SYMPOSIUM ON IMPORTANCE OF NONVOLATILE COMPOUNDS IN FLAVOR

Introduction

The good attendance at the symposium is yet another demonstration of the vitality of the Flavor Subdivision and of the enthusiasm of its officers and members.

It is not surprising that interest in research on the nature of the flavor of foods continues to be high since, while he is not the protagonist, the flavor chemist has an important role to play in helping to meet the rising demand for foods of acceptable quality all over the world. Restoration of flavor to highly processed foods in the industrially more developed countries also continues to offer interesting challenges.

The international character of the conference was one of its outstanding features and the writer wishes to thank the lecturers on his and the Flavor Subdivision's behalf. Particular thanks are due to those speakers who traveled to Atlantic City from foreign countries and contributed so much to the success of the meeting.

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Some Functions of the Sense of Taste

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The validity of observations on "taste as it relates to molecular structure" are reconsidered in terms of the results from investigations across species boundaries. Other topics discussed are: the function of nonvolatile compounds in diet selection and regulation of food intake, some physiological factors that modify perception of chemical taste stimulants, the nature of absorption of some chemicals from the oropharyngeal cavity and the significance of the rapid movement of these compounds from this area to the brain, and the rapid modification of both the volume and character of pancreatic flow by nonvolatile compounds introduced into the oropharyngeal area.

Commonly, in describing the taste of food, one incorporates all the sensations encountered with ingestion. For example, the apple that "tastes good" is actually a description of odor. You can test this by closing your nose and trying to distinguish between raw mashed apple and raw mashed potato. Another variable that is independent of the chemistry of a stimulus is temperature. The difference in taste between cold milk, beer, or soup and hot milk, beer, or soup is unmistakable. There is no doubt that temperature modifies the gustatory reception of meat or wine. Texture is also incorporated in our broad description of taste. The lumps in a pudding, or a gritty ice cream, will modify our taste reaction to these foods.

Even visual stimuli, which obviously do not contribute either physically or chemically, will modify our taste impression. Try to eat blue yoked eggs or black cereal. It is not the dark color, since caviar and olives, both black, rank among the most desired delicacies.

Taste, as the term is commonly used, is the result of the chemical senses being modified by a host of variables. Describing taste in animals is further confounded by the fact that the variables assume a role unique for each species. For example, in the bird an increase in temperature a few degrees beyond that of the body renders a fluid totally unacceptable. On the other hand, cooling down to freezing does not decrease the acceptability of water. Small differences in the surface texture of grain will be noticed by a bird; however, they appear to be indifferent to viscosity. A thick viscous sucrose solution (25%) is accepted equally as well as pure water. For these and other reasons, palatability based upon animal research has limited application for humans, and likewise, a human taste panel for dog food is nonsensical. It is critical that one be cognizant of these differences in taste research that involves animal experimentation.

Taste is even more complicated. Some chemicals injected subcutaneously at some distance from the taste buds are rapidly perceived. Even if the tongue is cocainized, the reception of the stimulus is unaffected. This would rule out a simple transport of the stimulus, via the circulation to the taste buds. Recent work has demonstrated direct neural connections between the gut and the central nervous system. Receptors within the gastrointestinal tract have been described and studied.

Chemicals are not essential to evoke a taste sensation. Some years ago it was demonstrated that electrical stimulation of the tongue results in a taste sensation. When the frequency of the stimulation was altered, the nature of the sensation changed.

INDIVIDUAL AND SPECIES VARIATION

The color of your eyes is determined by the color of your parents' eyes. To a substantial degree, your sense of taste is also inherited. Work with phenothiocarbamide established that some humans could taste this chemical and others could not, and established that further, this ability has a genetic basis.

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Interest in this area was stimulated by the fact that in many of our animal experiments, a minority of animals would contradict the taste behavior obtained with the vast majority of the same species. In more formal trials (Kare *et al.*, 1965) genetically related pigs were offered saccharin in a wide range of concentrations. A majority of the pigs avidly drank the saccharin solutions at every concentration, they could apparently perceive it, a few were indifferent to it, and a sizeable minority rejected the saccharin at every concentration that was offered. Subsequently quail were used because they have a short (six-week) maturation period. Initially a variety of chlorides were used to test the animals. It soon became apparent that the response of an individual quail to one chloride salt gave no indication as to how the animal would respond to a second. For example, an animal might be sensitive to ferric chloride at extreme dilution but unresponsive to solutions of ammonium chloride at much greater concentrations. The initial group of quail was separated into the two taste extremes—those very sensitive to ferric chloride solutions and those insensitive to it. Ferric chloride was the stimulant chosen because the amount of salt consumed by the animal in excess of its needs passes through the animal without being absorbed.

Sensitive birds were bred with each other, and those insensitive were bred with each other. Selection accompanied by rigid culling out of those birds with intermediate taste sensitivity was continued for five generations. At this point the distribution of the preference behavior measurements of the progeny began to separate into two distinct groups. Apparently taste preference behavior can be radically altered in a relatively few generations. The individual differences observed are overshadowed by species differences.

It is commonly assumed that animals share man's taste world. The fallacy of this contention can be illustrated in the species differences in response to stimulants described by humans as sweet (Kare and Ficken, 1963). In this category would be solutions of sucrose—e.g., 10 to 12%—and the taste equivalent of saccharin. The laboratory rat avidly selects both of these solutions. The calf, however is much more sensitive to sucrose than is man but is generally indifferent to saccharin. The dog has a "sweet tooth" in terms of the sugar, but many dogs reject saccharin solutions. The cat is indifferent to both solutions. More examples can be offered to support the conclusion that a "sweet tooth" is not so common a phenomenon among animals as was generally thought.

Species differences become even more evident when specific sugars are considered. For example, the chicken is indifferent to the common sugars, but rejects xylose. Xylose is one of the most preferred sugars of the calf. Lactose, to which the calf is indifferent, is highly acceptable to the opossum. Data which extend and supplement the foregoing have been obtained in systematic studies using salts, sucrose octaacetate, and acids.

Collectively, the results suggest that different species live in distinct taste worlds which may or may not overlap. Certainly, the taste reaction of one species to a chemical stimulus is not a reliable guide to predicting the taste response of a second species.

The pathway for energy production is similar in all of the higher vertebrates. Because so many species can use the same simple carbohydrates in their metabolic cycles for energy production, this might suggest a universal dietary selection of these compounds. However, the facts challenge an explanation of preference related to ease of metabolism. Many species of birds, the cat, and the armadillo fail to display a "sweet tooth."

Physiological systems in vertebrates approach a universal character. For example, an endocrine product taken from one species has a predictable response when administered to a second species. In marked contrast, evidence would suggest distinct as well as indistinct boundaries among the taste worlds of different species, strains, and even individuals. If all species or even all members of a single specie had an identical sense of taste, competition would be narrowed to a few food sources, and the pressure would be enormous. There are definite ecological advantages to a diversity in taste perception in terms of exploiting the food available in an environment.

At this stage, no simple chemical, physical, or physiological pattern can be offered to explain the collective comparative results. However, the apparent contradictions and absence of universal response behavior do not deny the existence of a general underlying pattern. The possibility can be considered that this lack of predictable response is simply an end result of evolution. The similarities in taste in diverse species could be the consequence of convergent evolution dictated by available nutrients.

THE FUNCTIONS OF TASTE

The primary function of taste is to stimulate eating. The relationship has not been precisely defined, but this self-evident observation would be difficult to deny. A complex consumatory response can be evoked in an isolated garter snake with no previous eating experience by presenting it with a swab dipped in the washings from an earthworm. This indicates that there can be an innate response to a specific chemical stimulus.

Some possible functions of taste are unique to the species. The taste buds on the back of the tongue of the cow are typically more sensitive to some stimuli than is the front of the tongue. It has been postulated that this posterior sensory perception is primarily related to regulation of rumination (Bernard, 1964).

Taste does serve as an indexing system—that is, foods once eaten can be identified by the animal. If rats that have been depleted of a specific nutrient such as thiamine are then offered a choice between an adequate and a deficient diet, they will select much more successfully when a flavor has been added to one of the choices. Apparently, they can rapidly associate the postingestion effects with the flavor of the diet. This identification of toxicity or benefit of a foodstuff by means of taste is a serious problem in the use of poison baits for rodents or other animals.

TASTE AND DIET

The function of taste is commonly associated with guiding an animal in its dietary habits. Obviously, a cow will not eat sawdust, and a dog does not relish hay. In the selection between edible materials, however, will an animal make a nutritionally wise choice?

The blackbird rejects a variety of dilute salt solutions in a choice situation, but will drink arsenate in solution and kill itself. The robin appears to be indifferent to sucrose solutions. Domestic rats were tested in electrophysiological and behavioral trials with a wide variety of amino acids. Included were the so-called essential amino acids, methionine, tryptophan, and valine, as opposed to the nonessential amino acids, glycine, and alanine. The magnitude of electrophysiological response to the nonessential amino acids was substantially greater than it was for the essential. Also, the animals selected and preferred both nonessential amino acids, and found all of the essential amino acids offensive (Halpern *et al.*, 1962). Certainly, man's response to the synthetic sweeteners would also contradict an immediate relationship between taste appeal and nutritive value. While the sense of taste appears to serve in securing an adequate diet, it is not a consistently reliable guide to the nutritive value or toxic quality of food.

Experiments have been carried out to compare the sense of taste in wild and domestic animals. Both wild and domestic rats exhibited a similar qualitative preference for a variety of common sugar solutions. However, the wild rat reacted by increasing its intake only slightly (12%) as opposed to the domesticated rats which almost doubled their fluid intake (87%). With this increased caloric intake from sugar solutions, the animals ate less of the balanced diet. In the case of xylose, which has a deleterious effect on vision, and nonnutritive saccharin, the wild rat's preference and intake were substantially lower than those of the domestic rat. The results suggest that the wild animal is much more responsive to the nutritional and pathological consequences of its selection and intake, whereas the domestic animal is selfindulgent and more concerned with the hedonic qualities of the available alternatives (Maller and Kare, 1965).

Since domestication has resulted in altered anatomical and physiological characteristics, the possibility arises that the function and ability to taste have also been altered or even lost. Apparently, it is critical that we ask the question of the correct animal.

Another related problem is the chemical form in which the cues are offered. For example, we deprived an animal of calcium and tested its ability to correct for the deficiency when various salts in solution were offered. It was concluded that discernment was better with some salts than others. A reagent grade chemical, although critically required by the animal, could fail to evoke a response, since in its offered form it is foreign to the animal's normal environment.

On the basis of the above and other experiments, it was apparent that an animal's preference behavior is not necessarily a reliable guide to the nutrient quality of food. However, use of the "correct" animal and the "correct" form of the nutrient in a contextural environment could provide at least an educated guess as to the nutritive value.

TASTE AND INTAKE

In studies with offensive tasting chemicals it was observed that hunger rapidly overcomes an offensive taste quality. With food that was totally unacceptable in a choice situation, it was necessary to increase the offensive quality 10-fold in a no-choice situation to effect a significant decrease in intake over a long-term study.

The effect of enhancing the taste of feed or making it less appealing by adding chemicals was studied in wild and laboratory rats. The addition of lard to the test meal caused the domestic rat temporarily to increase its caloric intake, whereas the wild rat reduced intake to try to maintain a uniform caloric intake. With the addition of quinine, the domestic rat temporarily dropped its food intake, but there was a more limited effect on the intake of the wild rat. The regulation of intake by the wild animal apparently takes precedence over appeal or offensiveness of a food (Maller, 1967).

The above results were confirmed in a similar study with jungle fowl and the domestic chicken. The wild animal exhibited a more rapid and more accurate correction for caloric dilution or enrichment (Kare and Maller, 1967).

TASTE AND DIGESTION

The relationship of taste stimuli to salivary flow is common knowledge. Further, the character of the stimulus will to some degree modify the nature of the saliva. Taste has an interesting effect on gastrointestinal activity. A strong oral stimulant will reduce gastric activity but increase intestinal motility.

Pavlov described a role for oral stimulation in digestive function. However, only a few definitive studies have been made. Dogs were prepared with both gastric and intestinal fistulas. The latter were placed so that the pancreatic duct could be cannulated and secretion collected without seriously disturbing the animal. With the gastric fistula open, the prevention of passage of chemicals used as stimuli from the mouth to the gut was substantially assured. With these preparations, the effect of taste and diet on pancreatic function over an extended period of time was measured. Kaolin, for example, did not elicit a pancreatic response whereas sugar was effective in increasing both flow and enzyme content. The volume of flow was highly correlated with the readiness with which the various mixtures were accepted by the dogs (Behrman and Kare, 1968; Kare, 1969).

Diet was observed, within a two-week period, to elicit an adaptative enzyme response. A high fat diet, for example, resulted in a greater lipase flow. The high carbohydrate diet, however, had no effect on amylase flow. It was concluded that taste as well as diet are involved in modifying the exocrine functioning of the pancreas.

NUTRITIVE STATE AND TASTE

Rats on low lysine diets, a situation encountered in human populations on cereal diets, were tested for taste preferences. Small but significant changes in preference for sugar and salt solutions were observed. Rats in the advanced stages of vitamin A deficiency displayed marked decreases in the rejection of quinine and selection of sodium chloride solutions (Bernard *et al.*, 1961). Administration of vitamin A resulted in rapid recovery of the salt selection but not of the quinine rejection. Vitamin A appears to have a direct role in the functioning of the taste cell. Within a period of two weeks, young rats placed on a vitamin B_6-deficient diet exhibit a marked alteration in preference behavior for sucrose and sodium chloride solutions.

Penicillamine, a chelating agent administered to young rats, effected pronounced changes in the sense of taste. After massive doses the rats selected sodium chloride at concentrations ($0.3M$) rejected by normal animals. Increased intake of and preference for glucose solutions were observed (Keiser *et al.*, 1968).

The limited data available focus on the critical importance of using adequately nourished animals in taste research. Apparently, deficiencies of trace minerals and vitamins, as well as proteins, can modify taste behavior. Whether or not it is more significant in some than in other species has yet to be established.

ORAL METERING

Animals and humans stop eating long before intestinal absorption of food occurs. The decision to consume a certain volume is made before an intestinal measurement can be made. When animals are depleted of some specific nutrient—e.g., sodium chloride—a specific hunger can occur. Sheep depleted of salt, when first presented with a saline solution, will usually consume (often in a single drink) approximately the amount needed to replenish the body needs. Certainly, the drinking is terminated before the salt has had time to move to the intestine to be absorbed and affect the deficient cells that initiated the sodium appetite. This leads to the postulate that some sort of oropharyngeal metering is occurring. Specifically the suggestion is that, during the oral phase of ingestion, information is transmitted to the cerebral structures associated with the mediation of consumption.

There is no doubt that neural taste information is transmitted from the mouth. To ascertain if humoral information is transmitted, experiments were designed to determine if nutrients can pass from the mouth to the brain prior to going to the gut. Labelled glucose (^{14}C) and sodium chloride (^{24}N) were introduced into the oropharyngeal cavity of rats and blackbirds in which the esophagus and trachea were cannulated to permit respiration. As a control, the isotope solutions were introduced into the duodenum. The animals were maintained in a near normal position in a special head holder. Significant quantities of both glucose and salt were detectable in the brain in less than 30 seconds after the solutions were introduced into the mouth. However, the amount of radioactivity detectable in brain samples was most modest after introduction of the solutions into the gut. The findings were confirmed in whole brain autoradiographic studies (Kare *et al.*, 1969). These findings suggest that a quantity of at least some nutrients introduced into the ligated oropharyngeal cavity rapidly move to the brain. This observation does not constitute proof for cerebral regulation of intake. The data do suggest that monitoring of nutrients during the oral phase of ingestion is possible. Furthermore, the information obtained via the extra-neural pathway could contribute to sensation and preference behavior.

SIGNIFICANCE

As the world population explosion is commonly thought of only in terms of pressures on man, it is creating habitat and food problems for animals. Man's activities disturb, to various degrees, the chemical cues in the environment of wild animals. If wild animals are to survive, it is critically important that we come to terms with the wild populations. Understanding their sensory behavior, particularly as it relates to feeding and reproduction, could be most helpful.

The relationship of the structure of taste stimuli to sensation and function is largely undefined. The chemical phenomena involved at the receptor surface constitute a major scientific challenge.

It remains for the scientists and the food industry to direct the accumulated knowledge and apply it for the effective use of the world's populations, both of man and animal. While we may not share in the same sensory world, we do have common problems. Knowledge on the function of the sense of taste could contribute to the effective use of the world's food resources.

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Received for review October 10, 1968. Accepted May 29, 1969. Presented in symposium on Importance of Nonvolatile Compounds in Flavor, Division of Agricultural and Food Chemistry, 156th Meeting, ACS, Atlantic City, N. J., September 1968.