ON FOOD AND COOKING

The Science and Lore of the Kitchen

COMPLETELY REVISED AND UPDATED

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Cooking with Vanilla Vanilla is used mainly in sweet foods. Almost half of the vanilla flavoring consumed in the United States goes into ice cream, and much of the rest into soft drinks and chocolate. But it also works in savory dishes: lobster and pork are popular examples. Added with a light touch, vanilla can contribute a sense of depth, warmth, roundness, and persistence to almost any food.

The flavor of the whole vanilla bean resides in two different parts of the bean: the sticky, resinous material in which the tiny seeds are embedded, and the fibrous pod wall. The first is easily scraped out of the bean and dispersed in a preparation, while the pod itself must be soaked for some time in order to extract its flavor. Because the volatiles are generally more soluble in fat than in water, the cook can extract more flavor if the extraction liquid includes either alcohol or fat. Prepared vanilla extracts can be dispersed throughout a dish instantly, and are usually best added toward the end of cooking; any period of time spent at a high temperature causes aroma loss.

TEA AND COFFEE

Tea and coffee are the most widely consumed drinks in the world, and their popularity stems from the same source as that of herbs and spices: the plant materials they're made from are crammed with chemical defenses that we have learned to dilute, modify, and love. Tea leaves and coffee beans have one defense in common, and that's caffeine, a bitter alkaloid that has significant effects on our bodies. And they both contain large doses of phenolic compounds. However, they're very different materials. Coffee begins as a seed, a storehouse of protein, carbohydrate, and oil, and is the creation of high heat, a robust epitome of roasted foods and flavors. Tea begins as a new, actively growing leaf, rich in enzymes, and is the delicate creation of those enzymes, carefully captured and preserved by minimal heat and drying. Coffee and tea thus offer two very different experiences of botanical inventiveness and human art.

CAFFEINE

Caffeine is the most widely consumed behavior-modifying chemical in the world. It is an alkaloid (p. 238) that interferes with a particular signaling system used by many different cells, and therefore has several different effects on the human body. Above all, caffeine stimulates the central nervous system, relieves drowsiness and fatigue, and quickens reaction times. It also increases energy production in muscles and so their capacity for work. It's said to improve mood and mental performance, though recent studies suggest that these may be the result of relieving the initial symptoms of overnight caffeine withdrawal! Less desirably, in high doses it causes restlessness, nervousness, and insomnia. It has complex effects on the heart and arteries, and can produce an abnormally fast heartbeat. There is some evidence that caffeine speeds the loss of calcium from bone, so habitual consumption may contribute to osteoporosis.

Caffeine reaches its maximum levels in the blood between 15 minutes and two hours after consumption, and its levels are reduced by half within three to seven hours. Its effects are more noticeable in people who don't normally consume it. Withdrawal symptoms can be unpleasant, but usually disappear within three days of abstaining.

A chemical relative of caffeine called theophylline is found in tea and is in some respects more potent than caffeine, but tea contains only trace amounts. Though coffee beans are 1–2% caffeine and tea leaves 2–3%, brewed coffee contains more caffeine than brewed tea because a larger weight of coffee is extracted per cup (8–10 grams, vs. 2–5 grams for tea).

Tea, Coffee, and Health

Not so many years ago, both coffee and tea were suspected of contributing to various diseases, including cancers, so they were among the many pleasures to feel guilty about. No longer! Coffee is now recognized as the major source of antioxidant compounds in the American diet (medium roasts have the highest antioxidant activity). Black and especially green teas are also rich in antioxidant and other protective phenolic compounds that appear to reduce damage to arteries and cancer risk.

Certain kinds of brewed coffee do turn out to have an undesirable effect on blood cholesterol levels. Two lipid (fat-like) substances, cafestol and kahweol, raise those levels, though they only get into the coffee when the brewing technique doesn't filter them out. Boiled, plunger-pot, and espresso coffees contain them. The significance of this effect isn't known and may well be small, since the cholesterol raisers are accompanied by a large dose of substances that protect the cholesterol from oxidation and causing damage (p. 255).

Water for Making Tea and Coffee

Brewed tea and coffee are 95–98% water, so their quality is strongly influenced by the quality of the water used to make them. The off-flavors and disinfectant chlorine compounds of most tap waters are largely driven off by boiling. Very hard water, high in calcium and magnesium carbonates, has several undesirable effects: in coffee, these minerals slow flavor extraction, cloud the brew, clog the pipes in espresso machines and reduce the fine espresso foam; in tea, they cause the formation of a surface scum made up of precipitated calcium carbonate and phenolic aggregates. Softened water overextracts both coffee and tea and gives a salty flavor. And very pure distilled water gives a brew best described as flat, with a missing dimension of flavor.

The ideal water has a moderate mineral content, and a pH that is close to neutral, so that the final brew will have a moderately acid pH of around 5, just right to support and balance the other flavors. Some bottled spring waters are suitable (Volvic is used in Hong Kong). Many municipal tap waters

Caffeine Numbers

Daily caffeine consumption in milligrams per capita, 1990s

Norway, Netherlands, Denmark	400
Germany, Austria	300
France	240
Britain	200
United States	170

Caffeine content, milligrams per serving

Brewed coffee	65–175
Espresso	80–115
Tea	50
Cola	40–50
Cocoa	15

are intentionally made alkaline to reduce pipe corrosion, and this can reduce the acidity and liveliness of both tea and dark-roasted coffee (light roasts contribute plenty of their own acid). Alkaline tap water can be corrected by adding tiny pinches of cream of tartar—tartaric acid—until it just begins to have a slightly tart taste.

TEA

Though it has lent its name to many other infusions, *tea*—from the Chinese word *cha*—is a drink prepared from the green leaves of a kind of camellia. Young tea leaves turn out to be as packed with interesting defensive chemicals as any spice. Beginning in southwest China around 2,000 years ago, people learned how to use physical pressure, mild heat, and time to coax a number of different flavors and colors from the tea leaf. Tea became a staple of the Chinese diet around 1000 CE. In 12th-century Japan, Buddhist monks who valued tea as an aid to long hours of study found that tea itself was worthy of their contemplation. They developed the formal tea ceremony, which remains remarkable for the attention it pays to the simplest of preparations, an infusion of leaves in water.

The History of Tea

Tea in China The tea tree, *Camellia sinensis,* is native to Southeast Asia and southern China, and its caffeine-rich, tender young leaves were probably chewed raw long before recorded history. The preparation of tea leaves for infusion in water evolved slowly. There's evidence that by the 3rd century CE the leaves were boiled and then dried for later use, and that by the 8th century they were also stir-fried before drying. These techniques would give green or yellow-green leaves and infusions, and mild but bitter and astringent flavor. More strongly flavored and orange-red teas like modern oolongs were developed around the 17th century, probably beginning with the accidental observation that the leaves develop a distinctive aroma and color when they're allowed to wilt or are pressed before being dried. It was around this time that China began to trade extensively with Europe and Russia, and the new, more complex style of tea conquered England, where consumption rose from 20,000 pounds in 1700 to 20 million in 1800. The strong "black" tea that's most familiar in the West today is a relatively recent invention, the result of intensive pressing; the Chinese developed it in the 1840s specifically for export to the West.

The Spread of Tea Production Until the late 19th century, all tea in world trade was China tea. But when China began to resist Britain's practice of paying for its expensive tea habit with opium, the British intensified tea production in their own colonies, particularly India. For warm regions they cultivated an indigenous variety, *Camellia sinensis* var. *assamica,* or Assam tea, which has more phenolic compounds and caffeine than China tea and produces a stronger, darker black tea. They planted the hardier China types in the Himalayan foothills of Darjeeling and at high elevations in the south. India is now the world's largest tea producer.

Today about three-quarters of the tea produced in the world is black tea. China and Japan still produce and drink more green tea than black.

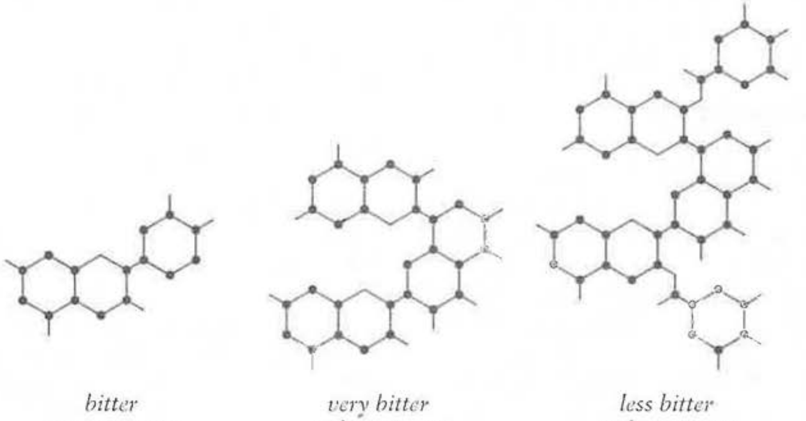
The Tea Leaf and Its Transformation A fresh tea leaf tastes bitter and astringent, and not much else. This is a reflection of the fact that its major chemical component, even more abundant than its structural materials, is a host of bitter and astringent phenolic substances whose purpose is to make the leaf unattractive to animals. And its aromatic molecules are locked up in nonvolatile combinations with sugar molecules. Green tea retains many of the qualities of the fresh leaf. But the key to making oolong and black teas is encouraging the leaf's own enzymes to transform these austere defensive materials into very different, delightful molecules.

How Tea Enzymes Create Flavor, Color, and Body The period of enzyme activity during tea-making has traditionally been called "fermentation," but it doesn't involve any significant microbial activity. In tea-making, "fermentation" means enzymatic transformation. It occurs when the tea maker presses the leaves to break open their cells, and then allows the leaves to sit for some time while the enzymes do their work.

There are two general kinds of enzymatic transformation in making tea. One is the liberation of a large range of aroma compounds, which in the intact leaf are bound up with sugars and so can't escape into the air. When the cells are crushed, enzymes break the aroma-sugar complex apart. This liberation makes the aroma of oolong and black teas fuller and richer than the aroma of green teas.

The second transformation builds large molecules from small ones, and thereby modifies flavor, color, and body. The small molecules are the tea leaf's abundant supply of three-ring phenolic compounds, which are astringent, bitter, and colorless. The leaf's browning enzyme, polyphenoloxidase, uses oxygen from the air to join the small phenolic molecules together into larger complexes (p. 269). A combination of two phenolics gives a kind of molecule (theaflavin) that's yellow to light copper in color, less bitter but still astringent. Complexes of from three to ten of the original phenolics are orange-red and less astringent (thearubigens). Even larger complexes are brown and not astringent at all. The more the tea leaves are pressed, and the longer they're allowed to sit before the enzymes are killed by heating, the less bitter and astringent and the more colored they become. In oolong teas, about half of the small phenolics have been transformed; in black teas, about 85%.

The red and brown phenolic complexes—and another complex, between double-ring molecules of caffeine and the theaflavins—lend body to brewed tea, because they're large enough to obstruct each other and slow the movement of the water.



bitter not astringent | *very bitter and astringent* | *less bitter and astringent*

The evolution of tea taste. The fresh tea leaf contains rich stores of simple phenolic compounds (catechin, **left)** ***that are colorless and bitter but not astringent. When the tea leaf is bruised or rolled, leaf enzymes and oxygen combine the simple compounds into larger ones with different colors and tastes. Brief enzyme action produces a yellowish compound (theaflavin,*** **center)** ***that is both very bitter and astringent. More extensive enzyme action produces a compound (theaflavin digallate,*** **right)** ***that is moderately bitter and astringent. As the phenolic molecules get larger, they get progressively darker and milder.***

Making Tea

The Tea Plant and Its Leaves **The best tea is made from the plant's small young shoots and unopened leaf buds, which are the most tender and vulnerable and contain the highest concentrations of chemical defenses and related enzymes. The choice "pluck" is the terminal bud and two adjacent leaves. Most tea is now harvested by machine, and therefore contains a large proportion of older and less flavorful** leaves.

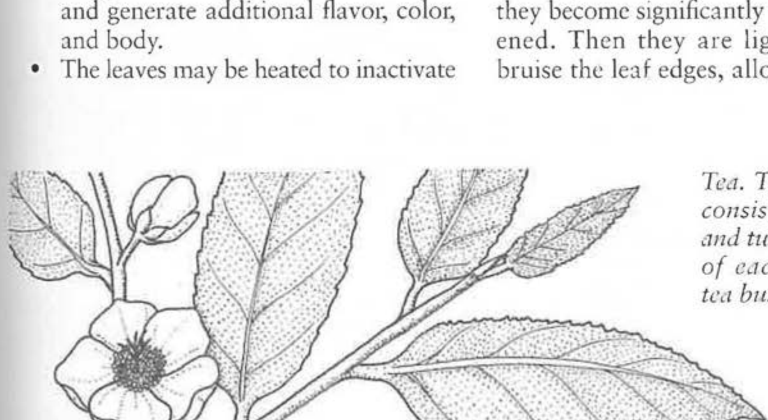
Tea Manufacturing The production of tea involves several different steps, some standard and some optional.

- The newly harvested leaves may be allowed to "wither," or sit and wilt for minutes or hours. Withering causes them to shift their metabolism in ways that change their flavor, and to become physically more fragile. The longer the withering, the deeper the flavor and color of the leaves and the brew they make.
- The leaves are almost always "rolled," or pressed to break down the tissue structure and release the cell fluids. If the leaves are rolled while they're still raw, this allows the leaf enzymes and oxygen to transform the cell fluids and generate additional flavor, color, and body.
- The leaves may be heated to inactivate their enzymes and stop the enzymatic production of flavor and color. High dry heat will also generate flavor.
- The leaves are heated to dry them out and preserve them for long keeping.
- The dry leaves are sieved and graded by piece size, which ranges from whole leaves to "dust." The smaller the piece, the faster the extraction of color and flavor.

Major Tea Styles The Chinese developed a half-dozen different styles of tea. Three of them account for most of the tea consumed in the world.

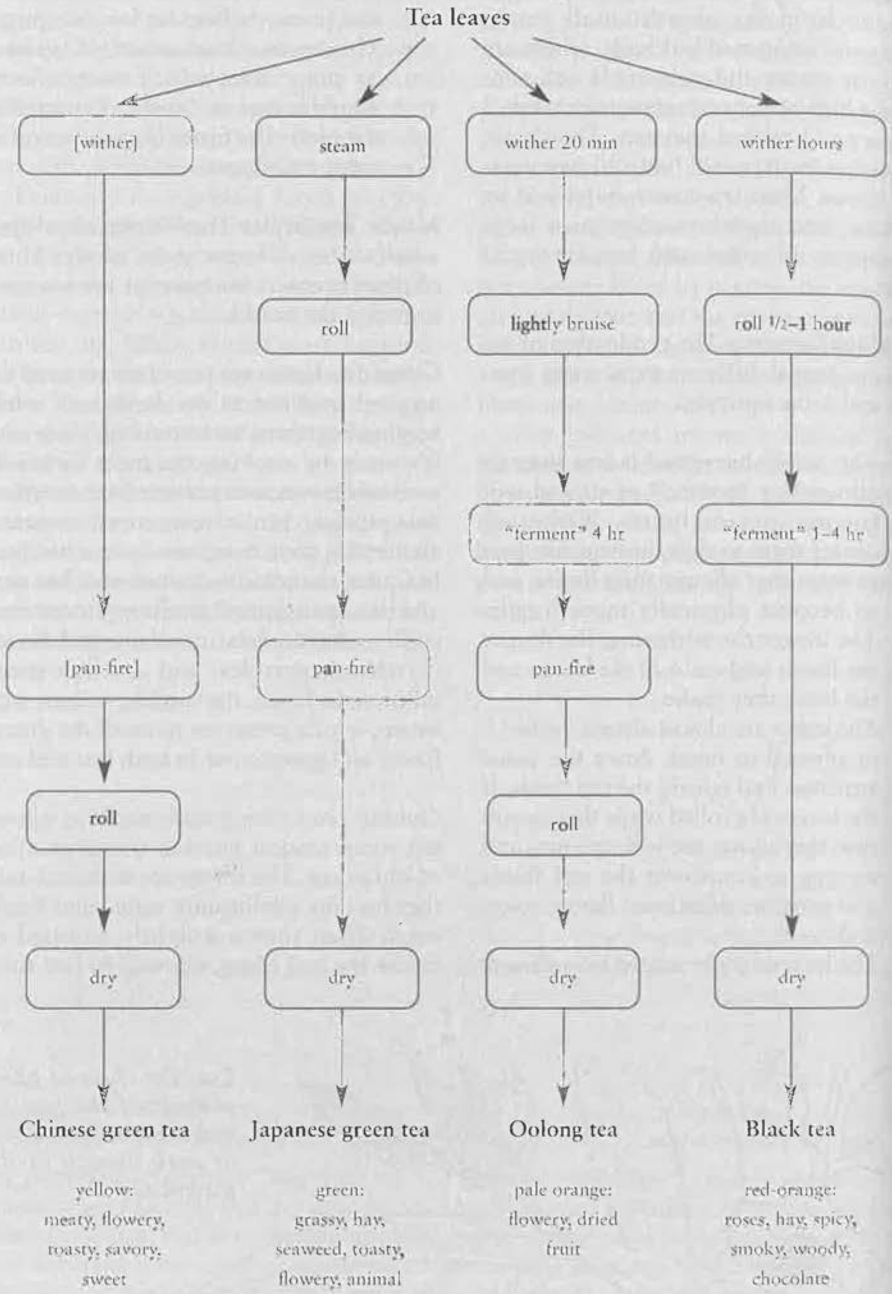
Green Tea Green tea preserves some of the original qualities of the fresh leaf, while heightening them and rounding them out. It's made by cooking the fresh or briefly withered leaves to inactivate their enzymes, then pressing them to release their moisture, and drying them in hot air or on a hot pan. In China, the cooking is done on a hot pan, and this "pan-firing" produces aroma molecules characteristic of roasted foods (pyrazines, pyrroles) and a yellow-green infusion. In Japan, the cooking is done with steam, which preserves more of the grassy flavor and green color in both leaf and tea.

Oolong Tea Oolong tea is made by allowing some modest enzyme transformation of leaf juices. The leaves are withered until they become significantly wilted and weakened. Then they are lightly agitated to bruise the leaf edges, allowed to rest for a



Tea. The choicest pluck consists of the bud tip and two youngest leaves of each branch of the tea bush.

Making Green, Oolong, and Black Teas



few hours until enzyme action has turned the bruised edges red, pan-fired at a high temperature, rolled, and finally dried gently, at temperatures just below 212°F/100°C. Oolong tea brews to a light amber color with a distinctive fruity aroma.

Black Tea Black tea is made by allowing a profound enzymatic transformation of the leaf fluids. The leaves are withered for hours, rolled repeatedly for as much as an hour, then are allowed to rest for between one and four hours, during which enzyme action turns them a coppery brown and causes them to emit the aroma of apples. Finally, the leaves are air-dried at temperatures around 100°C, and become quite dark.

Tea Flavor The taste of tea, a lively, mouthfilling quality, comes from several different sources. Tea is mildly acid and bitter and contains traces of salt. It's also rich in a unique amino acid, theanine, which is itself sweet and savory, and partly breaks down during manufacturing to savory glutamic acid. Chinese green teas also contain synergizers of savoriness (GMP and IMP, p. 342). Finally, bitter caffeine and astringent phenolics bond to and take the edge off each other and produce the impression of a stimulating but not harsh body. This effect is especially important to the taste of black teas, in which it's called "briskness."

The aromas of different teas are strikingly different. In green teas, early application of heat prevents much enzyme activity in the leaves. Steam heat gives grassy and seaweed, shellfish notes to Japanese green teas (the sea notes from dimethyl sulfide), while pan-firing and drying produce more

Some Prized and Unusual Teas

Here are a number of teas made in unusual ways, with unusual qualities:

- White tea: a Chinese green tea made almost exclusively from buds whose hairs make them look white, withered for two to three days, sometimes steamed, then dried without rolling.
- Pu-erh: a Chinese green tea that is made in the usual way, then moistened and fermented in heaps for some time by a variety of microbes. All of its phenolic contents are converted into nonastringent thearubigens and brown complexes, and it develops a complex, spicy, clove aroma.
- Lapsang souchong: a Chinese black tea, dried over smoky pine fires.
- Scented teas: Chinese teas of various types, scented by being held for 8–12 hours in the same container with flowers, including jasmine, cassia bud, rose, orchid, and gardenia. The packaged tea may include 1–2% flower petals.
- Gyokura and kabesucha: Japanese green teas made from shoots that have been covered with bamboo boxes and almost completely shaded for the two weeks before harvest. They develop a higher content of carotenoid pigments that contribute violet notes to the unique "covered aroma."
- Hoji-cha: Japanese green tea of standard grade that is roasted at high temperatures (360°F/180°C), which triples the volatile content and so boosts flavor.

OPPOSITE: *Making green, oolong, and black teas. Variations in processing produce very different colors and flavors from the same fresh leaves.*

savory, toasted notes in Chinese green teas. In oolong and black teas, enzyme activity liberates floral and fruity aroma molecules from their odorless storage forms, and produces a much richer, stronger aroma (more than 600 volatiles have been identified in black tea).

Cooks exploit tea flavor in a number of different preparations: marinades and cooking liquids, ices and ice creams, in steamed foods, and as a source of aromatic smoke (e.g., Chinese tea-smoked duck).

Keeping and Brewing Tea Well-made tea is fairly stable and can be stored for several months in an airtight container that is kept cool and dark. Tea quality does eventually deteriorate thanks to the effects of oxygen and some residual enzyme activity; aroma and briskness are lost, and the color of black tea infusions becomes less orange-red, more dull brown.

Teas are brewed in various ways in different parts of the world. In the West, a relatively small quantity of black tea leaves—a teaspoon per 6-oz cup/2–5 gm per 180 ml—is brewed once, for several minutes, then discarded. In Asia, a larger quantity of leaves of any tea—as much as a third the volume of the pot—is first rinsed with hot water, then infused briefly several times, with the second and third infusions offering more delicate, subtle flavor balances. The infusion time ranges from 15 seconds to 5 minutes, and depends on two factors. One is leaf size; small particles and their great surface area require less time for their contents to be extracted. The other is water temperature, which in turn varies depending on the kind of tea being brewed. Both oolong and black teas are infused in water close to the boil, and relatively briefly. Green tea is infused longer in much cooler water, 160–110°F/70–45°C, which limits extraction of its still abundant bitter and astringent phenolics, and minimizes damage to its chlorophyll pigment.

In a typical 3–5 minute infusion of black tea, about 40% of the leaf solids are extracted into the water. Caffeine is rapidly extracted, more than three quarters of the total in the first 30 seconds, while the larger phenolic complexes come out much more slowly.

Serving Tea Once tea is properly brewed, the liquid should be separated from the leaves immediately; otherwise extraction continues and the tea gets harsh. All kinds of tea are best drunk fresh; as they stand, their aroma dissipates, and their phenolic components react with dissolved oxygen and each other, changing the color and taste.

Tea is sometimes mixed with milk. When it is, the phenolic compounds immediately bind to the milk proteins, become unavailable to bind to our mouth surfaces and salivary proteins, and the taste becomes much less astringent. It's best to add hot tea to warm milk, rather than vice versa; that way the milk is heated gradually and to a moderate temperature, so it's less likely to curdle.

Lemon juice is sometimes added to tea to bolster its tartness and add the fresh citrus note to its aroma. It also lightens the color of brewed black tea by altering the structure of the red phenolic complexes (the complexes are weak acids themselves, and take up hydrogen ions from the lemon juice). Alkaline brewing water, conversely, tends to produce blood-red infusions from black tea, and can even make green tea red.

Iced Tea Iced tea is the most popular form of tea in the United States; it first caught on at the 1904 World's Fair in steamy St. Louis. It's made by brewing tea with about half-again as much dry tea per cup, to compensate for the later dilution by melting ice. The addition of ice to normally brewed tea tends to make the tea cloudy, due to the formation of particles of a complex between caffeine and theaflavin. The way to avoid this is to brew the initial tea at room or refrigerator temperature, over several hours. This technique extracts less caffeine and theaflavin than brewing in hot water, so the caffeine-theaflavin complexes don't form in sufficient quantities to become visible in the chilled tea.

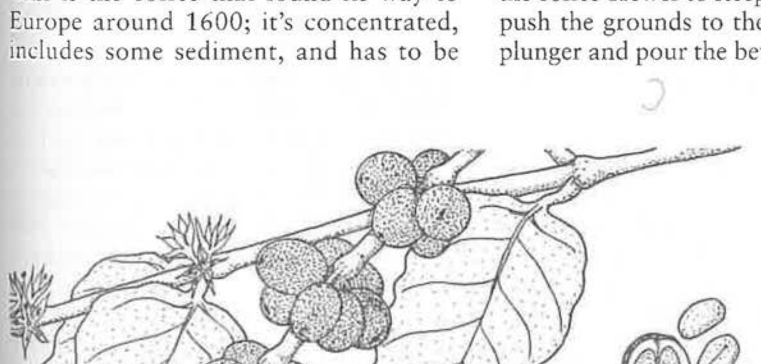
COFFEE

Coffee trees are native to east Africa, and were probably first valued for their sweet cherry-like fruits and for their leaves, which could be made into a kind of tea. Even today an infusion of the dried fruit pulp is enjoyed in Yemen, where the seeds or "beans" were apparently first roasted, ground, and infused in the 14th century. Our word coffee comes from the Arabic *qahwah,* whose own origin is unclear. The coffee tree was taken to south India around 1600, from India to Java around 1700, and from Java (via Amsterdam and Paris) to the French Caribbean shortly thereafter. Today Brazil, Vietnam, and Colombia are the largest exporters of coffee; African countries contribute about a fifth of world production.

The History of Coffee Brewing The original version of brewed roasted coffee beans is the Arab version, which still thrives in the Middle East, Turkey, and Greece. The finely powdered beans are combined with water and sugar in an open pot, the mixture boiled until the pot foams, then settled and boiled to a foam once or twice more, and finally decanted into small cups. This is the coffee that found its way to Europe around 1600; it's concentrated, includes some sediment, and has to be drunk right away or the sediment will increase the already considerable bitterness.

French Refinements The first Western modifications of coffee brewing date from around 1700, when French cooks isolated the solid beans within the liquid by enclosing the grounds in a cloth bag, and thus produced a clearer, less gritty brew. Around 1750, the French came up with the most important advance before espresso: the drip pot, in which hot water was poured onto a bed of grounds and allowed to pass through into a separate chamber. This invention did three things: it kept the temperature of the extracting water below the boil, it limited the contact time between water and ground coffee to a matter of a few minutes, and it produced a sedimentless brew that would keep for a while without getting stronger. The limits on brewing temperature and time meant a less complete extraction of the coffee. This reduced the bitterness and astringency, and allowed the other elements of coffee flavor more prominence, the tartness and aroma that were more appealing to European tastes.

Machine-Age Espresso The 19th century brought the invention of several new brewing methods. There was percolation, or allowing boiling water to rise in a central tube and irrigate a bed of ground coffee. There were plunger pots, which allowed the coffee brewer to steep the grounds, then push the grounds to the bottom with the plunger and pour the beverage off. But the



Coffee berries and seeds. Each red berry contains two seeds.

biggest innovation in coffee brewing made its debut at the Paris Exhibition of 1855. That was Italian *espresso,* a word which means something made at the moment it's ordered, rapidly, and for one customer. The way to make coffee fast is to force water through the grounds with high pressure. In the process, the pressure extracts a substantial amount of the coffee bean's oil, and emulsifies it into tiny droplets that create a velvety texture and lingering flavor in the drink. Espresso is an expression of the power of the machine to force the most and the best from a traditional ingredient and make it into something new.

Coffee Beans

Arabica and Robusta Coffees Coffee beans are the seeds of two species of a tropical relative of the gardenia. *Coffea arabica,* a 15 ft/5 m tree that is native to the cool highlands of Ethiopia and the Sudan, produces what are known as "arabica" beans; and *Coffea canephora,* a larger tree native to hotter, more humid West Africa, produces "robusta" beans. About two-thirds of the beans in international trade are arabicas, which develop a more complex and balanced flavor than the robustas. They contain less caffeine (less than 1.5% by weight of the dry bean, vs. 2.5% for robustas), less phenolic material (6.5% vs. 10%), and more oil (16% vs. 10%) and sugar (7% vs. 3.5%). Robusta varieties didn't become prominent until the end of the 19th century, when their disease resistance became important in Indonesia and elsewhere.

Dry and Wet Processing To prepare coffee beans, the ripe coffee berries are picked from the trees, and the seeds cleaned of the fruit pulp by one of two basic methods. In the dry method, the berries are left in the sun to dry, or first piled to ferment for a few days, then spread out in the sun. The fruit is then removed by machine. In the wet method, most of the pulp is rubbed from the seeds by machine, then the remainder is liquefied by a day or two of fermentation by microbes. The seeds are then washed in copious water, dried to about 10% moisture, and the adherent inner "parchment shell" removed by machine. Some sugars and minerals are leached out of wet-processed beans, so they tend to produce coffee with less body and more acidity than dry-processed beans. However they often have more aroma, and tend to be of more uniform quality.

Roasting Raw green coffee beans are as hard as unpopped popcorn, and about as tasty. Roasting transforms them into fragile, easily opened packages of flavor. Most people let the professionals take care of roasting, but it's a fascinating (and smoky) experience to roast coffee at home, as cooks in many countries have long done and still do with equipment ranging from frying pans to popcorn poppers to special roasters.

Coffee beans are roasted to temperatures between 375 and 425°F/190–220°C; the process usually takes between 90 seconds and 15 minutes. As the bean temperature approaches the boiling point of water, the small amounts of moisture inside the cells turn into steam and puff the bean up to half again its original volume. Then at progressively higher temperatures, the proteins, sugars, phenolic materials, and other constituents begin to break into molecular fragments and react with each other, and develop the brown pigments and roasted aromas typical of the Maillard reactions (p. 778). At around 320°F/160°C, these reactions become self-sustaining, like a candle flame, and extreme molecular breakdown generates more water vapor and carbon dioxide gas, whose production rises sharply at 400°F/200°C. If the roasting continues, oil begins to escape from the damaged cells to the bean surface, where it provides a visible gloss.

When the beans have reached the desired degree of roast, the roaster cools the beans immediately with cold air or a water spray to quench the molecular breakdown. The result is a brown, brittle, spongelike bean, with the holes in the sponge filled with carbon dioxide.

The Development of Coffee Flavor The hotter the bean is roasted, the darker it gets, and its color is a good indicator of flavor balance. In the early stages of roasting, sugars are broken down into various acids (formic, acetic, lactic), which together with their own organic acids (citric, malic) give light-brown beans a pronounced tartness. As roasting proceeds, both the acids and astringent phenolic materials (chlorogenic acid) are destroyed, so acidity and astringency decline. However, bitterness increases because some of the browning-reaction products are bitter. And as the bean's color becomes darker than medium brown, the distinctive aromas characteristic of prized beans become overwhelmed by more generic roasted flavors—or, conversely, the flavor deficiencies of second-rate beans become less obvious. Finally, as acids and tannins and soluble carbohydrates decline with dark roasting, so does the brew's fullness of body: there's less there to stimulate our tongue. Medium roasts give the fullest body.

Storing Coffee Once roasted, whole coffee beans keep reasonably well for a couple of weeks at room temperature, or a couple of months in the freezer, before becoming noticeably stale. One reason that whole beans keep as long as they do is that they're filled with carbon dioxide, which helps exclude oxygen from the porous interior. Once the beans have been ground, room-temperature shelf life is only a few days.

Grinding Coffee The key to proper coffee grinding is obtaining a fairly consistent particle size that's appropriate to the brewing method. The smaller the particle size, the greater the surface area of bean exposed to the water, and the faster its contents are extracted. Too great a range of particle sizes makes it hard to control the extraction during brewing. Small particles may be

The Effects of Roasting on Coffee Beans

Weight Loss of Roasted Coffee Beans

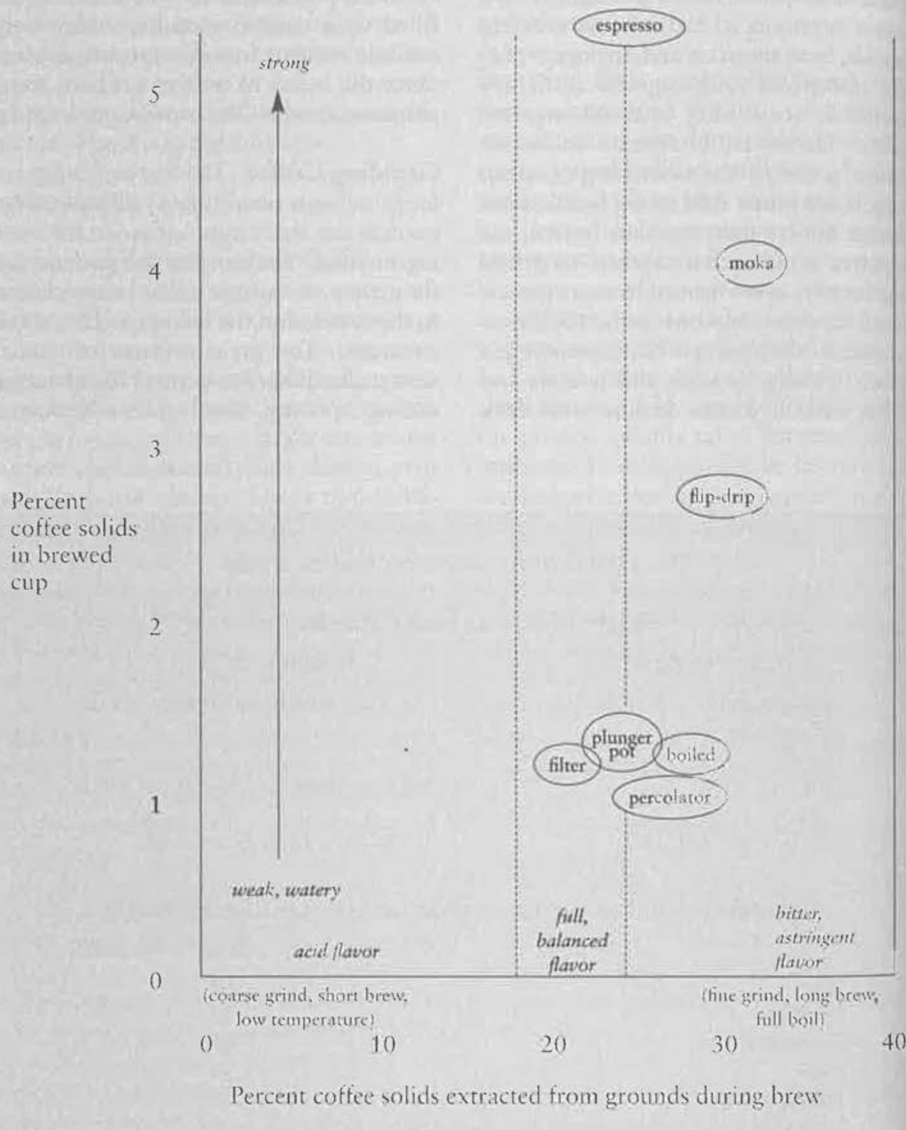
Degree of Roast	Weight Loss, %
Cinnamon (375°F/190°C)	12, mostly moisture
Medium	13
City	15
Full city	16, half moisture and half bean solids
French	17
Italian (425°F/220°C)	18–20, mostly bean solids

Composition of Raw and Roasted Coffee Beans, Percent by Weight

	Raw	Roasted
Water	12	4
Protein	10	7
Carbohydrate	47	34
Oil	14	16
Phenolics	6	3
Large complex aggregates that provide color, body	0	25

Coffee Flavor, from the Bean into the Cup

This chart shows the relationships between coffee flavor and the fraction of the coffee bean extracted into the water by various brewing methods. Balanced flavor corresponds to an extraction of around 20% of the coffee solids. The strength of the flavor depends on the relative proportions of coffee and water: espresso is made with a much higher proportion of coffee than other brews.



overextracted and large ones underextracted, and the resulting brew can be both bitter and weak. The common propellor grinder smashes all the bean pieces until the machine is stopped, no matter how small the pieces get, so coarse and medium grinds end up containing some fine powder. More expensive burr grinders allow small pieces to escape through grooves in the grinding surfaces, and give a more even particle size.

Brewing Coffee Brewing is the extraction into water of desirable substances from the coffee bean, in amounts that produce a balanced, pleasing drink. These substances include many aroma and taste compounds, as well as browning pigments that provide color (almost a third of the total extract) and cell-wall carbohydrates that provide body (also almost a third). The flavor, color, and body of the finished drink are determined by how much ground coffee is used for a given volume of water, and by what proportion of that coffee is extracted into the water. Inadequate extraction and a watery, acid brew are caused by grinding the beans too coarsely, so that flavor is left inside the particles, by too brief a contact time between coffee and water, or by too low a brewing temperature. Overextraction and a harsh, bitter brew result from an excessively fine grind, or long contact time, or high brewing temperature.

The ideal brewing temperature for any style of coffee is 190–200°F/85–93°C; anything higher extracts bitter compounds too quickly. For a standard cup of American coffee, the usual brewing time ranges from 1 to 3 minutes for a fine grind, to 6 to 8 minutes for a coarse grind.

Brewing Methods There are a number of different methods for brewing coffee. Most of them extract between 20 and 25% of the bean's substance, and produce a cup containing somewhere between 1.3% and 5.5% bean solids by weight. The facing chart places some of the major styles in relation to each other. Standard American filter-drip coffee is the lightest, and Italian espresso the strongest. The initial proportion of coffee to water is 1:15 for American, 1:5 for espresso. One clear lesson from the chart is that it's always best to use too much coffee rather than too little: a strong but balanced cup can be diluted with hot water and remain balanced, but a weak cup can't be improved. This principle can help avoid problems caused by the fact that cup and coffee scoop measures vary, and that scoops themselves are a very approximate measure (one 2-tablespoon/30-ml scoop may deliver anywhere from 8 to 12 gm coffee, depending on grind and packing).

Each brewing method has its drawbacks. Percolators operate at the boil and tend to overextract. Many automatic drip brewers aren't able to deliver near-boiling water, so they brew for a long time to compensate, lose aroma, and extract some bitterness. Manual drip cones give little control over extraction time. The plunger pot leaves tiny suspended particles in the brew that keep releasing bitterness. The Italian stovetop moka pot operates above the boil, at around 230°F/110°C (and 1.5 atmospheres of pressure), and produces a somewhat harsh brew. Overnight extraction in cold water doesn't obtain as many aromatic compounds from the ground coffee as the hot-water methods.

Espresso True espresso is made very quickly, in about 30 seconds. A piston or spring or electrical pump drives 200°F/93°C water through finely ground coffee at 9 atmospheres of pressure. (Inexpensive household machines rely on excessively hot steam, develop far less pressure, and take longer to brew, so the result is relatively thin and harsh.) The proportion of ground coffee is three to four times the amount used in unpressurized brewing, and deposits three to four times the concentration of coffee materials in the brew, creating a substantial, velvety body and intense flavor. These extracted materials include a relatively large amount of coffee oils, which the high pressure forces from the bean particles to form a creamy emul-

Methods of Brewing Coffee

This chart summarizes the important features of some common ways of brewing coffee, and the kinds of brew they produce. The stability of a brew is determined by how many coffee particles remain in it; the more particles, the more bitterness and astringency continue to be extracted in the cup or pot.

	Middle Eastern/ Mediterranean, Boiled	Machine Filter	Manual Filter	Percolator	Plunger Pot (French Press)	Moka	"Espresso" (Steam)	Espresso (Pump)
Coffee grind	Very fine (0.1 mm)	Coarse (1 mm)	Medium (0.5 mm)	Coarse (1 mm)	Coarse (1 mm)	Medium (0.5 mm)	Fine (0.3 mm)	Fine (0.3 mm)
Brew temperature	To 212°F/ 100°C	180–185°F/ 82–85°C	190–200°F/ 87–93°C	212°F/ 100°C	190–195°F/ 87–90°C	230°F/ 110°C	212°F/ 100°C	200°F/ 93°C
Brew time	10–12 min	5–12 min	1–4 min	3–5 min	4–6 min	1–2 min	1–2 min	0.3–0.5 min
Extraction pressure, atmospheres	1	1	1	1(+)	1(+)	1.5	1(+)	9
Flavor	Full but bitter (sweetened)	Light, often bitter	Full	Full, often bitter	Full	Full but bitter	Full but bitter	Very full
Body	Full	Light	Light	Light	Medium	Full	Full	Very full
Stability once brewed	Poor	Good	Good	Good	Poor	Fair	Poor	Poor

sion of tiny droplets, and which contribute to the slow, prolonged release of coffee flavor in the mouth, long after the last sip. Another unique feature of espresso is the *crema*, the remarkably stable, creamy foam that develops from the brew and covers its surface. It's the product of carbon dioxide gas still trapped in the ground coffee, and the mixture of dissolved and suspended carbohydrates, proteins, phenolic materials, and large pigment aggregates, all of which bond in one way or another to each other and hold the bubble walls together. (For the milk foams often served with coffee, see p. 26.)

Serving and Holding Coffee Freshly brewed coffee is best enjoyed immediately—its flavor is evanescent. The ideal drinking temperature is around 140°F/60°C, where a sip won't scald the mouth, and the coffee's full aroma comes out. Because it cools in the cup, coffee is usually held in the pot just below the brewing temperature. High heat accelerates chemical reactions and the escape of volatile molecules, so coffee flavor changes noticeably after less than an hour in the pot; it becomes more acid and less aromatic. Coffee is best kept hot by retaining its original heat in a preheated, insulated, closed container, not on a hot plate that constantly supplies excessive heat from below while heat and aroma escape above.

Coffee Flavor Coffee has one of the most complex flavors of all our foods. At its base is a mouth-filling balance of acidity, bitterness, and astringency. A third or less of the bitterness is due to easily extracted caffeine, the rest to more slowly extracted phenolic compounds and browning pigments. More than 800 aroma compounds have been identified, and they supply notes that are described as nutty, earthy, flowery, fruity, buttery, chocolate-like, cinnamon, tea, honeyed, caramel, bready, roasty, spicy, even winey and gamy. Robusta coffees, with their substantially higher content of phenolic substances than arabicas, develop a characteristic smoky, tarry aroma that is valued in dark roasts (they are also distinctly less acidic than arabicas). Milk and cream reduce the astringency of coffee by providing proteins that bind to the tannic phenolic compounds, but these liquids also bind aroma molecules and weaken the overall coffee flavor.

Decaffeinated Coffee Decaffeinated coffee was invented in Germany around 1908. It's made by soaking green coffee beans with water to dissolve the caffeine, extracting the caffeine from the beans with a solvent (methylene chloride, ethyl acetate), and steaming the beans to evaporate off any remaining solvent. In the "Swiss" or "water" process, water is the only solvent used, the caffeine removed from the water by charcoal filters, and the other water-solubles are then added back to the beans. Some of the organic solvents used in other processes have been suspected of being health hazards even in the tiny traces left in the beans (around 1 part per million). The commonest, methylene chloride, is now thought to be safe. More recently, highly pressurized ("supercritical") and nontoxic carbon dioxide has been used. Where ordinary brewed coffee may contain 60–180 milligrams caffeine per cup, decaffeinated coffee will contain 2–5 mg.

Instant Coffee Instant coffee became commercially practical in Switzerland just before World War II. It's made by brewing ground coffee near the boil to obtain aroma, then a second time at 340°F/170°C and high pressure to maximize the extraction of pigments and body-producing carbohydrates. Water is removed from the two extracts by hot spray-drying or by freeze-drying, which retains more of the volatile aroma compounds and produces a fuller flavor. The two are then blended together and supplemented with aromas captured during the drying stage. Instant coffee crystals contain about 5% moisture, 20% brown pigments, 10% minerals, 7% complex carbohydrate, 8% sugars, 6% acids, and 4% caffeine. As an essentially dry concentrate, instant coffee is a valuable flavoring for baked goods, confections, and ice creams.

WOOD SMOKE AND CHARRED WOOD

Neither wood nor the smoke it gives off is an herb or a spice, strictly speaking. Yet cooks and makers of alcoholic liquids often use burned or burning wood as flavoring agents—in barbecuing meats, in barrel-aging wines and spirits—and some of the flavors they supply are identical to spice flavors: vanilla's vanillin, for example, and clove's eugenol. That's because wood is strengthened with masses of interlinked phenolic units, and high heat breaks these masses apart into smaller volatile phenolics (p. 390).

THE CHEMISTRY OF BURNING WOOD

Charred wood and smoke are products of the incomplete combustion of organic materials in the presence of limited oxygen and at the relatively low temperatures of ordinary burning (below 1,800°F/1,000°C). Complete combustion would produce only odorless water and carbon dioxide.

The Nature of Wood Wood consists of three primary materials: cellulose and hemicellulose, which form the framework and the filler of all plant cell walls, and lignin, a reinforcing material that gives wood its strength. Cellulose and hemicellulose are both aggregates of sugar molecules (pp. 265, 266). Lignin is made of intricately interlocked phenolic molecules—essentially rings of carbon atoms with various additional chemical groups attached—and is one of the most complex natural substances known. The higher the lignin content of a wood, the harder it is and the hotter it burns; its combustion releases 50% more heat than cellulose. Mesquite wood is well-known for its high-temperature fire, which it owes to its 64% lignin content (hickory, a common hardwood, is 18% lignin). Most wood also contains a small amount of protein, enough to support the browning reactions that generate typical roasted flavors (p. 778) at moderately hot temperatures. Evergreens such as pine, fir, and spruce also contain significant amounts of resin, a mixture of compounds related to fats that produce a harsh soot when burned.

How Burning Transforms Wood into Flavor Burning temperatures transform each of the wood components into a characteristic group of compounds (see box, p. 449). The sugars in cellulose and hemicellulose break apart into many of the same molecules found in caramel, with sweet, fruity, flowery, bready aromas. And the interlocked phenolic rings of lignin break apart from each other into a host of smaller, volatile phenolics and other fragments, which have the specific aromas of vanilla and clove as well as a generic spiciness, sweetness, and pungency. Cooks get these volatiles into solid foods, usually meats and fish, by exposing the foods to the smoky vapors emitted by burning wood. Makers of wine and spirits store them in wood barrels whose interiors have been charred; the volatiles are trapped in and just below the barrels' inner surface, and are slowly extracted by the liquid (p. 721).

The flavor that wood smoke imparts to food is determined by several factors. Above all there's the wood. Oak, hickory, and the fruit-tree woods (cherry, apple, pear) produce characteristic and pleasing flavors thanks to their moderate, balanced quantities of the wood components. A second important factor is the combustion temperature, which is partly determined by the wood and its moisture content. Maximum flavor production takes place at relatively low, smoldering temperatures, between 570 and 750°F/300–400°C; at higher temperatures, the flavor molecules are themselves broken down into simpler