A Fragrant Feast

Using tools from chromatography to genetic engineering, flavor technologists work to improve our dining experience.

Flavor is made up of the chemical interaction of molecules from food and drink with the taste and aroma receptors in the human mouth and nose. Taste, in fact, is often the least important in differentiating between flavors. There are only five major taste receptor types—bitter, sweet, sour, salty, and umami (the unique flavor typified by MSG). The vast number of flavors we perceive are the result of the complex mixture of these few taste flavors acting on our taste receptors and on the interactions of chemical volatiles in food and drink that react with our even more discriminating scent receptors (of which there appear to be nearly a thousand types).

The identification, purification, synthesis, and transformation of these chemicals to improve food and beverage flavor represents chemistry at its finest. Changing or maximizing the flavor of foods to enhance the sensory experience has become ever more sophisticated. The food processing industry is even using enzymes from genetically modified organisms (GMOs) to boost flavor. But it remains the interaction of specific chemicals with receptors that serves up the courses of this increasingly mutable feast.

Patterns of Palette

So what is the basis of the chemistry of flavor? Improving flavor involves enhancing the "good" tasting and smelling molecules and diminishing or covering up the bad. Determining what these molecules are is a combination of analytical chemistry and human testing. Chromatography and spectroscopy are key to the isolation and identification of molecules for analyzing, improving, and commercially monitoring food flavors. Although the human nose and palate are the ultimate arbiters of "good taste", once that connection has been made, instrumentation can take over the process.

In addition, once flavor-specific compounds are determined, there are several ways to incorporate them into food products as

☐ simple chemical additives—whether synthesized or purified;
☐ genetically selected (or genetically engineered) "natural" accessories to the raw product;
☐ the result of processing modifications of the raw product using enzyme treatments or biological fermentation (such as with yeasts in beer, wine, and bread, as well as bacteria and molds in dairy products).

The Matter of Taste

The five basic taste receptor types are finally being elucidated using molecular biology. In the past few years, putative receptors have been identified for the bitter and sweet tastes perceived by humans. More recently, researchers at the Howard Hughes Medical Institute (Chevy Chase, MD) identified the receptor for umami.

Chemically, the other components of flavor due to taste are also fairly simple. Sweet tastes are generally associated with organic molecules such as sugars and alcohols. Salty tastes are the response to ionic solutions in which the cation dominates the degree of saltiness—the larger the anion, the less saltiness detected at the same concentration. Sour tastes such as that of vinegar are caused by the presence of hydrogen ions, but the anion affects the intensity of sourness that is detected. Bitter tastes are associated with organics, many of them poisonous, and the disagreeability is thought to be an evolutionary protection against many naturally occurring toxins. Specific, unique tastes are thought to be created by different patterns of firing of the five types of taste receptors in response to a complex food.

Scents and Scents-ability

But the true subtleties of flavor are primarily found in the aromatics, sensed through smell rather than taste. By definition, aromatics are volatile chemical molecules that diffuse to the olfactory epithelium in the upper part of the nose. The number of uniquely discriminated odors (in the low thousands) is more than an order of magnitude larger than the number of tastes (in the low hundreds).

Because aroma compounds are volatile, they disappear quickly and thus have to be stored in some fashion and released only when needed, as in flowering plants that attract insects for pollination and fruiting plants that attract animals to spread seed. Typically, many aroma compounds occur as glycosylated moieties that only become volatilized when the sugar components are removed by the activity of a variety of glycosidase enzymes. This is readily apparent in fruit species in which the sugar-free moieties liberated by glycosidase activity volatilize to provide the classic fruit scents.

Some Character Impact Compounds

Chemical	**Associated Food**
Eugenol	Cloves
4-Pentyl isothiocyanate	Horseradish
Ethyl-2-methyl butyrate	Apple
4-(p-Hydroxyphenyl)-2-butanone	Raspberry
1-Octen-3-ol	Mushroom
(Z)-3-Hexanol	Tomato (fresh)
2-Ethyl-6-vinylpyrazine	Potato (baked)

But how is it that we can detect one food uniquely from another? Is it all because of the components of flavor generally, since there can be dozens in a complex natural food, or is it due to what researchers refer to as “character impact compounds”—the one or few molecular species that seem to overwhelmingly define the flavor to the human palate? In fact, character impact compounds are at the heart of the flavor industry—the tastes or scents that define for us “butter” (2,3-butanedione), “banana” (isoamyl acetate), “blue cheese” (2-heptanone), and a host of other foods and flavors we seem to recognize instantly. It is here that the chemist is critical in providing structural analysis of the molecules in question, as well as in providing synthetic methods for producing the compound or variations that may have improved or altered flavor properties.

Often, however, chemical impact compounds are proving necessary, yet insufficient, to satisfy the growing sophistication of modern consumers. Indeed, vanillin (synthesized for use as imitation vanilla) is the chief character impact compound in vanilla beans and natural vanilla extract, but the accessory flavor compounds in a variety of configurations add the subtleties that appeal to true gourmets.

Small quantities of otherwise objectionable flavors can also have major impact on food acceptability. One of the most striking examples of this is cited by R. J. McGorrin of Oregon University: “At high concentrations, 4-mercapto-4-methyl-2-pentanone ('cat ketone′) has an off-odor associated with cat urine, but in the context of Cabernet Sauvignon wine, it provides the typical flavor impression of the Sauvignon grape.” And this is not to mention those authentic “off-flavors” that humans shy away from—presumably as a natural evolutionary protection against eating spoiled foods—that usually result from enzymatic breakdown of natural compounds, especially proteins, and have the effect of making food taste unacceptable.

Enzymes and Eats

A wide variety of enzymes are used to develop food and flavor additives and to modify the taste and consistency of foods themselves. These enzymes have traditionally been derived from naturally isolated or bred plant, animal, or microbial sources and have been added to various stages of food processing from beverage production to cheese making and from tomato canning to bread baking.

The basic enzyme types used in food production are hydrolases, isomerases, ligases, lyases, oxidoreductases, and transferases. Under these general categories are a host of enzymes fulfilling every function in food processing from juice extraction (pectinases) to dough structure control (certain proteases) to flavor release (glycosidases).

Since the mid-1980s, many of the enzymes used in food production have been derived from genetically engineered microbes. These specially selected enzymes from optimal flavor-producing sources are made more efficiently (and cheaply) by GMOs, from which they are purified and used as reagents. One of the most interesting cases is that of the enzyme chymosin, which helps to clot milk protein to make cheese. Traditionally, chymosin for cheese making was purified from the stomach walls of slaughtered calves. Researchers cloned the calf enzyme and inserted it into bacteria where it could be mass-produced in fermentation vats and subsequently purified for food production at vastly improved cost savings, especially as veal consumption is significantly down in the United States. The use of such chymosin is theoretically an animal rights breakthrough, but it is often decried because genetically engineered materials are anathema to many of the same constituencies as the most vocal of the animal rights groups. However, for true vegetarians, as well as for people desirous of having what many consider a Kosher hard cheese, the product serves a valuable function above and beyond cost savings. So popular has the product become among dairy manufacturers that more than 60% of hard cheese production in the United States uses the engineered enzyme.

According to the U.S. Food and Drug Administration (*Code of Federal Regulations,* 21, Section 101, 22 (a) (3)), natural flavors are defined as “the essential oil, oleoresin, essence or extractive, protein hydrolysate, distillate, of any product of roasting, heating, or enzymolysis, which contains the flavoring constituents derived from a spice, fruit juice, vegetable or vegetable juice, edible yeast, herb, bud, bark, root, leaf or similar plant material, meat, seafood, poultry, eggs, dairy products, or fermentation products thereof whose significant function in food is flavoring rather than nutrition.”

Because of this definition, in the United States and in other countries with similar regulations, if the result of using an enzyme from a GM microorganism is a “natural” product, then the process involved in producing it is considered irrelevant. This helps to maintain the designation of “natural flavors” even for biotechnology-derived products. Many people battling the development of GMOs find the use of the term “natural” an outrage when they discover it can be used for foods that use products derived from GMOs.

In some cases, microbial fermentation is used to produce a variety of flavors. Everyone is aware of the role of yeast in beers and wines and of lactobacilli in yogurt. But microorganisms are also used to produce specific natural flavors that are then purified for use as food amendments. For example, certain yeasts are used to produce isovaleraldehyde (a chocolate flavor base).

From Palette to Palate

Ultimately, flavor compounds are the final step of a significant series of chemical modifications of natural plant or animal products. Flavor production can now occur equally in nature or in the industrial fermenter where modifications can be made using purified enzymes (from natural or genetically engineered sources) or via synthetic reactions. And, although in nature metabolic pathways of individual organisms limit the variety of flavors, in the lab, all bets are off. For the first time in human history, an expanding palette of natural and designed tastes and aromas is becoming available to food scientists, setting the stage for a feast for the senses of potentially infinite mutability. And that is even before the foods reach the kitchen or the cook.

There does remain one caveat, however: whatever the optimism of our increasing understanding and control of tastes and smells, none of this can explain why flavored cough syrup still tastes like it does.

isoamyl acetate	banana (alarm pheromone of honeybee) (fruity, banana, sweet, fragrant)
ethyl butyrate	pineapple (fruity, fragrant, sweet, ethereal, banana-pineapple undertones)
isobutyl propionate	rum (heavy floral)
methyl anthranilate	grape (fruity, grape)
benzyl acetate	peach (sweet, floral, fruity, fresh)
methyl butyrate	apple
octyl acetate	oranges (fruity, floral, jasmin, herbaceous)
isopentenyl acetate	"juicy fruit" (green, banana, bergamot)
n-propyl acetate	pear (powerful celery odour)
ethyl phenylacetate	honey (sweet, honey)
isopropyl 2-methylbutyrate	fruity, sweet, ethereal, green, oily, tropical with pineapple nuance
2-methyl-2-pentanal	powerful, grassy, green, slightly fruity
diethyl sebacate	melon, wine, fruity, quince
benzaldehyde	bitter almond, fragrant, aromatic, sweet
ethyl formate	sharp, ethereal, sweet, rum, pungent
ethyl acetate	pineapple, ethereal
ethyl propionate	sweet, fruity, ethereal, rum, fragrant
ethyl acrylate	intense, harsh, fruity
ethyl benzoate	heavy, floral, fruity
ethyl cinnamate	sweet, honey, balsamic, cinnamon, plum
ethyl decanoate	brandy, oily, fruity, grape
ethyl heptanoate	wine-like, brandy, fruity
ethyl hexanoate	powerful, fruity, wine-like, apple, banana, brandy
ethyl octanoate	fruity, floral, banana, pineapple, brandy, pear
ethyl nonanoate	slightly fatty, oily, nutty, fruity
1-octanol	sharp, fatty, waxy
2-octanol	fatty, oily, earthy, citrus
3-octanol	oily, nutty, herbaceous, melon, citrus
octanal	fatty, citrus, honey on dilution
heptanal	oily, fatty, heavy, woody, penetrating, sweet, nutty or fruity on dilution
isoamyl alcohol	fusel oil, whiskey
vanillin	sweet, vanilla, chocolate, fragrant, malty, caramel
benzyl ether	spicy, sweet, mushroom, fruity, almond
2-methoxy naphthalene	intensely sweet, floral, mild orange blossom
4-hydroxybenzaldehyde	sweet, woody, balsamic
salicylaldehyde	pungent, phenolic odour, spicy, almond taste
L-Glu	virtually odourless
Gly	odourless, slightly sweet taste
2,6-dimethoxyphenol	smoky, bacon
hexyl acetate	apple, cherry, pear, floral

skatole	mothballs, putrid, decayed, fecal, jasmin on dilution
valeric acid	putrid, fecal, sweaty, rancid
methyl thiobutyrate	putrid, rancid, sour, pungent, cabbage, garlic, cheese on dilution
butyric acid	sharp, cheesy, rancid, sweaty, putrid, sour
butylamine	fishy, pungent

Anise, lemon, lime, creamy, floral (blossom, carnation, gardenia, geranium, hawthorne, hyacinth, iris, jasmin, jonquil, lilac, lily, marigold, narcissus, rose, violet), meaty, medicinal, minty, mossy, musty, pepper, smoky, soapy, spicy, sulfurous, vegetable, waxy, woody.

1. How do we taste the taste?
2. What is the difference between taste and flavour?
3. How many major taste receptors can you name?
4. How many scent receptors do we have?
5. Are taste receptors more discriminating than scent receptors?
6. What does react with our scent receptors?
7. What are the tasks of food chemists in the area of taste chemicals?
8. Why do we want to change the flavour of food?
9. Which part of GMOs in used to increase flavour of food/
10. What could be done to improve the taste of food/
11. Could the taste research use only analytical methods? Why?
12. Which techniques are used in taste research? What for?
13. Could the machine replace human sensors at every stage of taste research?
14. How the food could be changed to improve its taste?
15. What kind of food is subjected to yeast fermentation?
16. When a mold is a good sign?
17. Did molecular biology identify receptors for all tastes?
18. Who did find the receptor for umami?
19. Could you use any alcohol to sweeten your food?
20. Is sodium iodide saltier than sodium chloride?
21. Does the sour taste depend only on pH?
22. Are all bitter compounds poisonous/
23. How did evolution protect humans against natural toxins?
24. Could the result of collaboration of all five kinds of taste receptors be predicted?
25. Is there a difference between the aromatic compounds and aroma compounds (chemistry versus scent)?
26. Where is the area of scent receptors situated?
27. How many odours could be separately recognised?
28. Could one taste be associated with different smells?
29. Are the aroma compounds chemically stable?
30. Why do they have to be released just prior to use?
31. What are aroma compounds used for?
32. How are many aroma compounds activated?
33. How to make a fruit odourless?
34. What do the “Character Impact Compounds” define?
35. If you smell 2,3-butanedione, what kind of food comes to your mind?
36. Are “Character Impact Compounds” always sufficient to provide the acceptable taste?
37. Does the concentration affect the effect of chemical compound on flavour recognition?
38. How the ability to detect unpleasant smell could increase the survival ratio?
39. What are the traditional sources of enzymes used in food industry?
40. How to increase the juice extraction?
41. Are there any processes in food industry that are run without enzymes?
42. Is it possible to use microorganisms in food industry? Are all of them GMOs?
43. How the enzyme chymosin was obtained?
44. Why the “natural” production of chymosin was decreasing?
45. What are the advantages of microbial chymosin?
46. If a flovour compound is nutrient, is it still a flavour compound according to U.S. law?
47. Is there a legal difference between the cheese produced by using a chymosin from calf stomach and microbial enzyme?
48. Are the microorganisms used only to produce the complete food product?
49. Which chemical compound is responsible for the taste of chocolate?
50. Is it possible to produce more variations of taste than there are in nature?
51. Is the taste improvement process always successful?

Analyse the list, draw the chemical structures and find Polish equivalents of tastes and odours.