CHAPTER

TASTE, FLAVOR AND AROMA

3

CHAPTER OUTLINE

In one sentence, it can be said that "flavor" is largely a combination of two different sensations—taste and smell. Yet, before we go into any great detail about flavor, it is worth taking an overview, brief as it may be, of the way in which we actually perceive or sense food flavors themselves. While much of what we like and dislike remains subjective, it is nevertheless true to say we all share the same set of senses that are employed to interpret taste, aroma,[1] flavor, and texture of the food we eat.

When we consider taste, we invariably think of our tongues and the sensations of salts, sweet sugars, sour acids, savory amino acids, and bitter alkaloids; yet, much more is at play here than just our palate and what it comes into contact with it. In reality, one might be surprised to learn that the majority of our nontongue senses are utilized in the appreciation of the food we eat (New World Encyclopedia, 2015). Take sight, for instance; food has visual appeal; however, compare the visual effect appeal of say a fried egg dyed red with that of a medium cooked steak cut in two, and it's not difficult to see which one gets

[1]An aroma compound is also referred to odorant, aroma, or fragrance. In its basic definition, it is a compound that has a smell or odor. A compound has a smell or odor when it is volatile, so it can be transported to the olfactory system in the upper part of the nose.

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the gastric juices flowing. The same could be said when fine dining with China plates and silver cutlery versus paper plates and plastic cutlery; in this sense, the expectation on the palate is tangible (Belitz et al., 2009; Barham et al., 2010). Sight and touch aside, the most significant senses when it comes to our appreciation of food remain the chemical senses comprising taste, smell, and chemesthesis[2] (Section 3.5). These three unique and distinct systems facilitate the passing of information about the presence of chemicals in the immediate environment. Taste (gustation) detects chemical compounds using sensors mostly in the mouth. Smell (aroma or olfaction) detects airborne chemicals, both externally through the nasal passage and from those compounds emitted from foods masticated[3] in our oral cavity—the retronasal pathway. The retronasal passage (*next sections*) is the path in olfactory perception that is just as important as, if not more so than, the nasal passage. On top of this, there is also chemesthesis involving such things as astringency and pungency (see Fig. 3.1). Lastly, before we go any further, it is worth noting that in order to enjoy the holistic sense of food, we have at our disposal, an overall sense of aroma/smell taste and flavor. In turn, to aid in these processes, we have 9000 taste buds and several million olfactory epithelium neuron receptors (New World Encyclopedia, 2015; Murray, 2017; Heilmann and Hummel, 2004).

The complex smelling and tasting processes begin the moment molecules detach from food compounds and reach our nose or mouths. The fact that we can differentiate between thousands of tastes and smells is a result of complex processes that activate various combinations of odor and taste receptors

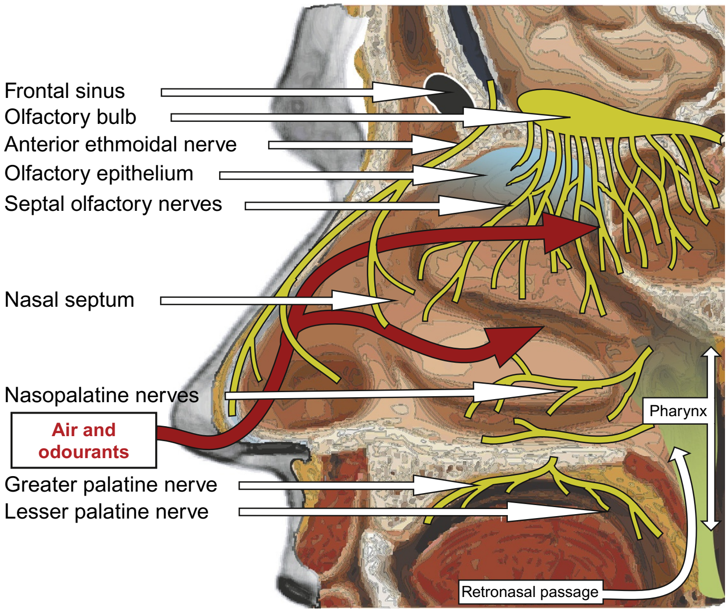

FIG. 3.1

Aroma and taste receptors.

[2]Chemesthesis arises when certain chemical compounds activate receptors normally associated with other senses that mediate pain, touch, and thermal perception, that is, false heat and false coolness.
[3]Mastication is the process of chewing food, breaking it down.

(Murray, 2017). It is also worth noting too that while the neural pathways of aroma and taste stimuli are different, the two often work in unison, especially at the dinner table. Indeed, much of what people perceive as flavor has a lot more to do with the aromas of food and drinks than people might expect. It is also noteworthy that much of what is eaten is connected to the areas of the brain responsible for emotions (Murray, 2017).

3.1 SENSE OF TASTE

There is one common misconception that must first be addressed, and that is, many believe that taste cells that respond to different tastes are bundled together in specific regions of the tongue (PubMed, 2016). In reality, taste cells scattered across the tongue and throat are able to sense a range of tastes (MSUN, 2009; Menche et al., 2014). Gustatory cells, or more commonly taste buds, are on the tongue, the palate (including the soft palate), and areas in the upper throat—in particular the pharynx and laryngopharynx. These number about 2–10,000 depending on who one reads (Ahn et al., 2011; PubMed, 2016). However, as we age, so we lose a few of these gustatory cells over time, especially after the age 50 or so. Every bud contains 10–100 receptor cells (once again depending on who one reads), each able to distinguish between all of the five basic tastes (MSUN, 2009; PubMed, 2016). At the tip of these buds is an opening onto the tongue. Within the bulb itself, the taste cells' receptor proteins (chemoreceptors[4]) embedded in the taste cell membranes function either by physically binding to a tastant[5] (sweet, bitter, and umami) or by acting as a channel to allow ions to pass through to other taste cells (salty and sour). It is these interactions that trigger a torrent of signals to the brain giving clues as to the flavors and complex compounds being tasted (DeMan, 1976). One's capacity to taste food and drink occurs when tiny molecules are released by chewing or drinking, which stimulate special sensory cells in the mouth and throat, which in turn send messages to the brain.

The five basic taste receptors are the following:

- *Sweetness*—which is usually regarded as an agreeable taste generally connected to sugars, some proteins, and other similar substances. It is also often associated with aldehydes and ketones containing the carbonyl group. Sweetness is detected by a variety of G-protein-coupled receptors. G proteins (guanine nucleotide-binding proteins) are a protein group inside cells that act as molecular switches conveying, in this sense "sweet" signals from stimuli outside the cell to its interior. The G protein in the gustatory system, specifically among the taste buds is "gustducin." Sweetness of a particular food substance is usually compared with sucrose or table sugar in which sugar has an index of 1 (UoD, 2017).
- *Sourness*—while the mechanism by which animals and humans detect sourness is still not fully comprehended, we can say that the tartness or sourness can be thought of in terms of acidity from substances such as vinegar, some unripe fruits, and lemon juice. According to the University of Delaware (UoD, 2017), although proteins are involved, evidence suggests that the protons from sour foods can enter the sour-taste cells directly without protein couplers. This ionic (proton) transfer can then trigger electric responses (neurotransmitters) in return. In this way through the

[4]Chemoreceptor is a sensory cell or organ responsive to chemical stimuli.
[5]A tastant is the masticated food molecule being tasted.

direct and indirect hydrogen ion intake. As with sweetness, the sourness of substances is measured or relatively compared with a dilute hydrochloric acid solution with a "sourness" index of 1. Using this scale, we can see that in decreasing levels, the sourness of tartaric acid, citric acid, and carbonic acid have indexes of 0.7, 0.46, and 0.06, respectively.

- *Saltiness*—it is a taste sensation produced mainly by the presence of sodium chloride (common salt) and other sodium ionic or salt compounds. These in turn belong to the alkali metal group on the periodic table. The further from sodium the substance is, the different salt "profile" is created on the palate—this is usually manifest in a less salty taste. As with other taste sensations so the index of saltiness is connected to sodium chloride that acts as a comparative measure of saltiness. Sodium chloride has an index of 1; potassium chloride, an alternative used as a salt substitute, has a saltiness index of 0.6 (UoD, 2017).
- *Bitterness*—the opposite of acids are the bases (alkaloids). These are the bitter tones that many people find unpleasant. Many alkaloids taste bitter, and for good reason, a significant number of these natural compounds are toxic. Thus, it has been suggested, particularly by evolutionary biologists, that a distaste for bitter things evolved over time allowing people to avoid toxicity and accidental poisoning. One of the more sensitive of tastes and in moderation can be quite agreeable. Common bitter foods and beverages include coffee, beer, bitters, bitter gourd, citrus peel, chicory, and quinine (found in tonic water) (UoD, 2017).
- *Savoriness (umami)*—it is difficult to describe the savoriness that is umami, so we have added the following longer description (MSUN, 2009; Ishimaru et al., 2006; PubMed, 2016).

Traditionally, it was long thought that there were only four taste receptor types on the tongue: salty, sweet, bitter, and sour—it turns out that there is a fifth—umami (Kurihara, 2009). Umami is a word adapted from the Japanese meaning a "pleasant savory taste." The subtle umami meaty or savory flavor derives from L-glutamate (an amino acid) often abbreviated to glutamate-rich foods—and while virtually all foods contain some degree of glutamate, there are some foods in which it is rich such as Roquefort cheese, seaweeds, tomatoes, and other foods (Field, 2011). Glutamates are naturally broken down through cooking or in the enzymatic processes in meat—it also happens naturally in fermented or aged foods like soy and fish sauces, Parma ham, and various natural foods like walnuts, seaweed (especially kelp), and mushrooms. The sodium salt of glutamic acid, a nonessential amino acid, is known as monosodium glutamate (MSG), also identified as sodium glutamate. This is often added to food to enhance food flavor especially in the industrial food sector, this is so even despite the MSG backlash over the last few years. Nowadays, MSG is made through the fermentation of molasses and sugar beet and is one of the world's most popular additives. The taste itself is difficult to describe; however, the Macmillan Dictionary provides a good place to start:

> Umami is subtle and not generally identified by people when they encounter it, but blends well with other tastes to intensify and enhance flavours. It therefore plays an important role in making food taste delicious. If it helps to visualise, a familiar example of the umami taste in action is parmesan cheese, maybe not as appetising as some cheeses when eaten on its own, but creating a delicious taste sensation when sprinkled on a dish of steaming spaghetti Bolognese
>
> **(MacmillanDictionary.com, 2010).**

There are of course other sensations that are experienced through the action of chemesthesis, and these include false heat and coolness including astringency and pungency (see also Section 3.5).

3.2 SENSE OF SMELL: THE OLFACTORY SYSTEM

Of the two principal senses that detect chemicals, smell and taste are an important arsenal of tools that allows one to discern food or liquid flavor profiles. Indeed, it has been said that

> only after taste is combined with smell is a food's flavour produced
>
> (PubMed, 2016).

Our sense of smell, just like our sense of taste, is part of our chemosensory system (the chemical senses) (Barham et al., 2010). The sense of smell in this case can be described variously as aromas, fragrances, odors, or odorants, etc. While taste receptors in the mouth detect small molecules by which foods are determined, receptors of the olfactory system (aroma/odorant receptors) detect volatile molecules in the air whether from liquids, gases, or even solids. It's worth noting too that people's sensitivity to aromas varies quite significantly between individuals.

In short, there are two pathways by which a volatile substance reaches the olfactory sensory cells in humans. Firstly, the orthonasal route whereby the chemical molecule to be smelled travels through the air, as it enters the nostrils and then travels onto to the nasal receptors called the olfactory epithelium. Secondly, the retronasal route, whereby odorants enter the mouth, then spreads through the nasopharynx that is located behind and above the soft palate and then travels on toward the olfactory epithelium then back out through the nostrils (Heilmann and Hummel, 2004; Halpern, 2009). As a result of the two pathways (ortho- or retronasal), odors, when presented, tend to be perceived differently.

The complex procedure of smelling starts the moment volatile molecules detach or are released from substances from which they belong (Murray, 2017). The sense of smell happens when aromas enter the nose (orthonasally) and are detected by olfactory receptor cells (many millions of them) located at the top of the nasal cavity properly called the olfactory epithelium neuron cells,[6] (Fig. 3.1) (New World Encyclopedia, 2015). The olfactory epithelium itself is composed of three types of cells: basal cells, olfactory receptor cells, and supporting cells, all of which are covered by the mucous membrane. This membrane is also the area in which small filaments dangling from the epithelium neuron cells known as "cilia" reside. It is these cilia cells, more specifically, the membrane receptors on the cilia that bind the chemical stimuli, that collectively determine a particular aroma (Murray, 2017; Purves, 2004). The basal cells are newborn olfactory receptor cells that are transformed over a period of approximately 40–60 days, to become new olfactory receptor cells—replenishing those that come naturally to the end of their life cycle. This is in contrast to the 10-day turnaround for the gustatory cells. Each olfactory receptor neuron (or cell) interacts with just one specific type of aroma molecule (or part of that molecule), although that said, the same molecule (different sections of which) can potentially bind with other receptors, thus interacting with more than one different receptor. This combination or pattern of the receptor types (a sort of code) ultimately triggers an aroma perception specific to that molecule (New World Encyclopedia, 2015; Heilmann and Hummel, 2004).

As well as the potential for aromas to be detected orthonasally via the nasal passages directly onto the olfactory epithelium, smells are also detected retronasally. This is the process when molecules are inhaled through the mouth and exhaled through the nose stimulating the same olfactory epithelium (Heilmann and Hummel, 2004). Retronasal identification is also the case whereby the food one eats

[6]Olfactory receptors are in fact neurons rather than cells. This is different from the gustatory receptors that are cells.

is masticated by chewing in the mouth, mixed with saliva, and releases volatile molecules that are then detected retronasally.

Howsoever, aroma molecules are released; all molecules must first be dissolved in the mucosa membrane that covers the epithelium receptor cells containing mucopolysaccharides, salts, antibodies, and enzymes. Once assimilated, dissolved aromas/odors stimulate specific neuron cell receptors (cilia), which in turn identify particular aroma molecules through their unique chemical structure. This "lock-and-key" fit (which is still debated by scientists) relays specific aroma patterns from the olfactory epithelium cells through the skull bone and to the olfactory bulb (part of the limbic system[7]) (Barham et al., 2010; Ahn et al., 2011).

Going back to the cilia (the aroma receptors) in the mucosa membrane, it is understood that the cilia are stimulated necessarily not only by a single molecular structure of a molecule but also by groups of structurally similar molecules/compounds (Murray, 2017). In this way, different smells can be distinguished quite easily because one aroma receptor might recognize a range of aromas, while a number of different aroma receptors might collectively recognize just one aroma. Consequently, the pattern or combination of aroma receptors activated gives one the ability to leverage the number of smells that we can detect. Not surprisingly then, thousands of different odors/aromas can be separated this way. As touched upon earlier, people can distinguish upward of 10,000 aromas or odorants; some are at concentrations so low (in the order of a few parts per trillion), as to defy belief. Consequently, it is not difficult to see that aromas are very complex things replete with nuances and vagaries of top, middle, and bottom notes (*next section*).

Another pathway to the olfactory epithelium happens when we chew our food. As food is masticated, so saliva mixes with the food, allowing certain molecules to become volatile and released. These molecules find their way to the olfactory epithelium retronasally (Barham et al., 2010; Heilmann and Hummel, 2004; Bender et al., 2009).

So, as discussed, the nose plays more of an important role in eating food than many might consider. We have also seen that when we taste food, it stimulates special nerve cells in both the nasal cavity. More specifically though, when we talk of aroma, we are talking of the ability to detect airborne particles that come directly through the nasal passages or from the back of the mouth/throat passage (retronasal transport) to reach the olfactory epithelium cells. These neurons then pass through the skull to reach the olfactory bulb, where they are identified. The extent to which aroma plays a part in the overall taste perception can simply be tested by tasting foods while holding one's nose closed. This has the same effect as when one has a cold; in this way, it can be seen that not all the senses are being used to the fullest; as a result, food can sometimes seem tasteless. In fact when it comes to the actual separation of taste senses, it has been estimated that only 10%–20% of a tasting experience comes directly from the tongue whereas the remaining 80–90% comes from the smell or the aroma (Ahn et al., 2011; MSUN, 2009). In this way, the words "taste," "flavor," and "aroma" are often used interchangeably. To further elucidate this, in perspective, we have around 5–10 million receptors capable of detecting aromas/smell, while we only have 2–10,000 to detect taste (Murray, 2017; PubMed, 2016). Smell or aroma makes up a large part of our sense of taste (Thierry and Hannon, 2014). Hence, flavor

[7]The limbic system is a collection of connected structures residing close to the middle of the brain. Linked within the central nervous system, these structures work together affecting a wide range of specific behavior including emotions, motivation, and memory.

results from the perception of taste and odor-active volatile compounds. It is also important to note that while taste and smell processes are quite separate and distinct, the sensation of eating and drinking work together in harmony sending the brain simultaneously signals of taste, flavor, and aroma.

3.3 VOLATILITY AND AROMA NOTES

Before one can fully appreciate the specific aromatic characteristics of smell, one must first ponder the notion of volatility, that is, the ability of a compound (liquids or solids) to become a gas or vapor—the ability of something to be smelled. Volatility is an important concept not only in organic chemistry in general but also to all flavors and fragrances in general, which, by definition, must be volatile to be smelled. At its very simplest, we can think of volatility as the ease with which a substance vaporizes. The weaker the forces holding the molecules together, the higher the volatility of a liquid or solid, the easier it becomes a gaseous vapor that releases molecules into the air. It is this quality, which allows one to smell a substance (Belitz et al., 2009; Vaclavik and Christian, 2014).

From this understanding, it can then be said that when it comes to volatility, there are three main factors that need to be considered—a compound's molecular weight, the temperature of the item to be smelled, and its intermolecular forces of attraction. The first is fairly straightforward in that it doesn't take a great leap of faith to understand that heavier molecules will require more energy to vaporize and thus are relatively lower in the volatility scale. The second is related to the first; that is, the application of heat or a change in atmospheric pressure or both are required to assist in volatility. This taps into the fact that higher temperatures excite molecules more, giving them the all-important "energy kick" that helps make the transition between a substance and vapor that much easier (Vaclavik and Christian, 2014). So, whatever the initial volatility of a substance is, as one increases the temperature, so the volatility of that substance increases too. The third item, the intermolecular forces, relates to the strength of the bonds that bind atoms and molecules alike.

Armed with the above, we can say that

- volatility is the force it takes for a substance, whether liquid or solid to release molecules—sometimes referred to as vaporization;
- all substances have different volatility thresholds;
- all substances can therefore be ranked relative to each other; that is, one might be higher than another at the same temperature and atmospheric pressure;
- volatility is connected to boiling points—boiling points are connected to polarity;
- the polarity of molecules or compounds (as determined by their intermolecular forces) represents the strength of the bond between atoms and molecules;
- the stronger the polarity, the more energy required to pull the atoms apart—equals a higher boiling point—lower volatility.

From the above, it can be seen that different flavors and fragrances (foods, liquids, or chemical compounds) have different volatility characteristics. Those with higher volatile characteristics are quickly (or easily) detected, while those with lower volatile characteristics tend to either be masked by others or have to be sought out through the nose or the palate. Herein lays the distinction—and a subtle one at that—of the different "top," "middle," and "bottom" or "base" notes of flavors and fragrances. Herein, lies the art of the connoisseur.

While tastes can be defined through a limited number of distinct groups—sweet, sour, salty, and bitter—aromas are that much more difficult to classify. Characteristically, aroma attributes tend to be much wider and more diverse than tastes; they can be fruity, flowery, spicy, resinous (of smoke, etc.), foul, rancid, pungent, and even burning, among others. The following aroma wheel (Fig. 3.2) is a visual aid that helps determine types of aromas.

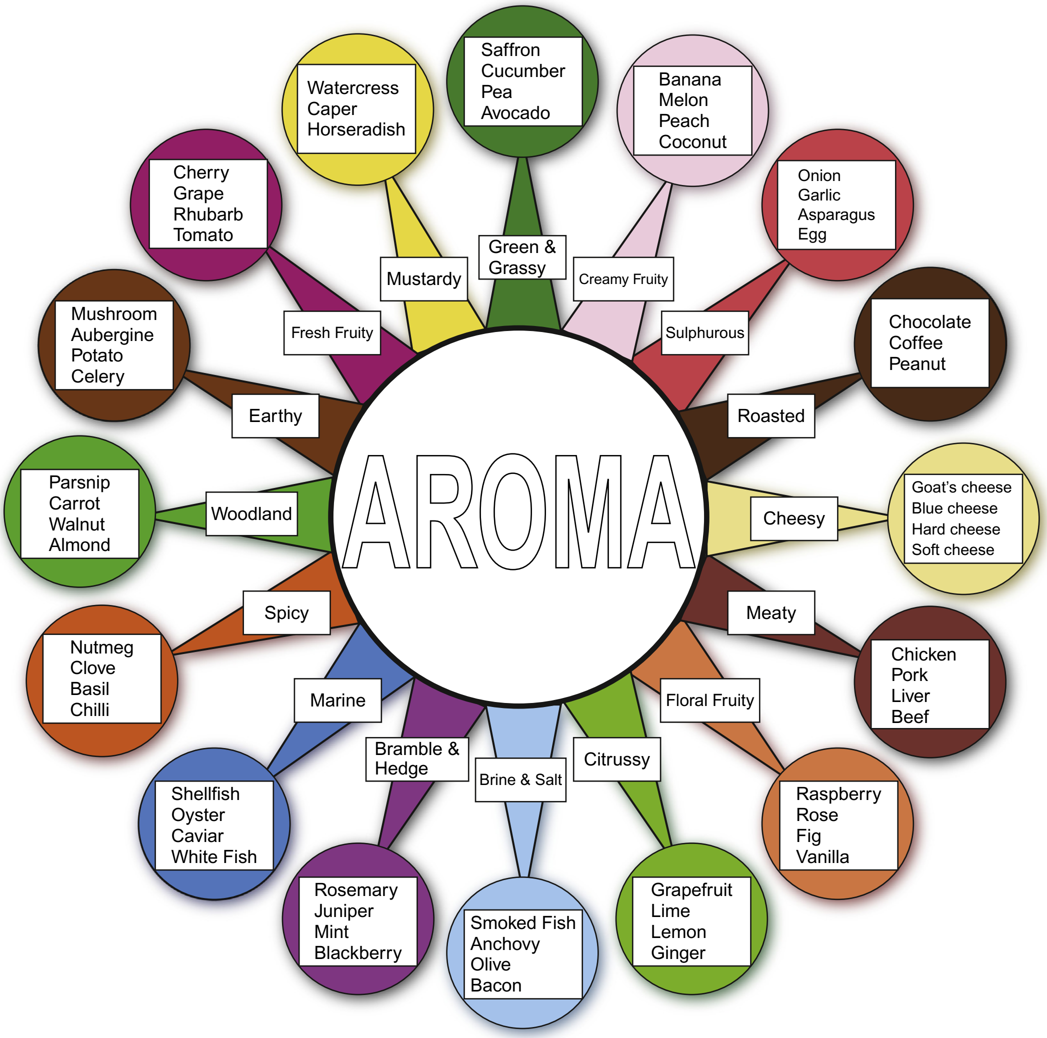

FIG. 3.2

An aroma wheel can aid in the process of identification of aroma notes.

Top notes—these generally give one a first impression, the peak notes of a substance or compound. These are usually the characteristic of the higher volatile components of a substance. In some wines, oils, and fragrances, these top notes often comprise the citrus, fresh, or green tones or notes.
Middle notes—these are thought of as the heart of compound. These usually unfold a few moments after the top note and are typical of the intermediate volatile substances. These can commonly be floral and aldehydic in nature.
Base notes—these are the "also rans" or "also founds"; this is often the clinging fragrance. The scent that remains the longest—the lower volatile compounds reminiscent of woody, powdery, or musky tones. Calling them the "also rans" is possibly a huge disservice as, despite this nomenclature, the base notes are an important dimension to any wine, oil, or fragrance.

With the above in mind then, the chemical composition of any compound being smelled or tasted and the concentration of its key volatile substances determine the individual notes of that substance and the collective overall impression. So, from this little excursion, we can see that volatility, temperature and polarity are all related. In order to understand the mechanics of this concept in more detail, it is worth reading the organic chemistry section of these appendixes (Appendix B).

3.4 SENSE OF TOUCH

It is not only the olfactory but also the gustatory senses that need to be considered when enjoying food. Physical touch provides the sensation of the texture of food too. From vision and the perception of texture, through to handling of the food (somesthesis[8] and kinesthesis[9]). During consumption, too, the oral processing, or masticating of foods is important to the overall sensations of taste and smell as there is a marked difference between the food when it first enters the mouth and the wetted bolus[10] that is subsequently swallowed. Thus, it can be said that, the whole process is the

> …summation of sensory impressions during the whole process from seeing the food, picking it up and putting it our mouths, chewing it, and eventually swallowing it…
>
> (Barham et al., 2010)

that we perceive as the texture of the food.

3.5 CHEMESTHESIS

As food is eaten, it activates receptors associated with senses in the mouth and nose like touch, taste, smell, and volatility. Mouths too also detect the temperature of foods; however, this sensation can be manipulated. In chemesthesis, chemical-induced reactions do not fit the traditional senses of taste and

[8]Somesthesis—sensory systems associated with the body includes skin senses and the internal organs.
[9]Kinesthesis—the sensation of movement or straining muscles, tendons, and joints, muscle sense.
[10]Bolus—a small rounded mass of a substance, especially of chewed food mixed with gustatory fluids at the moment of swallowing.

smell, but rather give the impression of false heat and false coolness. False coolness occurs when some substances activate cold trigeminal[11] receptors triggering a "cool," "fresh," or "minty" sensation in the mouth. Foods such as spearmint, menthol, ethanol, and camphor are in this category. Another phenomenon is false heat caused by chilies, ginger, mustard, horseradish, etc. This perceived burning sensation is induced by a trigeminal nerve reaction too (MSUN, 2009). The perceived heat or the "hot" or "spicy" in these cases is caused by food activating the same nerve cell ion channel as activated by hot temperatures. Such sensations of false heat and false coolness are often referred to in terms of freshness, astringency, spiciness, pungency, or piquancy, for example. Two in particular are worth looking at in more detail.

3.5.1 ASTRINGENCY

As mentioned above, for example, that dry-mouth constricting, puckering feeling that follows a sip of strong tea, red wine, or a bite into an unripe banana, is not quite a taste sensation nor an aroma. Instead, it can be thought of as a tactile sensation, a chemesthetic reaction that arises when certain chemical compounds like tannins activate receptors normally associated with other senses that mediate pain, touch, and thermal perception. Astringency physically constricts organic tissue, and the phenomenon is not widely known; instead, it is sometimes known by other terms including hard, dry, harsh, and sometimes tart (although this normally refers to sourness) (Vaclavik and Christian, 2014).

3.5.2 PUNGENCY

The painful irritation caused by chilies (active ingredient—capsaicin), mustard (active ingredient—allyl isothiocyanate (AITC)), horseradish (also allyl isothiocyanate), and black pepper (piperine), for instance, is also a chemesthetic reaction that lies somewhere between touch taste and smell. These were and still are originally intended to repel animals and humans from eating the foods in question. Some elements of these foods do actually do mild damage to the unprotected cell membranes in our mouths and nasal passages. This causes actual pain and chemesthetic pain. The receptors in the mouth lining responsible for recognition of such chemicals are the same receptors meant for registering physical pain from actual heat in the mouth. As a result, the body responds in certain ways. First, it releases sweat from sweat glands in order to cool the body and also flush out aberrant substances. This is why people sweat when eating chili, mustard, pepper-based foods, etc. The body also excretes more saliva to diffuse or flush out the offending foods. Lastly, the body generates endorphins, the body's natural painkillers. Cooking, however, will moderate the pungency of many, but not all of these types of foods.

3.6 FLAVOR

After a look at many processes involved in the perception of flavor, it has been noted that flavor is mainly a combination of the two sensations—taste and smell. Taste is perceived on the tongue and nearby regions, while smell is perceived in the upper nasal passage. In other words, flavor is the sensory impression of a food or beverage as determined by the collective chemical senses. We have also seen

[11]The trigeminal nerve sends messages to the brain.

that in the process, "smell" is the biggest factor in the flavor of our food and drinks. Indeed, smell receptors are almost limitless in their ability to detect aroma compounds. That is, not all in a scientific context flavor may be defined as

> …the complex combination of the olfactory, gustatory, and trigeminal sensations perceived during tasting. The flavours may be influenced by tactile, thermal, painful and/or kinaesthetic effects and expectations from visual presentation of the product
>
> (**Barham et al., 2010**).

This is why a food's flavor can be manipulated in a multitude of ways using texture, fragrance, or flavor compounds.[12] Take jellies of a similar taste; for example, simply by adding certain flavorings of a mainly odorific type, the jellies flavor can be altered in numerous subtle fashions. In this way, a food flavor can therefore be altered relatively easily simply by changing its odorific profile while keeping its taste similar.

3.6.1 NATURAL AND ARTIFICIAL FLAVORINGS

Flavorants focus on altering or enhancing the flavors of food products from meat to vegetables to candies and more. However, the definition of a flavorant is difficult to determine precisely as in the United States; for instance, the Food and Drug Administration's definition includes anything that contributes flavor to food:

> The term natural flavour or natural flavouring means the essential oil, oleoresin, essence or extractive, protein hydrolysate, distillate, or any product of roasting, heating or enzymolysis, which contains the flavouring constituents derived from a spice, fruit or fruit juice, vegetable or vegetable juice, edible yeast, herb, bark, bud, root, leaf or similar plant material, meat, seafood, poultry, eggs, dairy products, or fermentation products thereof, whose significant function in food is flavouring rather than nutritional
>
> (**FDA, 2015**).

While for artificial flavoring, the definition of the same code suggests that

> The term artificial flavour or artificial flavouring means any substance, the function of which is to impart flavour, which is not derived from a spice, fruit or fruit juice, vegetable or vegetable juice, edible yeast, herb, bark, bud, root, leaf or similar plant material, meat, fish, poultry, eggs, dairy products, or fermentation products thereof. Artificial flavour includes the substances listed in 172.515 (b) and 182.60 of this chapter except where these are derived from natural sources
>
> (**FDA, 2015**).

Flavorants are focused on scent and taste; for the purists, however, the problem is natural flavorings tend to be rather more expensive than the "nature-identical" chemical equivalent synthesized flavorings. The European Union has a similar stance on the above although certain flavorants are given an "E" number, which may or may not be artificial in nature. For artificial flavors, the flavor and fragrance

[12] While the terms "flavoring" or "flavorant" in lay terms denote the combined chemical sensations of taste and smell, the flavor and fragrance industries use the same terms to refer to edible chemicals and natural extracts that alter the flavor of food and food products.

industries must create a nontoxic artificial compound that denotes a specific flavor. Just like their natural counterparts, most artificial flavors are often complex mixtures of naturally occurring flavor compounds combined to either imitate or enhance a particular flavor (MSUN, 2009). As counterintuitive as it sounds, artificial flavors are an essential component in the flavor and fragrance industries if only to ensure that a batch of recipes maintains a consistent profile. Curiously too, just because something that is of a natural origin does not necessarily make it safe, and by contrast, artificial flavors might, in some instances, be considered somewhat safer to consume than their natural counterpart. This is due to the high standards of purity, consistency, and testing required of certain regulations.

Note—Umami or "savory" flavorants more commonly known as "taste enhancers" are based largely on amino acids and nucleotides.[13] These are manufactured as sodium or calcium salts such as glutamic acid salts.

> This amino acid's sodium salt, monosodium glutamate (MSG), is one of the most commonly used flavour enhancers in food processing
>
> **(MSUN, 2009).**

3.6.2 FLAVOR VARIATIONS

Of course, the flavor of plants depends on many factors from the various variety of a single species being grown to the way it is stored and prepared. Wine is a good example here; different grape varieties produce different flavored wines; even the same grape varieties grown in different soils and climates will produce a unique tasting wine. In fact, this phenomenon is not unique to grapes but in fact can be applied to all fruits and vegetables and meat and fish. Not only does the growing of goods affect flavor, but storage too also affects the way the flavors are concentrated or lost. In aromas too, much scientific effort has gone into trying to understand the chemical reactions that produce volatile aroma molecules. Cooks, by contrast, work mostly on experience and intuition backed up by an empirical understanding of techniques and processes that is the art of cooking.

The scientific approach clearly has an advantage in its objectivity and reproducible results despite given variations in ingredients used. Although a major setback in the scientific approach (and to some extent the traditional cooks approach) is the lack of a vocabulary to aid in distinguishing the nuances of both aromas and flavors (Barham et al., 2010).

3.7 COLOR OF FOOD

Alongside taste, smell, and texture, another factor to consider when describing foods is that of color; in the culinary world, for example, color sets up expectations of what we are about to eat. When the bright richness of green vegetables and red fruits are at their peak, the mouth salivates with expectations of freshness, juiciness, and flavor. This is also true of raw and cooked meats. Nowadays, the quality of meat is often judged by its immediate appearance; therefore, discoloration of meat is for many consumers, unacceptable (Barham et al., 2010). The color of meat is determined mainly by myoglobin

[13] *Nucleotides* are organic molecules that serve as the subunits of nucleic acids.

whose physiological function is that of oxygen storage in muscles. In avoiding or reducing the myoglobin oxidation, some retail venders now pack their meats in controlled or modified atmosphere packages in order to maintain the cherry red color for longer.

Pigments, the chemical compounds that reflect certain wavelengths of light, are responsible for the color of many foods we eat. Depending on the pigments involved depends on which wavelengths are absorbed. Because of this, pigments are useful to plants and other autotrophs in making their own food via photosynthesis. There are three basic classes of pigments: chlorophyll,[14] the carotenoids, and the phycobilins; however, we are only interested in the first two.

When it comes to fruit and vegetables, we can see that pigments play important physiological roles in living plants. The chlorophyll pigments in green plants, for instance, match the spectrum of sunlight for optimal conversion of light to chemical energy. In other plants of a different hue, like the blues, reds, or yellows, for example, we learn that these pigments belong to several classes of chemical compounds chief of which are the carotenoids and polyphenols. Carotenoids, also known as tetraterpenoids, are organic pigments that are found in chloroplasts[15] and chromoplasts[16] of plant cells and in other photosynthetic organisms including some bacteria and some fungi. Used primarily in the photosynthetic process, that is, the absorption and transformation of light's energy, there are over 750 naturally occurring carotenoid pigments (LPI, 2017). They are generally classified as carotenes (red and orange pigments) comprising alpha-carotene, beta-carotene, and lycopene, and xanthophylls (yellow pigments) including beta-cryptoxanthin, lutein, and zeaxanthin. Carotenoids produced in plants are also responsible for the bright red/orange colors of ripe tomatoes and carrots.

At the same time, we humans have adapted so that the bright green, red, or orange color of fruit and vegetables, for instance, provides us with the sense of perceived freshness. These carotenoids can also be passed along the food chain, providing color to other organisms. A prime example of this phenomenon happens when certain pink phytoplankton's pigmentation is transferred to krill then onto shrimp and eventually salmon. This is why when farmed salmon are fed artificial diets, their food mix is colored with pigment to mirror those found in the wild (Barham et al., 2010). Furthermore, while staying with color pigmentation, it can be seen that certain foods absorb certain amounts of color depending on seasonal variation and the food they in turn eat. Free-range chickens, for example, have access to a much wider variety of foods, so their diet is less restricted—in this way, free-range egg yolks[17] tend to have a darker, richer color than their industrially raised brethren.

Carotenoids are also useful in the health and diet of humans too. Fruit and vegetables are responsible for the greatest proportion of carotenoids (40–50) that form part of the human diet, while four carotenoids in particular, alpha-carotene, beta-carotene, gamma-carotene, and beta-cryptoxanthin, are also incidentally useful as provitamin A in the visual cycle[18] of humans (LPI, 2017).

[14]Chlorophyll, a green pigment, presents in green plants and in cyanobacteria, which is responsible for the absorption of light that provides energy for photosynthesis.
[15]Chloroplasts' main role is the action of photosynthesis, where it captures the energy from sunlight and converts it and stores it in energy-storage molecules.
[16]Chromoplasts are plant cells containing yellow or orange pigment.
[17]The color of an egg yolk is from the xanthophyll carotenoids—lutein and zeaxanthin.
[18]The visual cycle in humans is the biological conversion of light into an electric signal for the brain.

3.8 TEXTURE IN FOOD

The overall appeal of a particular food is determined not only by its flavor but also by its texture. Imagine a potato crisp; a crisp crunch is what is expected, but if allowed to go soggy, then the flavor is perceived differently, somehow not right. The same is true of limp salad greens or of ice cream that is not smooth enough due to large ice crystals contained within. All in all, texture of the food plays an important role in the overall flavor experience. Not surprisingly then, it follows that the creation, control, and modification of texture is therefore an important aspect of any skilled cook. Indeed, in a cook's parlor of tricks, they learn how to modify meat textures through tenderization, marination, and cooking. They prepare sugar sculptures resembling glass figurines. They make the lightest soufflé's and flavorsome hollandaise emulsions. Yet, when it comes to the science of the "what" and the "how" of what they do, they are left mainly a little in the dark. As Peter Barham puts it,

> A glance at any cookbook on how to produce a simple mayonnaise shows that many cooks do not have even a basic grasp of thermodynamics of emulsification
>
> **(Barham et al., 2010).**

That said, he does show optimism in the following:

> The understanding of the biological and physical chemistry to control texture in, for example, emulsions, gels, foams, and glasses has an enormous range of potential applications to produce foods of novel and interesting textures in the kitchen
>
> **(Barham et al., 2010).**

3.9 REACTIONS AFFECTING FLAVOR

Raw ingredients contain a vast array of naturally occurring flavors, for example, fragrant raspberries, sweet pumpkins, mildly acidic apples, and sharp limes. Yet, many of our most favored flavors actually do not occur naturally but are in fact created by chemical reactions within and between the food ingredients post harvest (Barham et al., 2010). Put another way, without processing technologies and chemical reactions, there would be no chocolate, no coffee, and no "meaty" flavors from the Maillard reaction, etc. (Section 5.1.2). Thus, collectively, flavor development arises from a wide variety of pre- and postharvest chemical, physical, and biological reactions as we nurture, grow, store, prepare, and cook our foods. Some reactions occur even before we start any cooking. Some happen in the ground as different soils and climates ultimately affect the foods as they grow. The same foods grown in rich, moist irrigated, and fertilized soils, for example, will taste different if grown in dry, arid, nonfertilized conditions. Another example is the different flavor profiles of grass versus grain-fed beef. Other examples include the physical processing of certain foods during cutting or mincing, fermentation or marination, for example. This is not to mention further reactions during cooking and processing including those of hydrolysis, oxidation, and Maillard and caramelization reactions (Barham et al., 2010).

In many cases when it comes to fresh ingredients, the first stage of processing involves the cutting or physical breaking down of food items into smaller pieces. The very act of fracturing the cell walls leads to the immediate release of enzymes and the start of enzymatic reactions that, given sufficient time, temperature, and moisture, can alter the flavor and texture of the product in use. This is why in many living plant and animal cells, enzymes are compartmentalized—separated naturally from their substrate so as to avoid self-destructive enzymatic reactions in the living body. However, upon harvesting if the cellular structure is cut into, or is otherwise destroyed, flavor-altering enzymatic reactions begin to occur. Yet, it is interesting too to note that heating or cooking of these meat and vegetable enzymes above a certain temperature becomes denatured (see Section 4.2) and their enzymatic powers arrested.

3.10 TASTING NOTES: FOOD-PAIRING

A theory, which suggests dishes, recipes, or plated accompaniments that share similar flavor compounds are more likely to taste well together than those that don't, has received much attention over the last decade or so (Ahn et al., 2011; Varshney et al., 2013; Kort et al., 2010; Møller, 2013). It has even been said that Blumenthal and Lahousse are practitioners of the theory and use food pairing as a tool to inspire new dishes (Kort et al., 2010). Not only does the theory carry weight at the top echelons of various industries from culinary to food processing, but also there is a whole stack of science that helps pair foods. This is usually achieved by chemists and food scientists who identify and compare numerous foods, which in turn are paraded in fashionable food pairing trees (Ahn et al., 2011). However, a database of volatile compounds in food, which was started way back in 1963, was employed to evaluate the food pairing theory; that is, the notion that two foods sharing the same major volatile molecules would taste nice when eaten together. However, in a sensory analysis experiment, results indicated there was some doubt as to the validity of the food pairing theory (Kort et al., 2010). Moreover, in another, more in-depth global analysis, focusing on food pairing by Ahn and colleagues (2011), they examined and analyzed the cuisine habits of several regions around the world. In their conclusion, it was found that the cuisines of both the North American and Western Europeans revealed significant tendencies for recipes that shared similar flavor compounds. By contrast, however, it was also shown that both the cuisines of East Asia and Southern Europe tended to avoid dishes whose ingredients shared similar flavor compounds (Ahn et al., 2011). In conclusion, food pairing based in similar flavor contents is not looking good as a universal theory (Møller, 2013). Instead, what the data are telling us is the idea that similarly flavored foods might work in some foods and in some regions, while nonsimilar or contrasting flavored foods work in other regions.

From these and other observations, one can confidently say that when it comes to taste combinations or the matching of flavors; as a rule, there is no right or wrong. That is to say, flavor pairing has always been and will always be to a large extent subjective. However, this does not necessarily mean food pairing is without rules or experiential knowledge. Indeed, while it is generally seen as an art form or a form of craftsmanship, there is a modicum of science thrown in too. So, as has been shown, there are several schools of thought with regard to the matching of flavors of different foods or even wines and foods for that matter. For simplicity sake, though we can think of the task of matching flavors as comprising two main branches—complimentary and contrasting. In this regard, it has been noted that the Western palate generally relies heavily on food pairing of similar flavorants while the East Asian and Southern European palates tend to avoid these, relying instead on contrasting flavors (Ahn et al., 2011).

Taking these findings to their logical conclusion, it can be said that nearly all meats, vegetables, and fish benefit from both complimentary and contrasting flavors whether from the Asian or Western larders. This is an important concept and one worth remembering. The same food that one serves with the same complimentary sauce or garnish might also benefit from a sauce that is contrasting in nature and flavor. There are some cooks who have an uncanny or a natural ability to marry certain foods without much consideration or forethought of the science behind what they are doing. For most of us, however, the art of "flavor pairing" has to be learned. Take, for example, a Dover sole; there are many ways in which this is regularly served, and cooks will often create a dish from instinct with little regard to their own thought processes involved. Absolutely, there is nothing wrong with this as this tendency comes with or is developed with experience. Dover sole contains just over 1% fat; now, this author, for one, does not consider this be too much fat at all, although once again, the matter is a subjective one. So, back to the sole, with a low-fat content, oftentimes, one might come across dishes that complement the sole with added fat in the form of a "nut-brown" butter that at once, because of the butters' soft creamy after-palate taste, combines to enhance the delicate flavor of the fish. An opposite or contrasting approach, and one equally acceptable, is a simple minimal butter glaze and a contrast tartness provided by a smattering of lemon juice. Of course, the two are sometimes combined to experience yet more complex sensations. Another example is to take foods richer in fats such as duck or some cuts of lamb. In this instance, the fattiness of both meats benefits from a contrasting acidity that cuts through the cloying oiliness, something like vinegar and mint for the lamb or a nice tart red-berry sauce with the duck are not uncommon. The art here is to choose the right acidic vehicle, the right amounts, and the right complimentary or contrasting flavors. As an aside here, fat in foods is an important carrier of flavor. Others still, mainly scientists and enthusiasts of the trend, go to great lengths to use gas chromatography-coupled mass spectrometry (GC-MS) results to work on unique and novel pairings. Note that this approach works on mainly complimentary flavor compounds that share similar flavor characteristics. Little research has considered the alternative scenario (Ahn et al., 2011).

In sum, in the pursuit of flavor pairings, some have relied heavily on science. One approach uses the chemical analysis of a foods' gas chromatographic profile to determine the makeup and relative strength of each molecule. The product's flavor profile is then compared to a database of other food and beverage products. Products that have flavor components in common with the original ingredient are grouped together accordingly. The results are then often graphically presented on a food pairing tree similar to the one shown below in Fig. 3.3 (Ahn et al., 2011; Møller, 2013; Kort et al., 2010).

Others still use their own skill and intuition and draw on generations of experiential knowledge in their pursuit of flavor pairings, whether complimentary or contrasting in nature. The point is that both complimentary and contrasting flavors are equally important. Although, the greatest sin, and a cautionary note here, is the practice of overpowering a dish with any flavor or flavor combination that, rather than enhancing a particular dish, simply masks or alters it completely. Get this basic premise right, and one can experiment to their hearts content and remember, as a subjective art, what works for one person might not work for someone else. The cook's difficulty here lies in that he/she is not cooking for him- or herself but is rather trying to appeal to the wider, mass audience. In this sense, the cook often might balance a menu with some proven flavor combinations and then add one or two dishes that push the boundaries and challenge widely held perceptions. Therein lays the art of an experienced professional or accomplished home cook.

From the preceding foray into the world of flavor, it can be said with great confidence that flavor, for all its complexities, turns out to be more of a composite organoleptic sensory perception than a

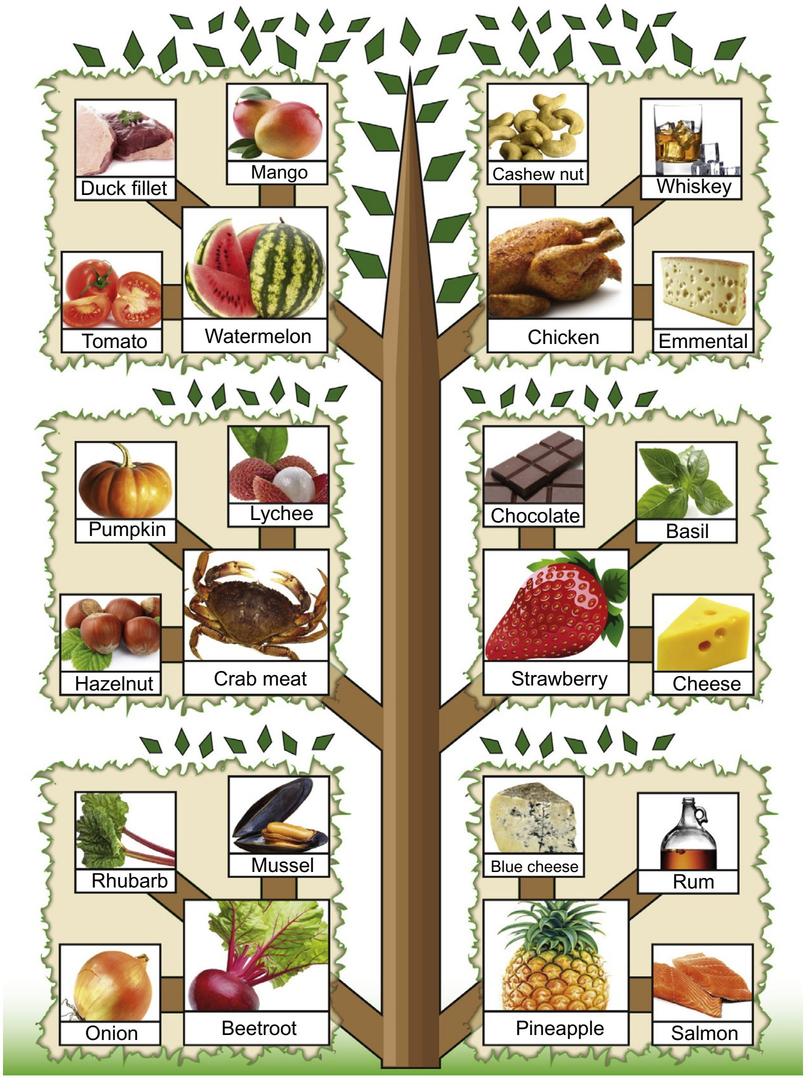

FIG. 3.3

A food pairing tree.

stand-alone sense. It is a combination of sensations that utilizes the eyes, drawing on visual cues that excite and stimulate; the taste buds, with their limited variability; and aroma, with its complex and somewhat sophisticated mechanisms. So, while there are just a scant handful of different tastes that can be leveraged, there are many thousands of different odors and colors to match (MSUN, 2009; Barham et al., 2010; Vaclavik and Christian, 2014). From there, neurotransmitters send signals to the brain about the flavor sensation of a particular food.

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