Valentine Bind

Scientists examine the nature of the sweet tooth

By ELIZABETH PENNISI

For all our concern about staying slim and reducing dietary fat, it's hard to imagine giving — or worse, getting — a box of low-calorie, low-fat chocolates for Valentine's Day.

For many people, knowing the health risks of rich foods — obesity, heart disease, cancer — has not really reduced the craving for the very foods we should cut back on.

Those cravings date back much further than the recognition of the foods' potential hazards. The energy needs of early humans honed preferences for foods rich in calories. But while evolution might readily account for the origins of the sweet tooth and our propensity to choose rich foods, the nature of sensing sweetness and fats appears quite complex.

Scientists investigating sweet-taste mechanisms have learned that not all people sense sweetness equally and that not all sweeteners work the same. "It's still a mystery, really," says Gordon G. Birch, a food chemist at the University of Reading in England. "We're all still piecing the picture together."

Through the decades, scientists have documented the widespread and innate nature of the sweet tooth. Twenty years ago, researchers found that sugar placed on the tongue caused newborns to relax and smile, while bitter substances made them frown, stick out the tongue, even spit. During the 1930s, German scientists found they could get fetuses to drink more amniotic fluid by injecting saccharin into the fluid. Sugar appeals even to bacteria, says Linda M. Bartoshuk, a psychophysicist at Yale University.

But we really crave more than sugar. Not many sweethearts would want to find that heart-shaped box filled with sugar. "When people say they love sweets, they generally mean that they love foods such as candy bars, cake and ice cream," says Bartoshuk. It's not sweetness *per se* but the calories associated with that flavor — contributed primarily by oils and fats — that the body desires. "The brain appears to detect fat by associating the flavors of food with the calories later released when it is metabolized," she adds.

Scientists have yet to work out the details of how the brain connects textures and tastes with calories, but some experts doubt that low-calorie, low-fat foods will easily trick people into healthier eating. Research shows that those who sometimes eat these foods, but do not monitor what they eat, tend to "make up for those calories by eating them at other times of the day," says nutritionist Richard D. Mattes of the Monell Chemical Senses Center in Philadelphia.

So, for instance, the addition of low- or no-cal sweeteners has not cut back U.S. sugar consumption. In 1978, Americans consumed 13 pounds of sugar substitutes per person; by 1988, they averaged 20 pounds. During that time, sugar and other caloric sweetener consumption also increased by 7 pounds a person.

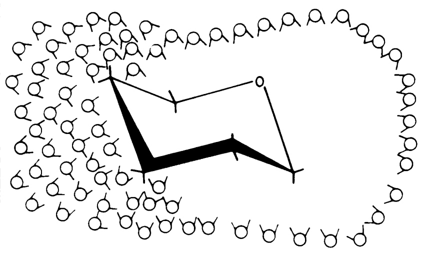
While most people in the United States do not really need all those calories, the human body evolved a yen for sweet and fatty foods during eras when food was often scarce. "Sweetness is a signal for carbohydrates," says Inglis J. Miller Jr., a sensory neurophysiologist at Bowman Gray School of Medicine at Wake Forest University in Winston-Salem, N.C. Those carbohydrates, along with fats, supplied our ancestors with calories needed to survive long enough to reproduce. Only recently have people lived long enough to experience the negative consequences.

Like many other traits, taste perception varies along a continuum. To try to understand how, Miller has counted taste buds on human and animal tongues. Two years ago, he and his colleagues trained a video microscope on the tongue tips of 16 people and counted the number of taste pores.

Some people averaged 374 pores per square centimeter, while others averaged just 135. Those with denser taste pores tasted sugary and salty solutions much more intensely than did those with fewer taste pores. But acidic and bitter substances affected both groups about equally, Miller reported in the June 1990 Physiology and Behavior.

He finds that overall, human tongues can have as few as 500 and as many as 10,000 taste buds. He thinks each taste bud provides very little information to the brain about what the mouth contains. But as a person chews food, mashing and mixing it with saliva, its flavor components reach many different receptors, which together communicate that food's particular identity.

Bartoshuk also finds a lot of variability in taste perception. By asking volunteers to taste and rate the sweetness or bitterness of various substances, she and her colleagues have found that some people are "supertasters." These individuals need only about half as much table sugar or sacharrin in their coffee to make it sweet; yet they perceive the newer sweetener aspartame the same as other people, Bartoshuk reports in the November 1991 Food Technology. These results indicate that inherent variations exist in taste perception and that not all sweeteners stimulate the nervous system in exactly the same way.



Birch et al./Royal Soc. of Chem.

In the mouth, water molecules may herd a sugar to a sweet receptor.

Indeed, many questions remain about how various substances make their "sweet" mark on the brain's taste centers. Examples range from table sugar (which contains no amino acids) to aspartame (consisting of two amino acids) and thaumatin (a plant compound with 207 amino acids). "People have tried to understand why these things all taste sweet even though they are very different in their chemical structures," Birch says.

In this quest, many researchers depend on a theory developed by two chemists 25 years ago. Robert S. Shallenberger and Terry E. Acree of Cornell University suggested that all sweet compounds share a common structure, which they called the glycophore. A glycophore can consist of different configurations of atoms as long as one atom, or one group of atoms, has a hydrogen attached, and two nearby atoms can pull extra electrons in close enough to have a negative charge. The glycophore seems to fall within a certain size and shape range. So, in large molecules such as thaumatin, the glycophore could branch out of the molecule.

With this setup, a sweet molecule easily forms hydrogen bonds. Its hydrogen atoms are simultaneously attracted to its own negative atoms and to negative

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atoms of neighboring molecules. Thus, linkages develop with water molecules and then, ever so briefly, with a receptor in the cell membrane of the taste bud. This fleeting connection, lasting a few nanoseconds, activates a chemical or electrical relay that conveys a taste message to the brain.

Water plays a key role in the perception of sweetness. "The hydration state will affect how well the molecule gets to the right place, and then the water molecules affect the activity of the molecule once it gets to the receptor," Birch explains.

Scientists have not yet isolated this receptor, so they can only infer water's role based on their experiments. For example, Birch is evaluating the solution properties of various substances whose molecules differ by just one atom or group of atoms. He studies how well their molecules pack and tumble among water molecules.

As part of this work, he measures the apparent molar volume – how much a mole of sweetener dissolved in water changes the water's volume. By dividing that value by the sweetener's molecular weight, he calculates the apparent specific volume. The smaller the apparent specific volume, the deeper the molecule moves into a cell membrane. The apparent specific volume of bitter substances falls between 0.7 and 0.9 cubic centimeters per gram (cm^3/g), he says in the November 1991 FOOD TECHNOLOGY. Sweet substances range between 0.5 and 0.7 cm^3/g. "You've got to pack well to get to the sugar receptors because they are deeper [in the membrane] than bitter [receptors]," he explains. Sour receptors lie deeper still, and salt receptors are deepest.

The values of sugars, at about 0.61 cm^3/g, represent a midway point. Sweeteners made of amino acids fall above and below these values, and these differences add sour, bitter and salty hues to their sweet taste, says Birch.

Now he is determining the packing characteristics of a group of sugars found in corn syrup. These sugars, maltodextrins, consist of varying numbers of glucose molecules strung together as a chain. Making maltodextrins of specific lengths has enabled him to study the effect of length on taste.

"You would expect that larger ones would be more difficult to pack, but in fact, they fit better because of the degree of order imposed on the molecules [themselves]," Birch notes. For example, a six-unit maltodextrin lines up six glucose molecules quite efficiently – more efficiently than individual glucose molecules arrange themselves.

The nature of sweetness also varies from one substance to the next. Some substances taste sweet right away and then fade quickly; others take a while for people to sense them. For example, the sweetener acesulfame-K (marketed as Sunette) tastes sweetest after 7.9 seconds, almost 2 seconds faster than most sweeteners, Dana B. Ott of Gerber Products Co., in Fremont, Mich., reported in January 1990 in the JOURNAL OF SENSORY STUDIES (5:53). But aspartame's sweetness lingered about 20 seconds longer than the rest of the sweeteners Ott tested.

These differences relate to the ease and order with which the molecules move to the receptor and, possibly, to how long they stay there, Birch says. He suspects that water lines up sweet molecules, presenting them one by one to a receptor. The rate of presentation, the spacing between molecules and the number of lines of molecules at a receptor may influence the sweetness characteristics, he says. The spacing and rate may affect how long the taste lasts, while the number of lines may determine its intensity.

Murray Goodman, a chemist at the University of California, San Diego, took a different tack in trying to make sense of sweetness. Over the past decade, he has worked out a computer program that can predict the sweetness of peptides – molecules made up of amino acids.

"We based our initial approach on Shallenberger's pioneering concept [of the glycophore]," Goodman says. "We think it makes a lot of sense." In addition to requiring that sweet substances form hydrogen bonds, his program insists that these substances have a section near the hydrogen-bonding region that is hydrophobic, turning away from water.

To build the model, he gathered data about the arrangement of atoms of substances tested for their taste qualities and used his computer to look for similarities in the structures of similar-tasting compounds. This analysis helped him determine which molecular shapes and amino acid compositions were sweet.

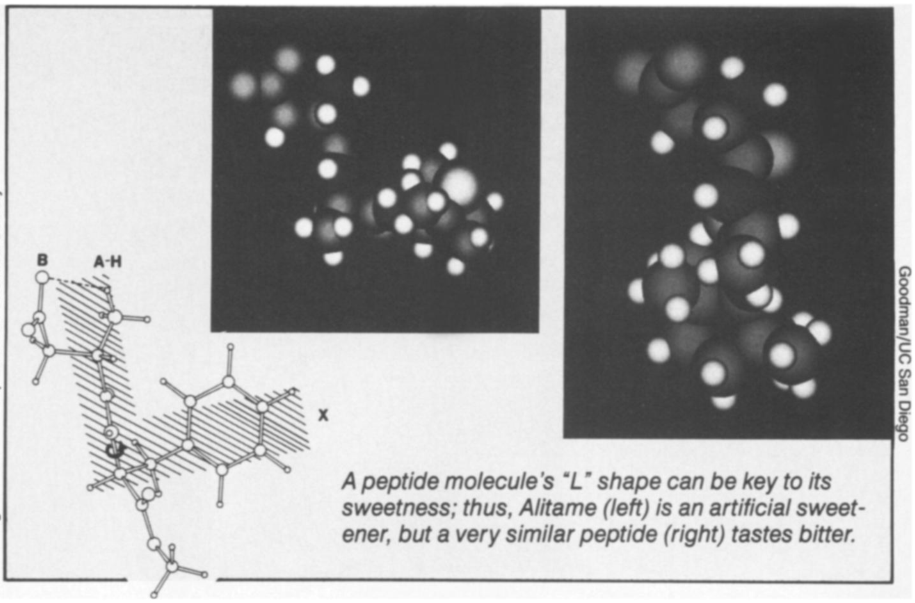
Goodman finds that a sweet molecule tends to be L-shaped and no more than 10 angstroms wide or tall. The upright part of the L consists of two charged units: a positively charged ammonium group and a negatively charged carboxylate group. The horizontal part of the L consists of a group of atoms that repel water. In addition, the L must lie flat. If twisted in one direction, it tastes bitter; if twisted another way, it has no taste.

Goodman says he has used his model to devise sweeteners that taste more like sugar than today's best artificial sweeteners. "But the kinds of molecules we make are, by and large, too expensive to be commercialized," he says.

Mix a sugar in with something like chocolate and the story gets even more complicated – and the food's seductive appeal, more elusive. Chemists trying to understand chocolate's sweetness must consider reactions that are water-based, and they must figure out the role that cocoa butter plays in that sensation. Fat molecules are hydrophobic, or water-repelling, so they may make it more difficult for the sweet molecules to pack well, says Birch.

In the quest for a healthier chocolate, the chemical complexities of artificial sweeteners might only complicate matters more. "When you start dealing with mixtures, most of what we're saying about pure substances doesn't hold up," Shallenberger says.

So chocolate lovers, take heart. Undoing millions of years of evolution will not be easy, and neither will tricking the palate with substitute fats and artificial sweeteners. It may be a long time before anyone devises a low-calorie, low-fat chocolate that lets one savor a Valentine's gift without guilt. For now, we might as well enjoy those sweets and eat healthier next week. □



A.J. Douglas and Goodman/American Chemical Society
Goodman/UC San Diego

A peptide molecule's "L" shape can be key to its sweetness; thus, Alitame (left) is an artificial sweetener, but a very similar peptide (right) tastes bitter.