the sun or low oven temperatures to drive evaporation. Today, a typical dehydrator for fruits and vegetables lowers the humidity of surrounding air with a gentle heat source and includes a fan to move air heated to 60–70 °C / 140–158 °F over the food. At these temperatures, the food dries without cooking, and the circulation of air speeds the drying process. The reason the warm air doesn't cook the food is that the evaporation of the water cools the food far below the air temperature until the food is nearly dry.

Food that is being dried is subject to a square-law dependence, just as heated or fermented food is. That means that the time required for drying goes up dramatically with merely incremental increases in the thickness of the food. A slice of food 5 cm / 2 in thick will take four times longer to dry than a 2.5 cm / 1 in slice of food, although the first is just twice as thick. To keep drying times short and predictable, slice fruits and vegetables as thinly as possible before drying or mash them in a puree and dry them into flat sheets of "leather."

You can further lengthen the life span of some dried fruits and vegetables by adding a preservative such as sulfite, which is commonly used in dried apricots as an antifungal agent and to help the apricots retain their flavor and the gleaming orange color that would otherwise turn dingy brown.

The texture of the dried product depends, in part, on the sugar content of the fruit or vegetable. Sugary foods become flexible and chewy as the sugars, concentrated by drying, clutch to water in the food. In some cases, the leathery effect that results may be just what you're aiming for.

If a crisp, fragile texture is more desirable, you may want to add a bulking agent, such as pectin, a hydrocolloid, a starch, or a starch-like substance such as maltodextrin. These agents, unlike most sugars, do not hold water tightly, so in their final, dried form, they don't draw water from the air and the food remains glassy and crisp. You can also use them to supply bulk to plant purees and juices that you want to dry. Generally, a greater percentage of bulking solids makes the food crisper; a smaller percentage makes it chewier.

In addition to textural changes, the color of food changes as it dries. In some cases, the difference is due to optical phenomena rather than to any change in pigmentation. Because plant foods are as much as 90% water, dehydration leaves them spongy shadows of their fresh state, with a texture akin to that of Styrofoam. The dehydrated material interacts with light much differently from the way the fresh tissue does. The surface is matte rather than glossy, with less-saturated colors.

Freeze-Drying

Freeze-drying is one of the best options for dehydrating foods with flavors and textures that would be significantly changed by other methods of drying. As it vacates food, liquid water can exert surprisingly large forces through surface tension and capillary action, so regular drying often distorts the shapes of food. Those same forces can damage cells, releasing desirable flavors that are carried away and evaporated with the water.

Such forces don't come into play in freeze-drying, however, so freeze-dried foods tend to keep the same shape and flavor they had when they were replete with moisture. Freeze-drying works by way of sublimation, in which water ice turns directly to water vapor without going through a liquid phase. This allows food products to dry out even though they're frozen solid.

So it's important to freeze plant foods very deeply, to between −50 °C and −20 °C / −60 °F and −5 °F. Such low temperatures are necessary to ensure no free liquid water remains. Next, apply the vacuum, and very slowly raise the temperature. The combination of low pressure and gradually rising temperature draws vapor directly from the ice, avoiding the damage that can happen when liquid vaporizes.

To appreciate the differences between traditional drying methods and freeze-drying, compare sun-dried tomatoes and freeze-dried fresh tomatoes. True sun-dried tomatoes have a prune-like appearance and a unique, concentrated flavor. The freeze-dried slice, in contrast, has a very different flavor and still looks remarkably like it did when fresh. Freeze-dried plants remain so true to form that florists freeze-dry bouquets to preserve them.

For more on dehydrating and freeze-drying equipment and techniques, see page 2·428.

For more on how food changes during drying, see Baking, page 2·101.

To avoid the flavor changes that heat can produce, try a vacuum desiccator (see page 2·433), an alternative way to lower the moisture content of food. The desiccator can be faster than a food dehydrator, especially if it is used in combination with a vacuum oven set to moderate heat.

Plant foods that have been properly freeze-dried and rehydrated can contain close to 100% of their original water content.

PARAMETRIC RECIPE

DEHYDRATED FRUITS AND VEGETABLES

Dehydrating, one of the oldest forms of food preservation, has become new and exciting again. Dehydrated fruits and vegetables, in all their varied forms, are widely used by such Modernist chefs as Wylie Dufresne, Heston Blumenthal, and Grant Achatz. They are valued not just for their unique and concentrated flavors but as a source of structural support, surprise, or textural transition. Vegetable and fruit chips are familiar dehydrated items, but the process can also yield papers and leathers when applied to purees, or glasses and wafers when applied to juices or foams.

The Best Bets for Dehydration table lists those applications we have found to work well for a wide range of ingredients. Once you have selected an ingredient and a dehydrating product, refer to the Formulas for Dehydrating Produce table for other ingredients that can help stabilize and thicken the food during dehydration and can also give you control over the texture of the final product.

Simple dehydrators are inexpensive. Vacuum dehydration has some advantages (see page 2·433), and if you have access to a combi oven, it also makes an excellent dehydrating tool. Keep all finished items in an airtight container in a dry, cool, dark environment.

DEHYDRATING PRODUCE

1. **Choose a product.** Use the table Best Bets for Dehydration below to select the dehydrated form you wish to make, cross-referenced with the kind of produce you are using.
2. **Select a texture.** The table on the next page presents our recommendations for chips, papers, leathers, glasses, and wafers.
3. **Prepare the fruit or vegetable as indicated in the table.**
4. **Combine slices, puree, juice, or foam with other ingredients.** Assign a scaling value of 100% to the fruit or vegetable preparation, and weigh the other ingredients proportionally. For example, use 0.8 g agar and 2.5 g of glycerol for every 100 g of raspberry puree to make a flexible raspberry leather.
5. **Dehydrate by using the temperature and time listed.**

Best Bets for Dehydration

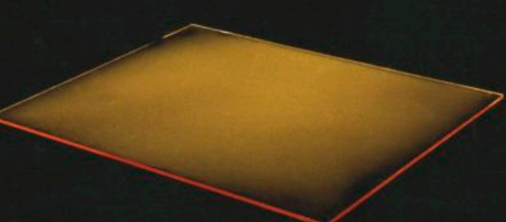
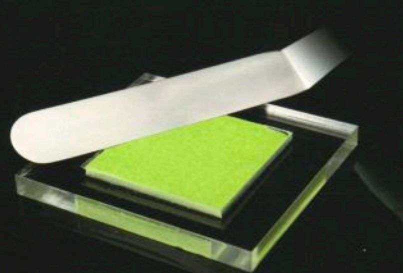
Ingredient	Chips (thin slices)	Papers (purees)	Leathers (purees)	Glasses (purees and juices)	Wafers (purees and juices)
apple	✓	✓	✓	✓	✓
apricot	✓	✓	✓	✓	✓
beet	✓	✓	✓	✓	✓
cabbage	✓				
cauliflower	✓				✓
citrus	✓		✓		
corn		✓		✓	✓
flower petals	✓				
leek	✓	✓			
mango	✓	✓	✓	✓	✓
mushroom	✓	✓			✓
onion	✓	✓	✓	✓	✓
passion fruit		✓	✓	✓	✓
pear	✓	✓	✓		
persimmon	✓	✓	✓	✓	✓
pineapple	✓			✓	✓
raspberry		✓	✓	✓	✓
spinach	✓	✓			
squash	✓	✓	✓	✓	✓
strawberry	✓	✓	✓	✓	✓

Formulas for Dehydrating Produce

Product	Texture	Preparation	Ingredients	(scaling)*	Dehydrate (°C)	(°F)	(h)
chips	very crisp	dust over sliced fruit or vegetable	trehalose or isomalt, fine powder	100%	50	120	8
	crisp	make syrup and brush onto slices	isomalt	100%	50	120	12
			water	65%			
	crisp	see next page	egg white	100%	50	120	7
			gum arabic	50%			
	crisp	soak slices for 20 min	water	50%	55	130	5
			maltodextrin DE19	100%			
	chewy	soak slices for 2 h	glycerol	30%	60	140	12
			water	40%			
			sugar or trehalose	100%			
papers	moist, chewy	spread mixture into paper-thin layer	methylcellulose E4M (Dow brand)	1.5%	55	130	6
	dry, flexible		glucose syrup DE 40	5.0%	55	130	7
			low-acyl gellan (Kelcogel F, CP Kelco brand)	0.7%			
	dry, brittle		N-Zorbit M (National Starch brand)	20%	55	130	3
leathers	tender	spread mixture into layer 1 mm / 1⁄16 in thick	vegetable oil	5%	55	130	8
	chewy		Ultratex 8 (National Starch brand)	3.0%	60	140	5
			xanthan gum	0.3%			
	chewy		agar	0.8%	60	140	5
			sorbitol	2.5%			
glasses	crisp	spread mixture into layer 1 mm / 1⁄16 in thick	glucose syrup DE40	2%	60	140	36
			isomalt	10%			
			icing sugar	18%			
	brittle	simmer mixture for 4 min, then spread into layer 1 mm / 1⁄16 in thick	Pure Cote B790	12.5%	60	140	15-18
wafers	crisp and airy	whip mixture into stiff foam, then spread into layer 3 mm / 1⁄8 in thick	egg white	18%	50	130	12
			xanthan gum	1%			
	crunchy and airy		xanthan gum	0.50%	55	130	12
			160 Bloom gelatin	1.25%			

*(*set weight of fruit or vegetable to 100%*)



CRYSTALLIZED ROSE PETALS

Yields 30 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Rose petals (organic)	50 g	100%	① Separate petals, and reserve.
Egg whites	50 g	100%	② Whisk together until gum arabic is fully dissolved.
Gum arabic	25 g	50%	③ Rest at room temperature until bubbles have dissipated, about 20 min.
			④ Brush mixture onto each petal to coat completely.
Sugar, isomalt, or trehalose	100 g	200%	⑤ Dredge petals.
			⑥ Place on dehydrator tray or parchment paper-lined baking sheet.
			⑦ Dry at 45 °C / 115 °F until dry and crisp, for 8–12 h.

(2008)

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7

EXAMPLE RECIPE

SPINACH PAPER

Yields 70 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Spinach puree see page 290	100 g	100%	① Season puree.
Salt	to taste		
N-Zorbit M (National Starch brand)	20 g	20%	② Whisk into puree. ③ Spread mixture thinly on silicone mat. ④ Dehydrate at **60** °C / **145** °F until crisp, 25–45 min.

(2009)

N-Zorbit, a modified starch (see page 4·34), dries to create a crisp glassy film.

EXAMPLE RECIPE

MANDARIN LEATHER

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Mandarins, quartered and seeds removed	200 g	100%	① Combine in pressure cooker. ② Pressure-cook at a gauge pressure of 1 bar / 15 psi for 45 min.
Water	150 g	75%	
Sugar	75 g	37.5%	③ Blend fully to puree. ④ Strain through fine sieve. ⑤ Cool puree, and measure 300 g.
Lime juice	10 g	5%	⑥ Blend together fully with puree.
Kosher salt	0.5 g	0.25%	⑦ Spread seasoned puree in layer 3 mm / ⅛ in thick on cellulose acetate sheet, 15 cm by 30 cm / 6 in by 12 in.
Grapeseed oil or other neutral oil	9 g	4.5% *(3%)**	⑧ Place sheet on dehydrator tray. ⑨ Dehydrate puree at **35** °C / **95** °F until leathery, about 8 h.

(2009)

**(% of total mandarin puree weight)*

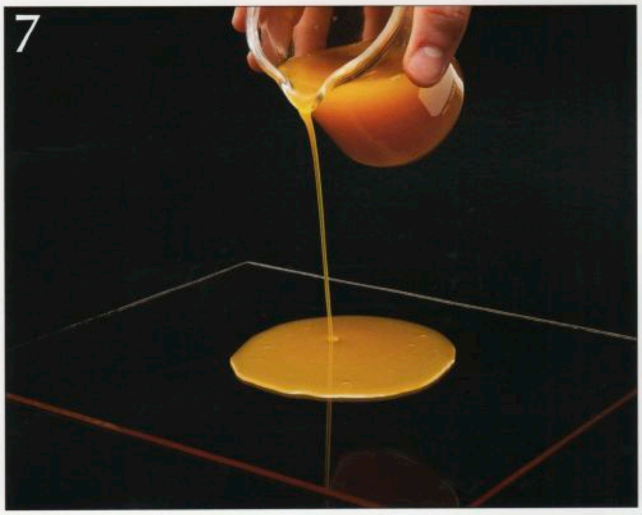
The addition of oil provides tenderness to the leather. Our favorite texture uses a scaling of 3% of the total puree weight. You can go up to 4.5% for even more tenderness. This recipe can be adapted to any fruit or vegetable puree.

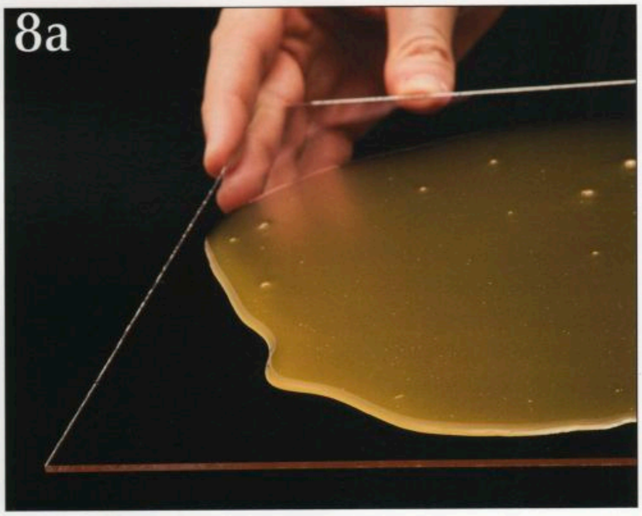
PINEAPPLE GLASS ADAPTED FROM GRANT ACHATZ

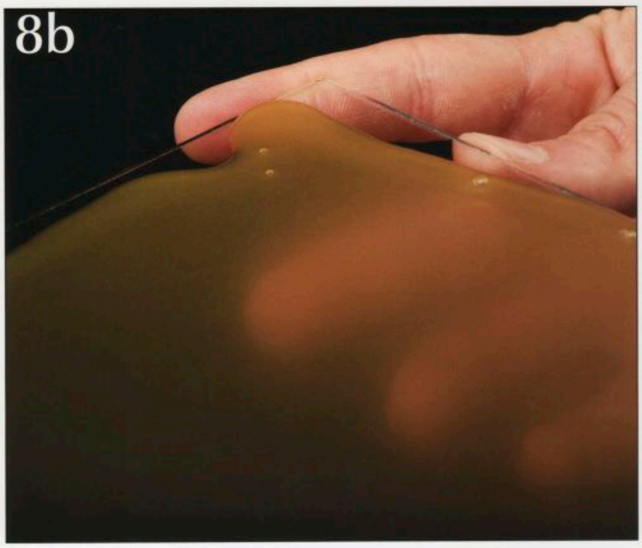
Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Pineapple, juiced see page 2·338	275 g	100%	① Strain through fine sieve.
Fructose	7 g	2.5%	② Combine with strained juice.
Malic acid	2 g	0.7%	③ Bring to boil over medium heat, and remove immediately.
Salt	2 g	0.7%	
Saffron threads	0.25 g	0.1%	④ Add to warm juice, cover, and steep for 5 min. ⑤ Strain.
Pure-Cote B790 (GPC brand)	35.5 g	13%	⑥ Blend with juice mixture on high speed for about 2 min. Simmer for 15 min. ⑦ Pour liquid onto center of cellulose acetate sheet. ⑧ Form sheet into U shape, and allow liquid to coat sheet evenly. ⑨ Lay sheet on flat surface, and rest at room temperature until dry, 12–15 h. ⑩ Peel glass off in single piece.

(original 2005, adapted 2010)







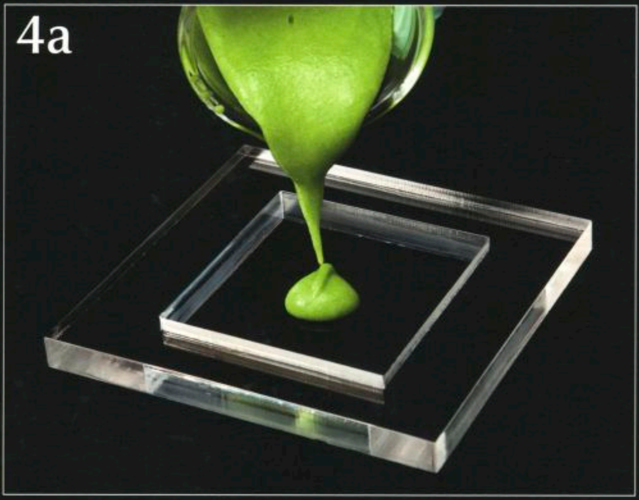
EXAMPLE RECIPE

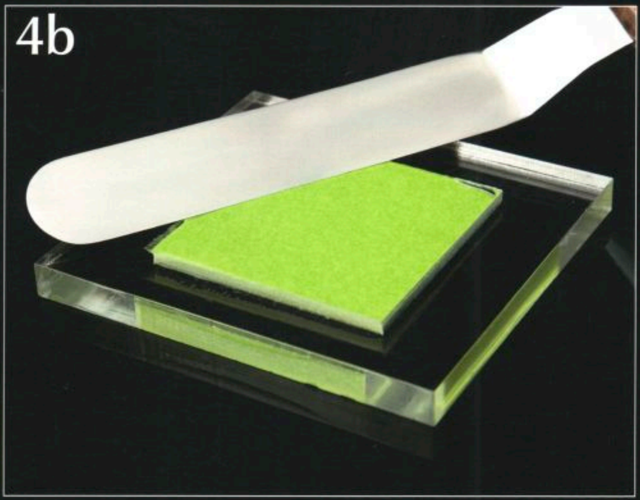
GREEN PEA WAFER

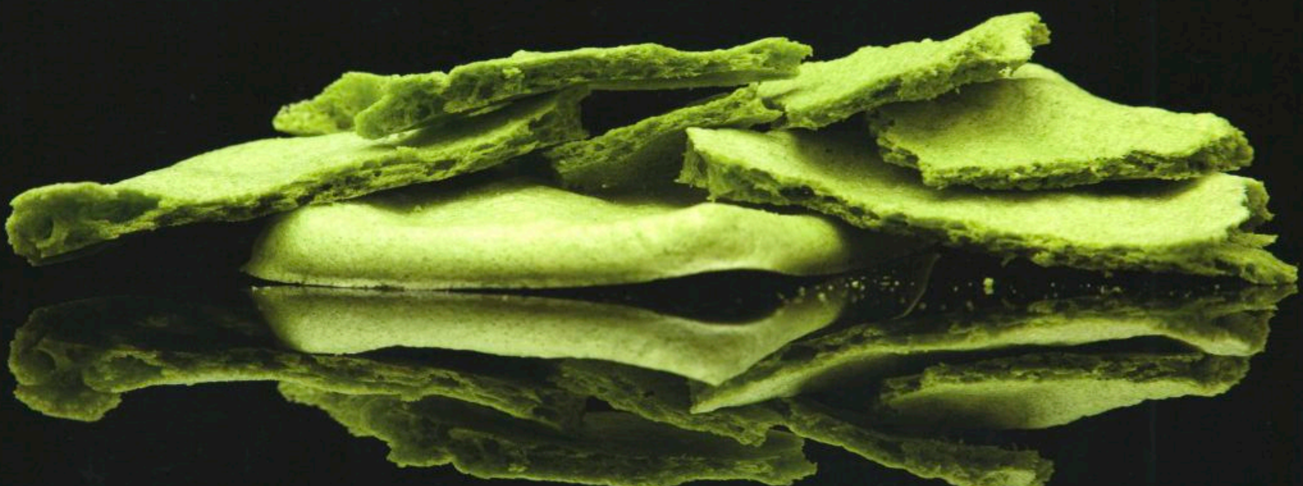
Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Green pea puree see page 2·424	400 g (from 750 g of frozen sweet peas)	100%	① Blend to fine puree. ② Pass through fine sieve.
Egg whites	75 g	18.5%	③ Whisk together into puree until light and fluffy in texture.
Xanthan gum (Keltrol T, CP Kelco brand)	4.75 g	1.2%	④ Cast puree evenly into nonstick mold in layer 0.5 cm / ¼ in thick. ⑤ Dehydrate at 57 °C / 135 °F until crisp, 2 h or longer. ⑥ Cut into rectangles.

(2009)







PARAMETRIC RECIPE

FREEZE-DRIED FRUITS AND VEGETABLES

Dehydration has many advantages, but also some drawbacks. Simple drying evaporates water with heat, which can change the taste and texture of food, particularly over the long time it takes to complete. Vacuum desiccation substitutes low pressure for high temperature, which reduces heat-related side effects. But any process that moves liquid water through the food will have some side effects, such as shrinking and cracking.

The trick to freeze-drying well is controlling the air pressure as well as the temperature. At low pressures, ice transforms directly from solid to vapor through a process called sublimation. This process avoids the traumatic thawing process, so the cell walls inside frozen plant foods don't collapse as they dry. The result is brightly colored, crunchy produce with antioxidant and flavor concentrations nearly as high as it had when fresh.

You can find freeze-dried plant foods in the grocery aisle as novelty snacks and ingredients in breakfast cereals. Increasingly, you can also find them in restaurants, where chefs finely grind freeze-dried fruits and vegetables to add full-bodied flavor to dishes without adding moisture or bulk, characteristics that make freeze-dried foods ideal for dressings or sauces. They can also boost the flavors of baked goods, breadings, and spice mixes.

Freeze-drying equipment is still expensive, but freeze-dried produce is now widely available. If you do make or buy some, store it in a dry, dark environment, vacuum-sealed if possible.

FREEZE-DRYING PLANT FOODS

1 **Prepare the ingredients.** The table Best Bets for Freeze-Drying Plant Foods below lists our recommendations.

2 **Arrange in a single layer on a tray.**

3 **Freeze-dry for the time indicated.** Temperature and pressure settings for primary and secondary drying are given in chapter 10 on The Modernist Kitchen, page 2·450.

For more on sublimation, see page 1·326.

Best Bets for Freeze-Drying Plant Foods

Ingredient	Preparation	Cut (mm)	Cut (in)	Dry (h)	Typical use	See page
apples	peeled	2	1⁄16	24	whole; grind into a fine powder, and use to enhance apple recipes	
bananas	peeled	3	1⁄8	48	whole; grind into a fine powder, and add to Thai spice mix or to mustard base	
butternut squash	peeled	2	1⁄16	36	grind into a fine powder, and add to fresh butternut squash puree to deepen the flavor and thicken	
carrots	peeled and sliced, then blanched for 30 s	1	1⁄32	12	instant ramen	2·455
chives, mint and other herbs		whole leaves		12	grind into a fine powder for seasoning	
corn, kernels		whole		36	whole; grind into a fine powder and use in Modernist breading, add to corn bread recipes or broths	4·36
grapes	perforated with a needle	whole		48	whole; pickled; add to pastry recipes; infuse into broths	
lettuce		whole leaves		24	caesar salad	next
mushrooms		1	1⁄32	12	infuse into stocks and broths; rehydrate to make a puree; grind into a fine powder for breading	5·14
onions	cooked until tender	2	1⁄16	12	grind into a fine powder, and add to savory pastry	next
piquillo peppers	blanched, peeled	quartered		36	grind into a fine powder, and add to spice blends	5·239
raspberries		whole		24	whole; grind into a powder, and add to pastry or infuse into vinegar	
strawberries		2	1⁄16	24	whole; grind into a fine powder for seasoning and breading	5·277
tomatoes	peeled, cored	thinly sliced		24	whole; infuse into oils; grind into a fine powder, and add to sauces and spice blends	2·403

EXAMPLE RECIPE

CAESAR SALAD

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Egg yolk powder, freeze-dried see page 5·250	12 g	24%	① Dry blend powders.
Acetic acid	7 g	14%	
Salt	7 g	14%	
Black peppercorns, finely ground	3 g	6%	
Anchovy powder, freeze-dried	2 g	4%	
N-Zorbit M (National Starch brand)	20 g	40% *(50%)**	
Extra-virgin olive oil	40 g	80%	② Whisk into powder mixture until fully incorporated.
Romaine lettuce, freeze-dried	50 g	100%	③ Toss greens together with dressing.
Basil leaves (small), microwave-fried	8 g	16%	④ Arrange salad on plate.
Chives, cut into 1 cm / ⅜ in batons and freeze-dried	8 g	16%	
Parsley, microwave-fried see page 312	4 g	8%	
Parmesan nuggets see page 4·35	20 g	40%	⑤ Garnish salad.
Salt-cured anchovies, freeze-dried	16 g	32%	
Brioche, cut into 1 mm / ⅓₂ in slices and dehydrated	12 g	24%	

(2010)

(% of weight of olive oil)

For more on freeze-dried ingredients, see page 2·444.

EXAMPLE RECIPE

FREEZE-DRIED ONION POWDER

Yields 40 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Sweet onions, thinly sliced	350 g	100%	① Sauté in nonstick pan over low heat until translucent and tender, about 15 min.
Neutral oil	as needed		
Water	100 g	28.5%	② Deglaze as needed to prevent any browning. ③ Cool at room temperature. ④ Freeze-dry for 12 h. ⑤ Grind into powder. ⑥ Store in cool, dry place.

(2008)

See previous page for freeze-drying instructions.

MODIFYING TEXTURES

One of the simplest ways to modify the texture of plant foods is by freezing them. Because the ice crystals that form during slow freezing are particularly large, freezing and thawing over a longer period tears up the insides of a fruit or vegetable. Raspberries and other soft berries give up their juices more easily when their tissues have been masticated by ice crystals.

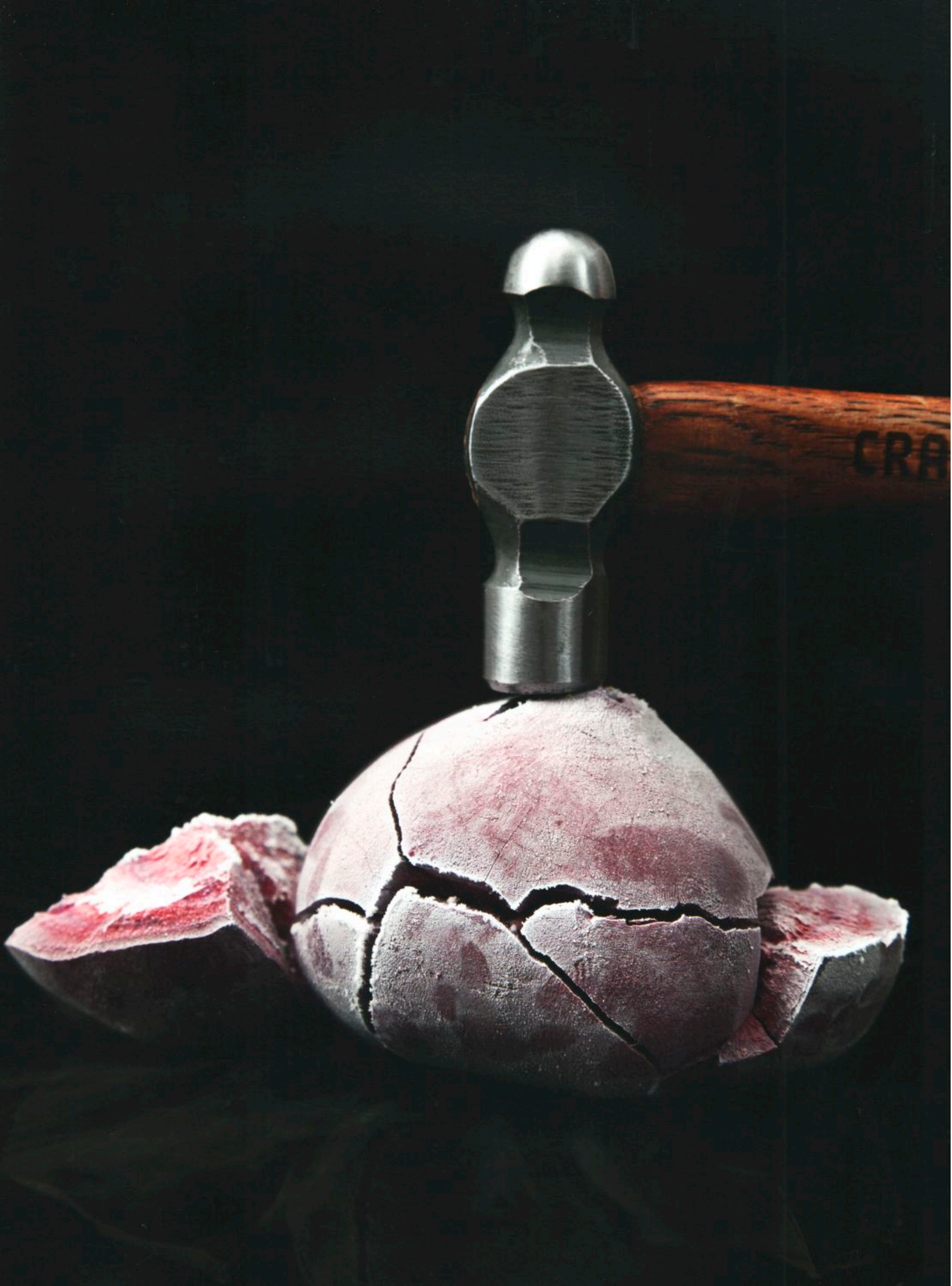
You can also manipulate the textures of frozen plant foods in ways their fresh counterparts don't allow. A cooked beet frozen in liquid nitrogen, for example, will acquire a glass-like texture so brittle that you can shatter it with a hammer. You can freeze a blackberry or similar fruit in liquid nitrogen and then separate it into individual drupelets. Liquid nitrogen grants fresh corn the same texture as dried corn, so you can grind it into frozen grits. Other seeds and grains acquire new characteristics when they're milled while frozen. Frozen, milled nuts, for example, are more apt to become a powder than to turn into nut butter or paste.

But some frozen plant foods are best left well enough alone. Freezing is often the only way to preserve fragile flavors that change rapidly after harvest. Peas and corn are the classic examples. Enzymes start converting sweet sugars in peas into dull-tasting starch immediately after harvest. Flavor compounds in corn can break down within hours after the ears are picked.

To enjoy corn at its peak sweetness and flavor, we can either break the ears off our own backyard stalks and put them directly into a cooking pot—or we can buy frozen corn. The very idea of frozen vegetables may be noxious to those who believe that fresh is always better than frozen and that the best guarantee of freshness comes from buying from a small artisanal farmer or at a farmer's market. But for the fugitive, transitory flavors of some produce, even the farmer's market is too far from the field.

Packagers of frozen corn and peas have made their industrial-size processes so efficient that the vegetables are chilled and preserved almost immediately after picking. These products are sweeter and more flavorful than any fresh produce distributed conventionally. Sure, quick-frozen peas and corn will never beat the flavors of those we pick ourselves and cook fieldside—but they come surprisingly close.

Like most foods, a beet becomes so brittle when frozen in liquid nitrogen that it shatter like glass when struck. Cooks can exploit this phenomenon to create textures that are nearly impossible to achieve any other way.

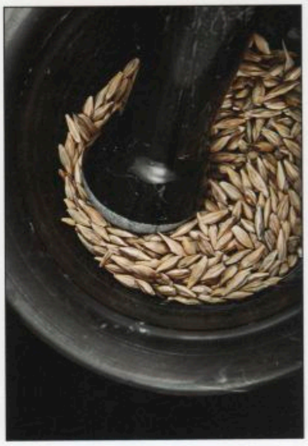


Milling and Pressing

A basic and useful way to prepare nuts, grains, beans, and seeds for cooking is to mill them, or grind them into a fine powder. While we tend to regard milling as a means of turning grains into flour for bread (an application outside the scope of this book), there's a range of other popular and useful milled foods, including some we might not think to categorize as such.

We can also grind fruits and vegetables that are full of moisture, of course, but in those cases, we call the final product a puree or a juice.

The term milling applies to the act of grinding ingredients that have a water content low enough to yield a flour or, in the case of oily materials, a butter. Ingredients high in oil, such as nuts, turn into smooth pastes when milled. Peanut butter and other nut butters are prime examples of this and can generally be served as is—with no additions except those called for by personal taste. Although we refer these pastes as "nut butters," tahini, the Middle Eastern paste made from sesame seeds, falls into the same category—there isn't really a technical distinction between seeds and nuts.



A mortar and pestle are among the oldest tools for milling grains to flour. Modern approaches yield far more consistent results with a lot less physical effort.

Milling nonoily ingredients produces a flour. Most flours are milled from wheat and other grains, such as barley and rye. While these flours are commonly used for baking, their starch (and, to a lesser extent, their protein) also makes them useful as thickeners. Flour and butter cooked together, for example, yield a classic roux, as we discuss on page 4·20.

The same properties of flour that thicken liquids also come into play in flour-thickened gels, as when we add flour to beaten eggs in a soufflé. When heated, the starch in the flour thickens the mix and, as it dries and gels during baking, makes the soufflé a bit stiffer. In the same sense, bread is effectively a gel: a foamed gel made of particular grains. If that seems far-fetched, take a close-up look at a cut loaf, with its holes and air bubbles; the relationship is clear. As bread bakes, the starches and the proteins in the dough dry out until the hardened dough can support its own weight.

Bread flours need a large fraction of high-quality protein to act as a binder. In wheat flour, two proteins—gliadin and glutenin—form **gluten**, which also supplies elasticity. Recipes for gluten-free breads use wheat-free flours supplemented with xanthan gum to create an acceptable texture.

Most milled grains can be made into pasta. Like bread, pasta also requires a protein binder for strength and elasticity. If the flour doesn't contain enough protein, we add an egg yolk. Grains such as buckwheat and rice can be ground into flour—and both are used for pastas—but they have too little protein to help bread retain gases as it ferments and bakes. Their lack of protein is evident in the soft and yielding texture of the noodles made from them. Rice flours are added to the wheat flour in Asian dumpling wrappers to give a brittle, less elastic texture.

Protein-rich beans and pulses, particularly chickpeas and lentils, can also be made into serviceable flours. Because they lack the proteins that form gluten, they generally can't be used in the same way as grain flours, but they are useful in many other culinary contexts. Both are popular in Indian cuisine, for example; papadum is a puffed flatbread often made from lentil flour.

Although vegetables may not spring to mind when you think of flours, milled vegetables do make useful additions to the pantry. You can mill dried potatoes into a flour that serves as an everyday thickener—as well as a staple of the Jewish holiday of Passover, when leavened foods and most grains are forbidden. Cassava flour is important in some parts of the world, and the starch refined from cassava is fairly ubiquitous in kitchen cabinets, although it is commonly known by another name: tapioca.

Not every plant food makes a good flour, of course. Vegetables like cauliflower and squash have neither the starch nor protein necessary to be useful as flours. Drying and milling those vegetables yields a powder that, while perhaps of some culinary interest, is not a true flour.

Once frozen, corn is brittle enough that a blender can grind it to grits. Normally, you would need a grinder that exerts much more pressure. Serve with sous vide cooked shrimp or lobster (see page 102) for a more substantial meal.

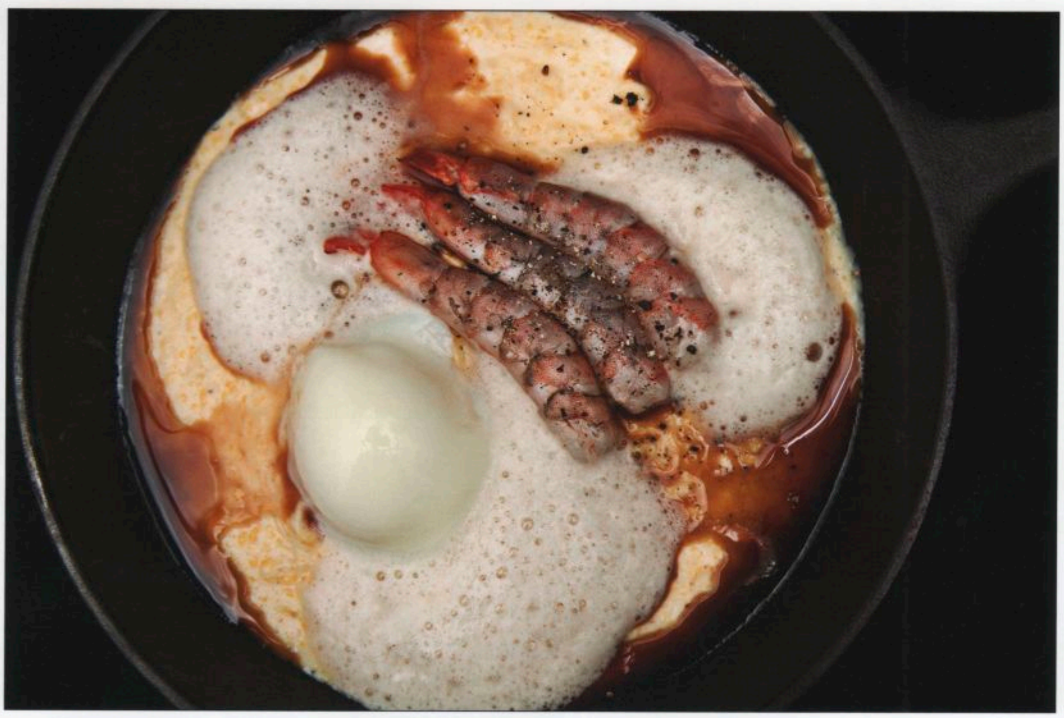
EXAMPLE RECIPE

SHRIMP AND GRITS INSPIRED BY SEAN BROCK

Yields 750 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Bacon, thinly sliced	100 g	50%	① Vacuum seal together.
Water	100 g	50%	② Cook sous vide in 88 °C / 190 °F bath for 2 h.
			③ Strain bacon broth, and cool.
			④ Discard resulting layer of fat, and measure 100 g of broth.
Bacon broth, from above	100 g	50%	⑤ Blend sucrose esters and whey protein isolate into broth, and reserve.
Sucrose esters (Sucro, Texturas brand)	2.4 g	1.2%	
Whey protein isolate	1.5 g	0.75%	
Eggs	four large		⑥ Cook in shells in 65 °C / 149 °F bath for 35 min.
Dried corn kernels or hominy	200 g	100%	⑦ Dip dried corn in liquid nitrogen until frozen.
Liquid nitrogen	as needed		⑧ Blend frozen corn on high power until coarse texture is achieved.
			⑨ Pass through coarse sieve to remove any unground pieces.
Water, shellfish stock, or vegetable stock see page 2·296	1 kg	500%	⑩ Combine with cornmeal from above, and cook over medium heat for about 40 min; stir constantly until mixture softens and forms grits.
Spot prawn or shrimp tails, peeled	150 g	75%	⑪ Dip prawns in liquid nitrogen until frozen.
Liquid nitrogen	as needed		⑫ Blend frozen prawns on high power until fine powder is achieved.
			⑬ Fold into warm grits.
			⑭ Warm bacon broth, and whip with foaming wand.
Mascarpone	80 g	40%	⑮ Fold into grits, and reheat to make sure grits are warm.
Salt	to taste		⑯ Season grits, and portion into four bowls.
			⑰ Place peeled, cooked egg in center of each bowl.
Red-eye gravy see page 5·102	80 g	40%	⑱ Pour gravy over eggs and grits.

(original 2009, adapted 2010)



Pasta

When you mix together a batch of pasta, you may think of the result as a dough, but as with bread, you're actually making a gel. Pasta is a specialized starch- and protein-bound gel, one made from grain flours that the cook wets, kneads to work the proteins together, and then presses into various shapes.

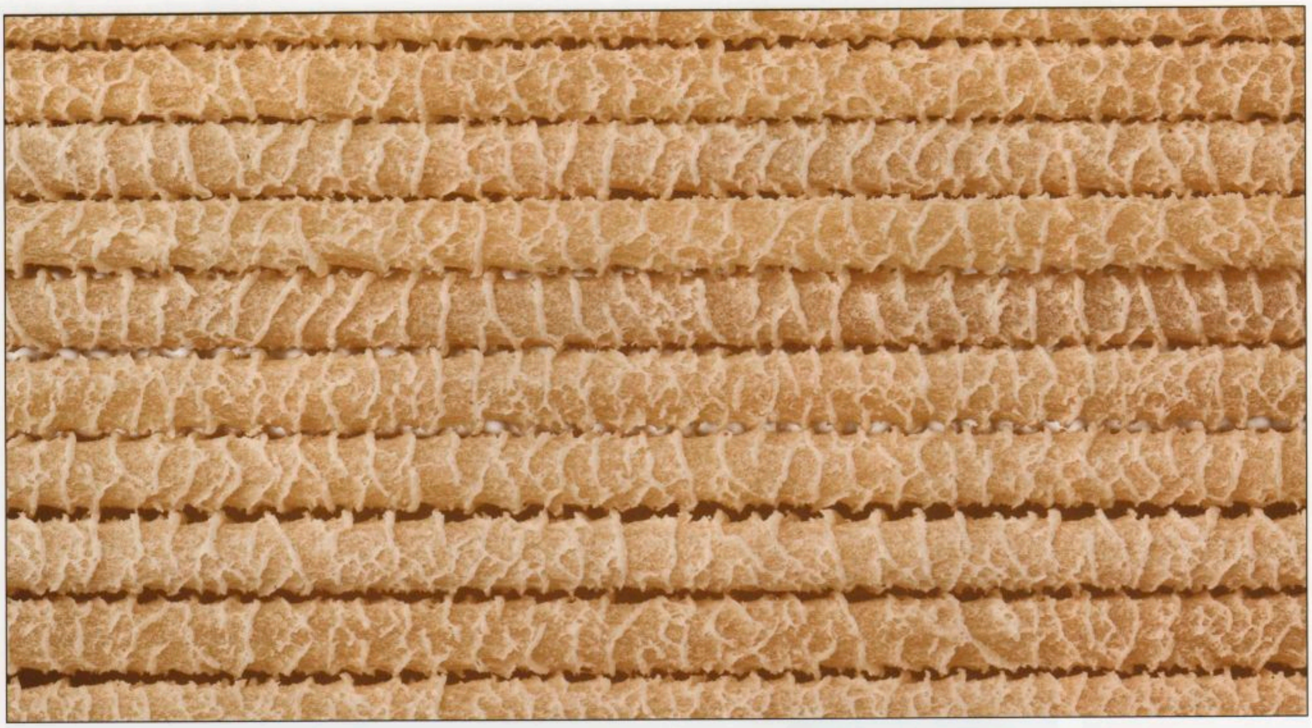
Pasta is an ancient creation. Although its provenance is uncertain, it is thought to have originated in China, and Asia is a leader in noodle production to this day. Asian pasta products run the gamut from clear cellophane noodles of rice starch to the hearty buckwheat and bouncy, stretchy sweet potato varieties.

Hard as it is to imagine a world without pasta, the ancient Romans had none. They ate grain pastes, which were panfried in fat and added to stews or other dishes. These fried pastes were much more like fritters or falafel than true noodles or pasta. It was the Arabs who, through trade, initially introduced Europe to noodles—yet today, pasta is portrayed as an Italian dish, and Western-style pastas are based on Italian culinary tradition.

Pasta requires flour with the correct mixture of starch and proteins. In some pastas, egg yolks supplement the flour protein to serve as a further binder. The flour is kneaded into a stiff dough. Moisture content is important: if the mixture is too sticky, it will be difficult to craft into pasta. If it is too dry, it will not bind cohesively.

The pasta dough is then formed in one of several ways. It can be shaped by hand (literally for some rustic pastas or by using a rolling pin), pressed in a pasta machine between two rollers, or extruded through a die to make shapes like fusilli and rigatoni. Asian pasta makers sometimes carve or shave noodles from a ball of dough with a knife.

Pasta dough rolled by hand must be wetter than machine-processed dough because bare hands and rolling pins can't exert the same pressure as a mechanical roller does on dry dough. Hand-rolled pasta may also require more of the binding ingredient. The pressure generated by a pasta machine is better at forcing the dough together and can transform a stiff, dry dough into a cohesive sheet.



The rough surface of this pasta is ideal for gripping a sauce. Obtaining a texture like this requires the right pasta extrusion die (one that is made of bronze and that is not too smooth), as well as pasta dough of the right consistency.

PARAMETRIC RECIPE

PASTA

Good pasta is all about texture. Traditionally, the dense, slippery, slightly chewy characteristics of a good noodle have come from a combination of starch and protein from the flour. Kneading the dough helps to hydrate the starch and develop the elastic strength of the gluten. Fresh pastas, wonderful as they may be, will rarely have the al dente texture we so love in dry pasta because the cores of fresh noodles are moist and soft—unless they are tweaked a bit with modern ingredients.

We have re-created some of the most popular international varieties of pasta dough, all designed to replicate the appealing al dente texture that comes from classic dried Italian pasta or traditionally made Asian noodles, but without the difficulty or labor.

Use a rolling pin, hand-cranked pasta roller, or extruder to shape the dough. For classic semolina pasta, we use a beautiful commercial machine that extrudes the dough through bronze dies. These give the pasta a jagged, coarse surface (see photo) to which sauces love to cling.

All of the pastas listed in the Best Bets for Pasta Doughs table are designed to be used fresh. The eggless recipes, including semolina and rice flour, dry beautifully on a rack or in a dehydrator. We like to dry our pasta in a vacuum dehydrator because it dries evenly and quickly.

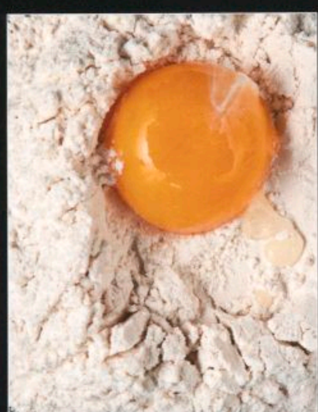
To make sodium carbonate for the alkaline ramen recipe on the next page, place some sodium bicarbonate in a shallow pan, and bake it in a 150 °C / 300 °F oven for 1 h.

Pasta machines come in several forms, including roller and extrusion machines. Each design requires using a slightly different technique, so you should consult the manual and get to know your machine.

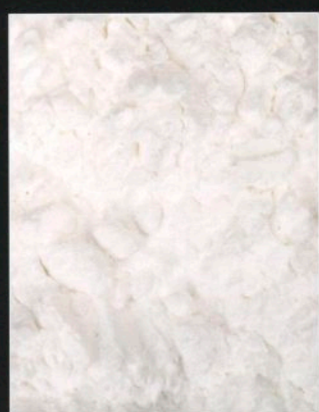
Flours

Semolina flour

Whole-wheat flour



All-purpose bleached wheat flour and egg yolk



Rice flour

MAKING PASTA

1 Mix dry ingredients, texturing agent, and salt.

2 Whisk in liquids.

3 Knead, or blend until dough is elastic, 5–10 min.

4 Roll out, and cut to desired shape.

5 Dry (optional). See page 2·430 for dehydrating strategies.

Best Bets for Pasta Doughs

Pasta	Dry ingredient	(scaling)	Texturing agent	(scaling)	Salt (scaling)	Liquid	(scaling)	Dry
wheat	00 wheat flour	100%	xanthan gum	1%	2.5%	water	9%	no
						egg yolk	56.7%	
						neutral or olive oil	10.7%	
buckwheat	buckwheat flour, sifted	100%	Activa RM	4%	1.75%	milk	75%	optional
	all-purpose unbleached wheat flour	50%				egg yolks	37.5%	
						olive oil	20%	
semolina	all-purpose bleached wheat flour	25%	albumin powder	2%	1.3%	water	35%	yes
	semolina flour	100%				white wine	7%	
cocoa tajarin	00 wheat flour	100%	vital gluten	4%	1.5%	egg yolks	117%	no
	semolina flour	65%				water	27%	
	cocoa powder	44%				olive oil	22.5%	
rice flour	rice flour	100%	konjac gum	10%	2.5%	water	160%	yes
	tapioca starch	50%						
	glutinous rice flour	50%						
alkaline ramen	bread flour	100%	sodium carbonate	0.9%	1.5%	water	37.5%	no
			potassium carbonate	0.1%				

Pastas

Semolina campanelle

Whole-wheat fusilli

Fresh pasta sheet

Rice noodles

EXAMPLE RECIPE

SEMOLINA PASTA

Yields 450 g

INGREDIENT	QUANTITY	SCALING
Semolina flour	400 g	100%
All-purpose bleached wheat flour	100 g	25%
Water	100 g	25%
White wine (dry)	28 g	7%
Albumin powder	8 g	2%
Salt	5.2 g	1.3%

(2008)

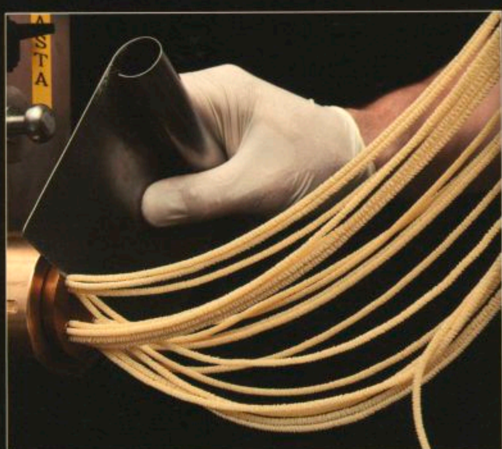
For more on using a vacuum dessicator, see page 2·433.

1 **Combine.**

2 **Process dough in kneading machine, or knead by hand for 10 min (not shown).**

3 **Push through extruder die.**

4 **Dehydrate pasta in vacuum desiccator for 4 h.** For instructions, see page 2·433.



HERB-EMBEDDED PASTA VEIL

Yields 300 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
All-purpose unbleached wheat flour	210 g	100%	① Combine to form smooth dough. ② Knead for 12 min.
Water	50 g	24%	③ Vacuum seal, and refrigerate for 12 h.
Egg yolks	28 g	13.5%	
Canola oil	7.2 g	3.5%	
Toasted sesame oil	7.2 g	3.5%	
Gluten flour	2.5 g	1.2% *(1%)**	
Salt	1 g	0.5%	
Cilantro, dill or other small-leaved herbs	as desired		④ Roll dough to 1 mm / 1/16 in thick. ⑤ Divide into two sheets of equal length and width. ⑥ Lay herbs individually on first sheet, and cover with second sheet. ⑦ Roll layered dough to 1 mm / 1/16 in thick. ⑧ Transfer to flour-dusted, parchment paper-lined tray, and cover with damp cloth. ⑨ Refrigerate until needed.

(2009)

(% of total weight of all other ingredients*)

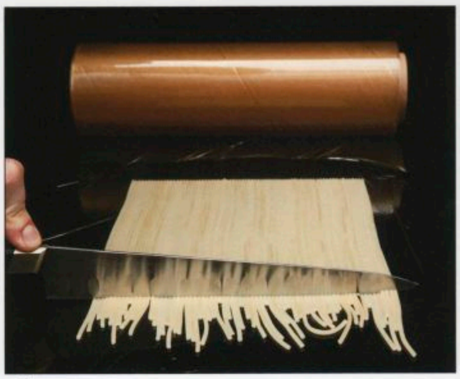
SPAGHETTI CARBONARA INSPIRED BY JEAN-FRANÇOIS PIÈGE

Yields 1.5 kg (about 30 portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Whipping cream	200 g	200%	① Combine, and vacuum seal.
Bacon, thinly sliced	90 g	90%	② Cook sous vide in 88 °C / 190 °F bath for 2 h.
Parmesan, grated	20 g	10%	③ Strain cream, and reserve warm.
Garlic, thinly sliced and blanched	15 g	7.5%	
Water	1 kg	1000%	④ Boil spaghetti in salted water until al dente, about 8 min.
Dry spaghetti	100 g	100%	⑤ Transfer spaghetti to bacon cream, stirring to coat evenly.
Salt	20 g	20%	⑥ Arrange pasta strands straight and pressed against each other on sheet of plastic wrap.
			⑦ Refrigerate coated strands until set, about 2 h.
Sodium citrate	2.3 g	2.3%	⑧ Dry blend.
Low-acyl gellan (Kelcogel F, CP Kelgo brand)	0.6 g	0.6% *(0.26%)**	
High-acyl gellan (Kelcogel LT 100, CP Kelco brand)	0.3 g	0.3% *(0.13%)**	
Whole milk	100 g	100%	⑨ Disperse powder blend in milk and bring to simmer.
Parmesan cheese, finely grated	130 g	130%	⑩ Shear cheese into simmering milk.
			⑪ Cast into nonstick mold in layer 1 cm / ⅜ in thick.
			⑫ Cool, and refrigerate until set, about 5 min.
			⑬ Cut set gel in strips measuring 5 cm by 10 cm / 2 in by 4 in.
			⑭ Place strips over cold spaghetti ribbons.
			⑮ Roll spaghetti with cheese strips into tight parcels.
Egg yolks, blended	50 g	50%	⑯ Vacuum seal.
			⑰ Cook sous vide in 68 °C / 154 °F bath for 35 min to form fluid gel.
			⑱ Pass fluid yolk mixture through sieve.
			⑲ Transfer to squeeze bottle with 5 mm / ¼ in diameter tip.
Chives, finely minced	10 g	20%	⑳ Steam spaghetti parcels until warmed through, about 4 min.
			㉑ Pipe stripe of egg yolk fluid gel across each spaghetti parcel.
			㉒ Garnish parcels with chives.
			㉓ Serve carbonara with braised pork belly, or finish with fresh black truffles.

(original 2002, adapted 2009)

(% of total weight of whole milk and Parmesan cheese*)



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EXAMPLE RECIPE

PAD THAI ADAPTED FROM PIM TECHAMUANVIVIT

Yields 500 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Palm sugar	56 g	18.5%	① Combine, and bring to simmer until fully dissolved.
Fish sauce	40 g	13.5%	② Remove sauce from heat, and reserve.
Tamarind paste see page 5·99	18 g	6%	
Rice vinegar	11 g	3.5%	
Dried baby shrimp	50 g	16.5%	③ Fry baby shrimp over medium heat until golden brown, about 10 min.
Neutral oil	as needed		④ Transfer to paper towel-lined tray.
			⑤ Cool.
			⑥ Mince finely, and reserve for garnish.
Rice stick noodles	300 g	100%	⑦ Cover with warm water, and soak at room temperature for 2 h.
Shrimp, peeled and deveined	12 shrimp		⑧ Fry over medium heat until half cooked, about 1 min.
Neutral oil	as needed		
Bean sprouts, cut into 3 cm / 1¼ in strips	40 g	13%	⑨ Add, and stir-fry until slightly wilted and shrimp are fully cooked, 1–2 min.
			⑩ Remove shrimp, bean sprouts, and garlic chives, leaving oil in pan.
Garlic chives, diced	24 g	8%	
Shallot, minced	20 g	7%	⑪ Add to pan, and increase heat to high. Cook until golden, about 45 s.
Garlic, minced	10 g	3%	⑫ Add soaked noodles, and stir-fry over high heat until translucent, 2–3 min.
Ginger, minced	10 g	3%	⑬ Remove from heat.
Egg, beaten	60 g	20%	⑭ Add to pan, stirring constantly until incorporated and cooked through, about 1 min.
			⑮ Add 40 g of reserved sauce.
			⑯ Cook over high heat for 1 min.
			⑰ Stir in cooked shrimp, bean sprouts, and garlic chives; remove from heat.
Lime juice	to taste		⑱ Season.
Salt	to taste		⑲ Add more sauce if necessary.
Pressure-cooked peanuts, finely ground see page 303	30 g	10%	⑳ Garnish with dried shrimp, peanuts, and chili powder.
Roasted chili powder	to taste		

(published 2007, adapted 2009)

PASTA MARINARA INSPIRED BY H. ALEXANDER TALBOT AND AKI KAMOZAWA

Yields 450 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Tomato water see page 2·366	500 g	100%	① Combine, and vacuum seal. ② Infuse refrigerated for 12 h. ③ Strain tomato water.
Basil	5 g	1%	
Thyme leaves	2.5 g	0.5%	
Bay leaf, julienne	1 g	0.2%	
Salt	10 g	2%	④ Season tomato water.
Spaghetti or tagliatelle (store-bought)	140 g	28%	⑤ Soak spaghetti in tomato water for 1 h. ⑥ Drain, reserving tomato water. ⑦ Transfer tomato water and pasta to separate containers, and refrigerate. Pasta can be stored for up to 8 h. ⑧ Bring tomato water to boil. Add soaked pasta, and cook for 1 min 10 s. ⑨ Drain.
Tomato confit, thinly sliced see page 5·62	40 g	8%	⑩ Toss with pasta to finish.
Basil leaves, julienne	5 g	1%	
Extra-virgin olive oil	to taste		

(original 2009, adapted 2009)

5

EXAMPLE RECIPE

MAC AND CHEESE INSPIRED BY HAROLD MCGEE

Yields 400 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	100 g	50%	① Whisk together.
Wheat beer	75 g	37.5%	② Bring to simmer.
Sodium citrate	10 g	5%	
Salt	4.5 g	2.25%	
Iota carrageenan	1.25 g	0.63% *(0.26%)**	
Aged Gouda cheese, grated	200 g	100%	③ Hand-blend slowly into hot liquid until cheese is completely emulsified.
Sharp cheddar cheese, grated	85 g	42.5%	④ Transfer to shallow bowl, and cool to room temperature.
			⑤ Refrigerate until set, about 30 min.
			⑥ Grate coarsely.
Water	300 g	150%	⑦ Boil together over high heat until pasta has absorbed most of water and is al dente, about 7 min. Do not drain.
Macaroni (store-bought)	100 g	50%	
Salt	2.4 g	1.2%	⑧ Whisk 160 g of cheese and remaining liquid into pasta until cheese is melted.

(2009)

(% of total weight of first two ingredients and cheeses*)

This cheese sauce contains no starch, as it typically would—instead we use emulsifying salts and a hydrocolloid thickener to produce a much brighter cheese flavor.

Culinary Deception

Things aren't always what they seem. When we discover this, we experience surprise; it is the emotion that reconciles our first impression with the actual truth of the matter. Chefs have sought to elicit surprise with dishes that fool diners into thinking that they are eating something quite different than what actually enters their mouth. Like all deceptions, this trickery is a two-edged sword. If the surprise is a letdown, then the diner is apt to be unhappy. But if the surprise is a good one, then it enhances the dining experience in a way that few other things can.

Faux or mock dishes in which one food is imitated as another are a classic approach to culinary deception. A huge market has developed for vegetarian dishes that simulate meat, for example. The origins of vegetarian "meats" extend back centuries to the many mock pork and duck dishes used in traditional East Asian cuisine. More contemporary examples include the veggie burger, which is made to simulate a ground-beef patty, and tofurkey, a vegetable protein—usually seitan (wheat gluten) or soy (tofu)—textured and flavored to approximate turkey.

A few trompe l'oeil dishes are best made with gels, such as faux pastas made with hydrocolloids (see page 4·124).

Another class of mock dishes pretend to include ingredients that are expensive or scarce. In the 19th century, chefs concocted mock oysters and mock turtle soup to simulate such luxuries. These dishes have since fallen out of favor, but surimi has much the same goal: it seeks to emulate expensive crab meat while using much cheaper protein processed from fish.

Mock dishes generally try to evoke some aspect of both the taste and the look of the food being simulated, with varying fidelity. Usually, the attempt is not really to fool the diner and invoke surprise but merely to simulate the appearance, taste, and texture of the "flattered" food to some degree. Not many vegetarians who eat tofurkey or surimi actually think that these foods really are turkey or crab meat—indeed, vegetarians typically choose these products precisely because they contain no meat—but the customers enjoy the fact that the taste and texture aim in that direction.

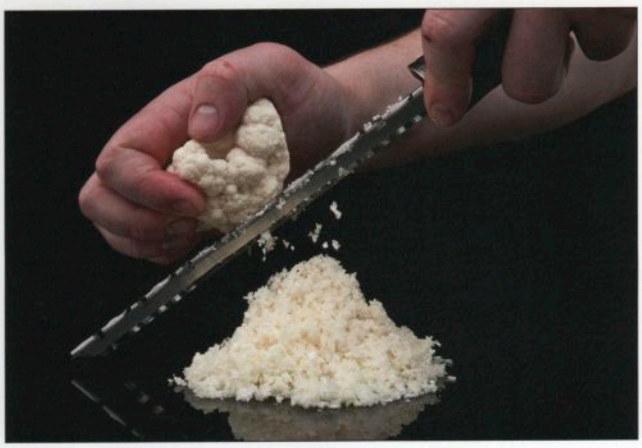
We close this chapter with a set of dishes that represent a different form of culinary deception. Instead of being mock versions of foods, they aim primarily to provoke surprise by offering radically unexpected tastes. They visually deceive the diner by looking very much like one thing but tasting like something else altogether.

In the world of art, the phrase trompe l'oeil (from the French for "deceives the eye") describes realistic art that tries to fool the viewer into believing something that is simulated is real. It is a good phrase to describe these dishes because they are purely visual forgeries. Without the dissonance between what you see and what you taste, they would not achieve the surprise that is their ultimate goal.

With some effort, you can make watermelon look like raw meat, cassava root look like a piece of coal, and grated cauliflower look like couscous. The watermelon surely will not taste like meat, and you wouldn't want the cassava to taste like coal. Instead, you want to delight the diner with the surprising discovery that these dishes taste nothing like what they appear to be.

Plant foods are the best basis for these

Cauliflower is prone to crumbling. Use a sharp grater, such as a Microplane, to grate and crumble raw cauliflower into a sort of faux couscous. Ferran Adrià pioneered this technique after discovering the power of the Microplane grater (see page 1·36). He served the dish at elBulli as Cauliflower Couscous.



camouflaged deceptions. The wide range of plant foods, and the myriad ways in which we can manipulate them, make them a much better base for this task than meat foods are. It is far easier to make watermelon look like meat than it is to make meat look like watermelon. A few trompe l'oeil dishes are best made with gels, however. For examples, such as faux pastas made from cheese, see chapter 14 on Gels, page 4·64.

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PARAMETRIC RECIPE

COMPRESSED AND IMPREGNATED FRUITS AND VEGETABLES

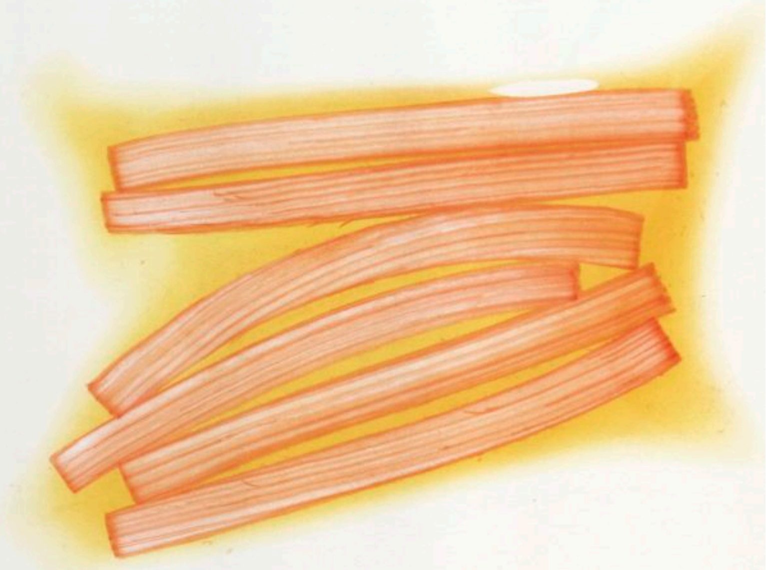
A chamber vacuum sealer makes a powerful tool for manipulating the texture of porous fruits and vegetables. The effect is easily visible when you vacuum seal a slice of melon or a cucumber. As soon as you release the vacuum and allow air at normal pressure to refill the chamber, the cells of the plant tissue collapse, turning the fruit darker, denser, and more malleable. Once vacuum-compressed, peaches and apricots become much easier to handle and shape with precision. They also seem juicier, as though they have been salted, but without the change in flavor.

Although a commercial chamber sealer produces the most dramatic results, edge sealers marketed for home use generate enough of a pressure differential to induce a perceptible compression effect. You'll get the best results with porous fruits—notably watermelon. After compressing, keep the fruits sealed until you're ready to use them.

Pressure impregnation is a related technique that also employs a vacuum chamber (edge-sealing machines don't work well for this process because they tend to suck liquid into the mechanism). Arrange the food in a sous vide bag or a rigid container, and then add a liquid. The fluid must be no thicker than syrup or thin cream to work well. As the pressure falls, the pores of the food will swell, the cell walls will begin to break open, and the liquid will start to boil. Now release the vacuum; the rising pressure forces the liquid into the cells, completely saturating the produce. The impregnated food remains crunchy and has even more juice and flavor than before.

Best Bets for Compressing or Impregnating Produce

Ingredient	Liquid	See page
apple	apple juice	393
apricot	chamomile tea	
asparagus	asparagus juice	
celery	blue-cheese water	
cucumber	pickling brine	348
dragon fruit	lychee juice	
eggplant	barbecue sauce diluted in water	
fig	port	
grape, peeled	verjuice (store-bought sour grape juice)	
kiwi	strawberry juice	
lettuce	smoked water	5·15
melon	bacon water or prosciutto stock	
onion	pickling brine	5·58
peach	vanilla syrup	
pear	red wine syrup	
pineapple	coconut water (store-bought or fresh), rum	
plum	almond milk	
rhubarb	grenadine syrup	
strawberry	thin cream infused with basil	
tomato	ketchup diluted in water	
watermelon	green tea	



Rhubarb absorbs the flavor of grenadine syrup when they are packed together in a vacuum-sealed bag.

COMPRESSING AND IMPREGNATING PRODUCE BY VACUUM-SEALING

1 **Peel, and cut the ingredients into even-size pieces (not shown).** Arrange the food in a single layer in a sous vide bag.

2 **Add liquid (optional).** To impregnate the fruit or vegetable with a liquid, add it to the bag or container; see the table on the previous page for suggestions.

3 **Vacuum-seal by using full vacuum power.** Rest the produce in the bag or container for at least 10 min after the vacuum is released.

Bagged fruit is placed into the vacuum chamber.

Bag swells as vacuum is pulled.
Vacuoles in plant cells begin to burst.

Bag is sealed, pressure is restored, and vacuoles begin to collapse.

Many vacuoles have collapsed.

COMPRESSED MELON TERRINE ADAPTED FROM H. ALEXANDER TALBOT AND AKI KAMOZAWA

Yields 675 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
For the calcium lactate solution:			
Cold water	500 g	167%	① Disperse calcium lactate gluconate in water, and stir until fully dissolved.
Calcium lactate	2.5 g	0.8% *(0.5%)**	
Honeydew melon, cut into five planks, each 1 cm / ⅜ in thick, 5 cm by 10 cm / 2 in by 4 in	375 g	125%	② Vacuum seal planks in one even layer with calcium solution. ③ Refrigerate for 20 min. ④ Remove from bag, and pat dry.
Cantaloupe, cut into four planks, each 1 cm / ⅜ in thick, 5 cm by 10 cm / 2 in by 4 in	300 g	100%	
For the pectin solution:			
Cold water	500 g	167%	⑤ Mix pectin in water, and blend until fully dispersed.
LM pectin (Genupectin LM 104 AS, CP Kelco brand)	15 g	5% *(3%)**	⑥ Bring solution to a boil while shearing for 1 min to fully hydrate. ⑦ Cool. ⑧ Brush one calcium-infused cantaloupe plank with cooled pectin solution, and lay calcium-infused honeydew plank on top. ⑨ Repeat brushing and layering process with remaining six planks. ⑩ Vacuum seal each stack to compress. ⑪ Refrigerate until bonded, about 12 h. ⑫ Cut terrines into slices, and serve.

(original 2008)

(% of total weight of water used in the individual solution)

Pectin can be used to glue fruit together in a manner reminiscent of the way that Activa glues meat together. The analogy is only superficial, however, because Activa is an enzyme, whereas pectin is a gel. The bonds formed by pectin are not very strong, but it will remain the best option until someone invents a better "vegetable glue."

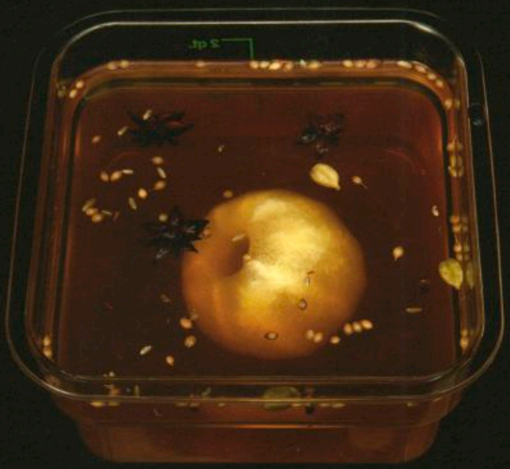
EXAMPLE RECIPE

CURRY-IMPREGNATED APPLE

Yields 1 kg

INGREDIENT	QUANTITY	SCALING
Apple juice see page 2·338	1 kg	100%
Turmeric, freshly grated	20 g	2%
Black peppercorns (whole)	3 g	0.3%
Coriander seeds	2 g	0.2%
Cinnamon stick, toasted	1.5 g	0.15%
Cardamom	1 g	0.1%
Cloves (whole)	1 g	0.1%
Star anise, toasted	1 g	0.1%
Saffron threads	0.2 g	0.02%
Apples, peeled and cored	900 g	90%

(2010)



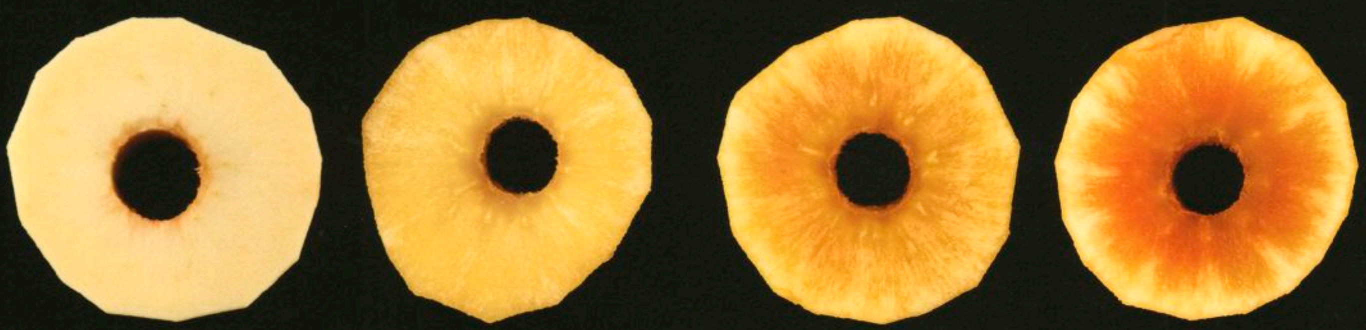
1 **Vacuum seal juice and spices (not shown).**

2 **Refrigerate for 12 h to infuse (not shown).**

3 **Place apples in bowl, and cover with infused juice.**

4 **Place bowl in chamber sealer, and pull moderate vacuum.** Release vacuum when liquid begins to boil, and then run vacuum cycle twice more to boil a total of three times.

5 **Hold under vacuum for 15 min.** After last cycle, turn machine off, and leave machine sealed. When apples have fully absorbed liquid, release vacuum, and remove food.



Amazingly, you can double the weight of an apple by infusing it with liquid. That may seem strange—people usually think of apples as being solid—but the children's game "bobbing for apples" wouldn't work if apples didn't float. And the reason they do float is that they contain a lot of air.

WATERMELON MEAT INSPIRED BY ANDONI LUIS ADURIZ

Yields 250 g

INGREDIENT	QUANTITY	SCALING
Watermelon, peeled and white rind discarded	500 g	100%
Water	100 g	20%
Salt	5 g	1%

(original 2007, adapted 2010)

1 **Cut into 2.5 cm / 1 in "steaks."** Cut from surface, seedless part only, reserving all remaining watermelon flesh for another use. Leave small lip of white rind to mimic fat cap of steak, if desired.

2 **Whisk together water and salt to make brine.**

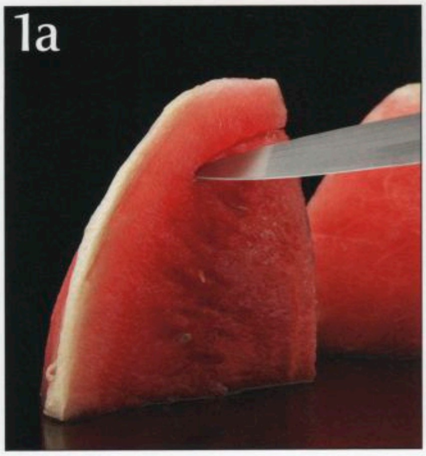
3 **Vacuum seal watermelon steaks with brine, and refrigerate for 2 h.**

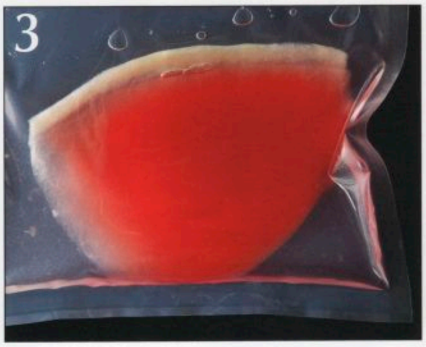
4 **Drain brined watermelon, and pat dry.**

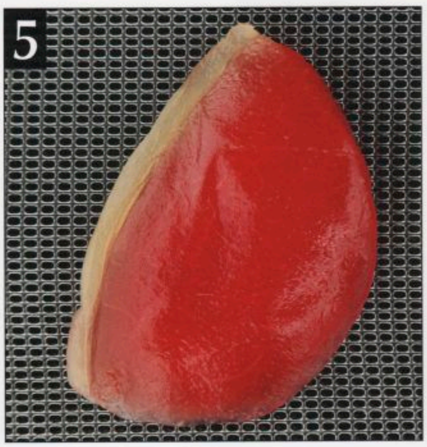
5 **Dehydrate slices at 55 °C / 130 °F until dry and leather-like, 8–12 h.**

6 **Brush slices with water, vacuum seal, and refrigerate.** This will moisten them just enough to keep them tender.

7 **Serve as fun replacement for meat.** See the plated-dish recipe for Watermelon Bulgogi on page 5·285.







EXAMPLE RECIPE

VEGETABLE COALS ADAPTED FROM ANDONI LUIS ADURIZ

Yields 250 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Cassava roots, peeled	675 g	100%	① Cut into 4.5 cm / 1¾ in cubes.
White fish stock see page 2·303	350 g	52%	② Combine stock and ink. ③ Mix with cassava cubes.
Squid ink	15 g	2.2%	④ Simmer together until tender, 35–40 min.
Salt	to taste		⑤ Drain ink-stained cubes. ⑥ Season.

(published 2005)

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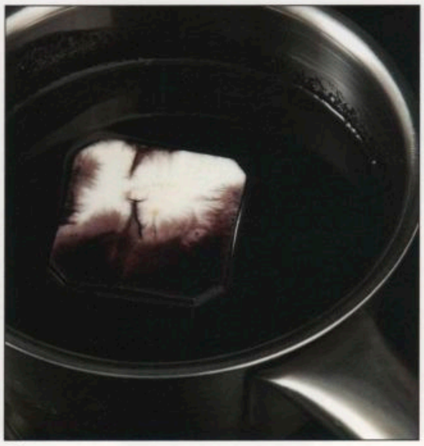

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At Mugaritz, Andoni Luis Aduriz serves these vegetable coals with confit potatoes and crushed soft-boiled eggs.

Photo courtesy of José Luis López de Zubiría—Mugaritz

EXAMPLE RECIPE

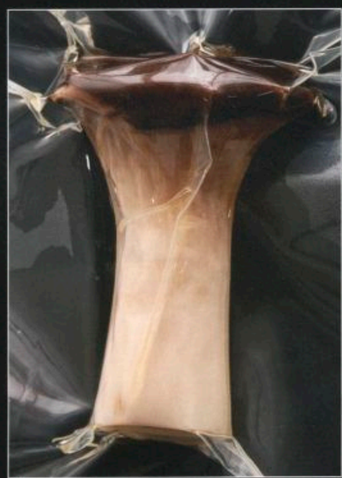
PULLED MUSHROOM INSPIRED BY H. ALEXANDER TALBOT AND AKI KAMOZAWA

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
King Trumpet mushrooms, sliced in half lengthwise	250 g	100%	① Vacuum seal oil with mushrooms.
			② Cook sous vide in **90** °C / **194** °F bath for 4 h.
Neutral oil	50 g	20%	③ Drain on tray lined with paper towels.
			④ Pull mushrooms apart into individual fibers.
Barbecue sauce see page 5·66	to taste		⑤ Mix in, and serve.

(original 2008, adapted 2010)

This process also works really well for enoki mushrooms. Simply cut off the mushroom heads, vacuum seal, and cook sous vide for 2½ h at 90 °C / 194 °F.



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EXAMPLE RECIPE

SQUID-INK BEAN-SPROUT RISOTTO ADAPTED FROM FERRAN ADRIÀ

Yields 700 g (eight portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Bean sprouts	250 g	100%	① Cut off ends. ② Cut into 1 cm / ⅜ in sticks to resemble rice, and reserve.
Squid stock (or water) see page 2·297	50 g	20%	③ Blend stock and ink, and reserve, refrigerated.
Squid ink	2.5 g	1%	
Squid stock (or water)	50 g	20%	④ Disperse agar in stock, and bring to boil. ⑤ Simmer for 2 min, and remove from heat. ⑥ Cast evenly into nonstick mold in layer 1 cm / ⅜ in thick. ⑦ Refrigerate until set, about 10 min. ⑧ Cut squid jelly into cubes, and reserve.
Agar (Texturas brand)	0.3 g	0.12%	
Egg yolks	30 g	12%	⑨ Blend.
Garlic, mashed	8 g	3.2%	
Extra-virgin olive oil	150 g	60%	⑩ Drizzle slowly into yolks, while blending, until emulsified and mayonnaise forms.
Salt	to taste		⑪ Season and reserve.
Squid legs	75 g	30%	⑫ Sauté legs for 20 s on each side until just cooked through. ⑬ Season, remove from pan, and reserve.
Neutral oil	as needed		
Salt	as needed		
Squid ink stock, from above	50 g	20%	⑭ Sauté bean sprouts. ⑮ Add squid ink stock to sautéed sprouts. ⑯ Simmer together until risotto is just cooked through and still crunchy, about 2 min. ⑰ Portion risotto into four bowls. ⑱ Garnish with squid jelly, garlic mayonnaise, squid legs, and parsley oil.
Neutral oil	as needed		
Lemon herb oil see page 2·330			

(original 2000)

CLAY POTATOES ADAPTED FROM ANDONI LUIS ADURIZ

Yields 200 g

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	3 kg	1500%	① Combine in pot.
Salt	24 g	12%	
Whole baby Yukon Gold potatoes, skins on	200 g	100%	② Simmer in salted water for 20 min, until cooked but still firm. ③ Strain. ④ Place on bamboo skewers, and reserve warm.
Water	40 g	20%	⑤ Combine.
Kaolin clay	30 g	15%	⑥ Dip warm skewered potatoes into clay mixture to coat.
Lactose	20 g	10%	⑦ Place two cooling racks in deep hotel pan, one on bottom and one on top.
Carbon black powder	1.5 g	0.75%	⑧ Thread skewers to stand upright in racks. ⑨ Dry in 45 °C / 115 °F oven for 15 min. ⑩ Transfer potatoes from skewers to serving plates.
Garlic confit see page 354	100 g	50%	⑪ Blend.
Egg yolks	40 g	20%	
Extra-virgin olive oil	250 g	125%	⑫ Blend into garlic and yolk mixture until emulsified and aioli forms.
Salt	to taste		⑬ Season aioli, and serve with warm potatoes.

(published 2005)

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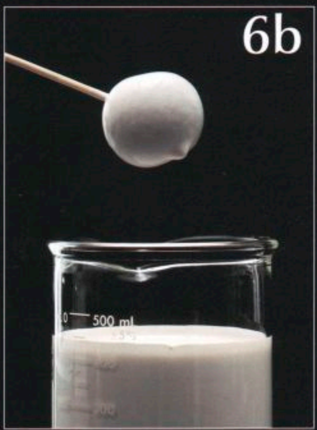

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EXAMPLE RECIPE

FOSSILIZED SALSIFY BRANCH ADAPTED FROM ANDONI LUIS ADURIZ

Yields 350 g (four portions)

INGREDIENT	QUANTITY	SCALING	PROCEDURE
Water	500 g	125%	① Whisk calcium hydroxide into water to make brine.
Calcium hydroxide	4.5 g	1.13% *(0.9%)**	
Salsify root, scrubbed and peeled	400 g (four medium roots)	100%	② Soak in brine at room temperature for 3 h; stir every 30 min to ensure that calcium hydroxide is distributed evenly. ③ Remove from brine, and rinse. ④ Bake in 170 °C / 340 °F oven for 45 min, and reserve warm.
Salted cod roe or pollock roe	100 g	25%	⑤ Whisk and reserve.
Extra-virgin olive oil	16 g	4%	
Sea beans (Salicornia)	40 g	10%	⑥ Toss.
Extra-virgin olive oil	10 g	2.5%	⑦ Place salsify root in center of each warmed plate. ⑧ Garnish evenly with fish roe and sea beans.

(original 2009)

(% of weight of water used for brine*)

Photo courtesy of José Luis López de Zubiría—Mugaritz

EXAMPLE RECIPE

FROZEN WHITE "TRUFFLE"

ADAPTED FROM QUIQUE DACOSTA

1 **Disperse gelatin in cold soy milk, and then stir over medium heat until dissolved and fully hydrated.**

2 **Blend in cheese until melted and fully incorporated into the mixture.**

3 **Strain and chill.**

4 **Add white truffle oil, salt, and pepper, and then place in 1 l whipping siphon.** Charge with two cartridges of nitrous oxide.

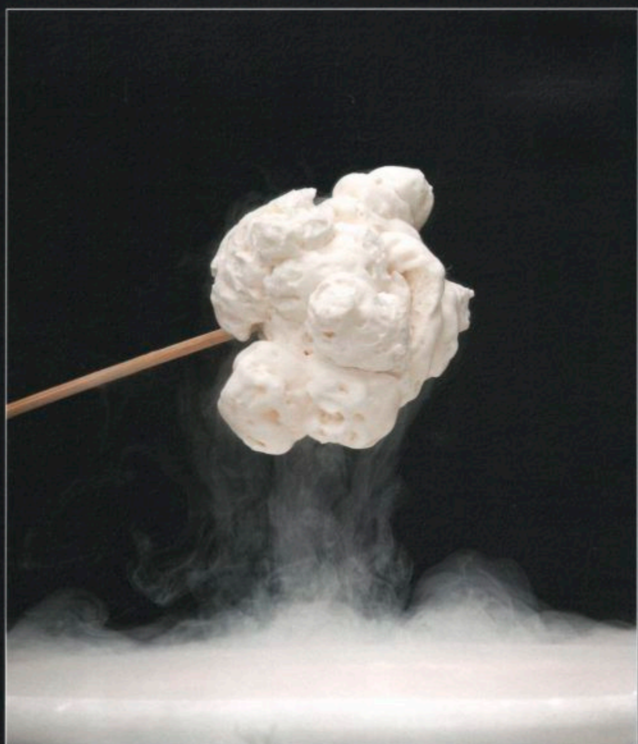
5 **Melt mannitol in small saucepan, and bring to 200 °C / 390 °F.** Add colored powders, and then hold at **180 °C / 355 °F.**

Yields 900 g

INGREDIENT	QUANTITY	SCALING
160 Bloom gelatin	6 g	2%
Soy milk	500 g	166%
Aged Parmesan cheese, grated	300 g	100%
White truffle oil	12 g	4%
Black pepper, finely ground	0.5 g	0.17%
Salt	6 g	2%
Mannitol	800 g	267%
Gold powder	2 g	0.7%
Bronze powder	0.2 g	0.07%
Dried porcini powder	60 g	20%

(original 2008)

6 **Dispense foam onto offset spatula in desired shapes.** Insert bamboo skewer into each "truffle."



7 **Dip in liquid nitrogen.** After dipping, baste with nitrogen to ensure even freezing.

8 **Swirl frozen truffle in warm mannitol to coat evenly and soften rough edges.**

9 **Refreeze in nitrogen.** A brief dip will set mannitol shell.

10 **Thaw in refrigerator for 1 h.** Parmesan cream will soften as it warms.

11 **Garnish with porcini powder.**

Salmon skin

Black-eyed peas