PRESIDENT'S ADDRESS

THE SCIENCE OF TASTE

O. C. DERMER, Oklahoma A. and M. College, Stillwater

The subject is an ancient one; there are a number of references to it in the Bible. One from Matthew goes, "Ye are the salt of the earth; but if the salt have lost its savor, wherewith shall it be salted? It is thenceforth good for nothing, but to be cast out and trodden under foot of men." This presumably refers to natural salt deposits that have lost their saltiness by leaching. But in spite of mankind's long interest in taste, Alexander Graham Bell could remark that the science of smell and taste was still in the Dark Ages. Even today it is certain there is no field in which it is more essential to take every literature statement "with a grain of salt."

The fact is that the chemical senses—smell, taste, and general irritability to chemicals—are more difficult to study than the physical senses—sight, hearing, and touch. Taste, smell, and the sensation caused by tear gases arise from the effect of chemicals on nerve endings, taste usually requiring a higher concentration of the stimulating agent than the other two. The sensations are distinct, though often confused because human anatomy places the several detectors so close together.

But why is knowledge of the chemical senses so imperfect and even unscientific? Not for lack of effort: psychologists and physiologists have studied the nature of sensation; philosophers have philosophized on the connection between nature and mind; chemists have prepared synthetic flavors; and nutritionists and pharmacists have worked to make foods and drugs palatable. The great lack is a measuring instrument. Light we turn into dial readings with a photoelectric cell or a spectrometer, temperature with a thermometer, sound with other meters; but for taste we have to depend on somebody's tongue. And no two tongues are alike; even the same tongue does not taste things alike on different days. As a result the literature is full of contradictions and questionable data.

It is only in the higher animals that the senses of taste and smell are differentiated. In simple ones like *Hydra* or a starfish there is only a generalized chemical sense to indicate the presence of food or of irritants, such as acid or salt. Differentiation is observed in many insects; ants, bees, and moths use odors as the main basis of communication, and bees can distinguish sugar solutions from glycerin or saccharin solutions, although they all taste sweet alike to us. In insects, and in some fishes, notably catfish and carp, some of the taste receptors are scattered over the outside of the body—much as if we could taste with our elbows or our knees! Reptiles, amphibians, and birds show little sensitivity to taste; among mammals, whales are least sensitive, but then their feeding habits are highly undiscriminating.

In general we can say that dogs and insects excel in sensitivity to odor, birds in sight, and man in taste, although one type of monarch butterflies *(Danaus archippus)* has been shown to recognize a sugar solution at 1200 times the dilution perceptible to man. Whether children have higher taste sensitivity than adults is still disputed; certainly they hate bad-tasting medicines more.

In man, the taste buds, where the taste nerves end, are scattered over the top of the tongue, mostly in the papillae. There is great variation in their sensitivity to different basic tastes, but it is certain that bitterness is tasted mostly at the back of the tongue. The confusion of odor and taste can be reduced or prevented by stopping the nose; it is a commonplace observation that foods lack flavor when one has a bad cold. Chloroform is often said to have a sweet odor, but it really has a sweet taste and an ethereal odor—whatever that is.

Classification of odors remains an unsettled problem, but for tastes it is well agreed that there are four fundamental ones: sweet, sour, salty, and bitter. Every other true taste is then a blend of these. Of course the tongue can also notice pressure, pain, warmth, cold, and chemical irritants. So-called metallic tastes, as of silver nitrate or alum, involve some true taste and much astringency, which is a touch sensation. Perhaps the indescribable taste of alkalies belongs in this category. Peppery tastes, as of mustard, onions, and carbonated water, represent chemical irritants, which stimulate the mucous membranes of the nose and eyes also.

The effect of temperature on taste sensitivity was studied about a hundred years ago by Weber. The optimum is body temperature, and much higher or lower temperatures partly anesthetize the tongue. Thus if soup is hot enough, one cannot tell whether it is salted; and lemonade and ice-cream manufacturers know that it takes more sugar to sweeten these delicacies than it would if they were served warm.

The technique of taste tests has been developed by professional tasters of products such as tea and wine. Using solutions whenever possible, the taster rinses the mouth with a fixed portion of the sample at about 37° C and then spits it out. After a few minutes the process is repeated with a standard. It is simplest to use distilled water as the standard and to determine the minimum concentration of solution just distinguishable from the water, the threshold concentration. We must note that there is a difference between sensation value—the ability to distinguish the unknown from water—and quality value—the ability to recognize the taste as, say, sweet. For sodium chloride the most reliable values (Moncrieff 1946) are 0.016 percent sensation value and 0.087 percent quality value.

Instead of comparing substances on the basis of threshold concentrations, we may find for each the concentration at which the tastes are of equal intensity (most-exact method), or make up solutions of all substances at the same concentration, and rank them in order of intensity (least exact). The psychologist here would remark that Weber's law holds for taste as for other sensations: the least noticeable difference is a constant fraction of the stimulus. For example, a change of one candlepower in light is easily noticeable in a dim light, but not in a bright one; and a little more salt is not easily noticed in a solution already very salty.

Sweet taste has been most studied, in keeping with the fact that in the history of human culture sweetening agents play a noteworthy role. They have always been sought and refined as something costly and pleasant, while salts and sour substances were regarded as mere necessities, and bitter ones as downright hateful. To quote H. G. Wells (Wells, Huxley, and Wells 1934:1150) on this point:

"The sense organs which life does possess are narrowly conditioned by the facts of the lifeless environment. Sugar is abundant in nature, and sugar-containing substances are nutritious. Hence we not only possess sense-organs capable of detecting a sweet taste, but we find sweet things agreable. Had the nutritious sugars been rare in nature, and saccharin, which is useless for food purposes, been abundant, the sensation of sweetness would doubtless not have been pleasant; while if lead acetate or sugar of lead, which is sweet but poisonous, had been the common sweet substance, sweetness would of necessity have been disagreeable to the higher animals, for only those with natures that found sweetness nasty could have escaped being poisoned."

It is familiar that some herbivorous animals develop a craving for salt, which is not abundant in plants. Since the taste buds respond to substances in the blood stream as well as to those in saliva, it appears that a deficiency in the blood stream increases their sensitivity to the external stimulus (Hartridge 1945). It is a temptation to associate unpleasant, bitter taste with poisonous nature in foods, for we know that many animals are warned away from toxic plants by taste or odor. In support of this, the alkaloids, such as strychnine, nicotine, and morphine, are the bitterest known substances. But they are not poisonous in the same order that they are bitter; and moreover we actually like some bitter tastes in combinations, as in grapefruit, tea, coffee, and beer.

It was formerly believed that it takes longer to taste bitterness than other tastes, because a mixture of sweet and bitter substances usually tastes first sweet, then bitter. Actually this probably demonstrates only the much lower threshold for the bitter, which makes it persist after the sweet is too dilute to be perceptible. Since a weak electric current between electrodes on the tongue induces taste sensation, a current interrupted with sufficient rapidity just to give a continuous sensation can be used to measure duration of taste (Allen and Weinberg 1925). By this means taste was found to have a shorter duration than touch, hearing, or sight; no one has yet conceived a method for similarly studying odor. Of the four tastes, bitter has the shortest duration, but values for all of them are of the order of 0.002 second.

As we have noted, one of the worst obstacles to taste research is variation in sensitivity of individuals; thus for one bitter substance, phenylthiourea (phenylthiocarbamide, "PTC"), the threshold concentration in aqueous solution ranges from 1/312 to 1/280,000, and for quinine 1/5000 to 1/320,000. Moreover a taster may be relatively insensitive to phenylthiourea and still taste quinine well. This fortunately is not typical; the ratio of threshold bitternesses of various substances is fairly constant from individual to individual, except for phenylthiourea and relatives (Wasicky, Barbieri, and Weber 1942-43). The same constancy is assumed for sweet taste. However, Blakeslee (1939) obtained a "vote" of 3121 persons on the taste of mannose, a rare sugar, at a meeting of the American Association for the Advancement of Science. The compound was sweet to 1120, tasteless to 895, bitter to 352, sour to 93, salty to 38, bitter then sweet to 90, sweet then bitter to 286, and bitter-sweet to 46, and reported in still other combinations. All this evidence calls for tolerance in the matter of food preferences; don't expect others to like olives, spinach, and liver just because you do!

The extreme range of sensitivity to the taste of phenylthiourea has led to designation of low ability or total inability to taste it as "tasteblindness" or better "taste deficiency." Among white people 70 percent can taste it, among Chinese and American Indians 90 percent. The geneticists report that the ability to taste phenylthiourea is a dominant characteristic, whereas the taste deficiency is a recessive one. Phenylthiourea is suitable for use in accelerating the vulcanization of rubber, and was so used in the rubber of ice-cube trays in refrigerators until the manufacturers began to get complaints! It is also the nearest chemical neighbor to the important new rat poison, alpha-naphthylthiourea, which rats evidently do not taste.

Taste impressions, like others derived from the senses, are subject to the phenomena of mixture (combinations, neutralizations), adaptation (fatigue), and contrast. The idea of combinations is too familiar to need any discussion; we really do not sweeten lemonade much, but merely add another taste to it. It is rare to find any true cancellation of tastes. The pharmacists have always looked for something to cancel bitter tastes of drugs, but the best they can do is to mask them with sweet sirups, or else partially anesthetize the taste buds with one of several plant extracts.

The sweetness of a 15-percent-sugar solution is increased by the addition of a trace of sodium chloride or quinine sulfate. It is common knowledge that a taste is intensified by contrast with a previous different one. Fruits seem much sourer after candy or other sweets, and water itself appears sweet after one has been tasting something salty, bitter, or sour. Fatigue of taste is as easy as that of other senses; a 1 percent solution of sucrose soon cannot be tasted at all. To add one more complication: solutions being tested often do not obey the dilution law, i.e., that twice the concentration will give twice the effect. Whether because of ionization, association, dissociation, or some other factor, sweetness relative to sucrose usually does not change as expected upon dilution.

The basic question in the science of taste is: What factors determine the quality and the intensity of taste of a compound? The chemist in particular has always hoped and tried to find a connection between taste and structure of the molecule. In Tables I, II, and III are assembled quantitative data on compounds with sour, bitter, and sweet tastes; since sodium chloride is the only purely salty-tasting compound, nearly all other salts having bitter components, no scale of saltiness has been established.

The sour taste is produced by acids and nothing else. As one would guess, the sourness depends mainly upon pH of the solution, but it is modified by diffusibility of the anions and unionized molecules, which contribute to the taste. Beatty and Cragg (1935) have shown that sourness, defined as the normality of an equally sour hydrochloric-acid solution, can be measured by a nonbiological method. This is done by titrating the unbuffered unknown to a pH of 4.4 with a phosphate buffer solution; the sourness is directly proportional to the volume of buffer used. The results agree very well with taste tests, and demonstrate that relative sourness of equimolar solutions is independent of concentration, unlike relative sweetness.

The data on relative bitterness are largely very old and in need of confirmation, preferably by the more accurate procedure of determining at what concentration each compound is as bitter as a standard, instead of the threshold method. But bitterness is of no great commercial importance, and it is not easy to assemble a group of tasters willing to work on it.

Research on sweetness and sweeteners is stimulated by wars; Napoleon in 1810 offered a prize of a million francs for a practicable process of obtaining sugar from sugar beets, and Table III shows a preponderance of literature reports dated soon after World War I or II. The newest sweetening agents—synthetic aromatic compounds which also have local anesthetic action—were studied in the Netherlands during German occupation and now give promise of displacing saccharin, which they far surpass in sweetening power.

A survey of Table III shows that all the compounds of sweetening power more than 2.5 times that of sucrose (excepting chloroform) are nitrogen compounds, either substituted amines, amides, imides, nitriles, or oximes. Those below this value are either sugars, sugar-like alcohols, or amino acids. One easy check on the purity of synthetic glycine is to find whether it is pleasantly sweet. In addition to the quantitative data, it must be noted that soluble beryllium and lead salts, most halogenated hydrocarbons, and many mononitro hydrocarbons are sweet.

It is common practice in the food-manufacturing industries to invert sucrose before or during its use; whether or not this process increases the total sweetness has been much argued (Willaman, Wahlin, and Biester 1925; Sale and Skinner 1922; Täufel 1926; Anon. 1946; and others). We can see from Table III that the confusion has been due to different methods of assay. A molecule of sucrose gives one of glucose and one of fructose; of these glucose is definitely about 0.7 times as sweet as sucrose. Where, as by the threshold method, fructose is found to be 1.7 in sweetness, invert sugar, the average, is sweeter than sucrose. If substantial sweetening power is tested instead, fructose has the value of 1.1 to 1.2 and invert sugar is if anything a little less sweet than sucrose. Since the latter is the condition in practical use, inversion should not be expected to increase the sweetening power of ordinary sugar.

Now what can we say in conclusion about the reasons for the taste of a compound? There is clearly some relation with structure, and yet the most widely differing chemicals have the same taste, and apparently insignificant changes in molecular architecture radically alter the taste. This is the organic-chemist's standard research procedure, but saccharin and dulcin, for example, become tasteless or bitter with nearly every change; the results hardly make sense. It must be that some particular combination of physical and chemical properties is required; not surface tension alone, nor lipoid solubility, nor chemical behavior determines taste, but all these together, and more. Clearly this is the place for some of the cooperative, interdisciplinary research advocated by Dr. H. E. Carter at our meeting a year ago.

This is the same attack that must be used in explaining other physiological activity of chemicals—the toxicity of DDT for insects, the local anesthetic action of *p*-aminobenzoic esters, the antibiotic potency of penicillin and streptomycin. At present we really have no very satisfying explanation of these things. Perhaps some day we can do better.

TABLE I

Relative sourness indices of acids[a]

Acid	Sourness	Reference
Formic	1.1	Beatty and Cragg 1935
Hydrochloric	1.00	(the standard)
Chloroacetic	0.9	Beatty and Cragg 1935
Lactic	0.92	Fabian and Blum 1943
	0.78	Paul 1922
Acetyllactic	0.85	Paul 1922
Tartaric	0.8	Beatty and Cragg 1935
	0.64[b]	Komm and Lämmer 1940
	0.63	Paul 1922
	0.56	Fabian and Blum 1943
Acetic	0.69	Paul 1922
	0.36-0.38	Beatty and Cragg 1935
	0.37	Fabian and Blum 1943
Malic	0.6	Beatty and Cragg 1935
Potassium H tartrate	0.58	Paul 1922
Citric	0.55	Komm and Lämmer 1940
	0.37	Fabian and Blum 1943
Carbonic	0.09	Paul 1922
	0.02	Beatty and Cragg 1935

[a] Calculated from sourness as defined by Paul (1922) and Beatty and Cragg (1935) by dividing by normality of the acid tested.

[b] By comparison with lactic but calculated relative to hydrochloric by using the mean value lactic = 0.85.

TABLE II

Bitterness of various substances

Substances	Relative bitterness	Method	Reference
Brucine	100-125	Threshold	Scholl and Munch 1937
Chlorostrychnine	50	Threshold	Cohn 1914
Strychnine	30-32	Threshold	Scholl and Munch 1937, Cohn 1914
Nicotine	13	Threshold	Cohn 1914
Quinine	10.0 (standard)	Threshold	Cohn 1914, Scholl and Munch 1937
Ethylstrychnine	10	Threshold	Cohn 1914
Colchicine	9	Threshold	Cohn 1914
Phenylthiourea	9 maximum	Threshold	Blakeslee 1935
Sucrose octaacetate	6.7	Threshold	Brigl and Sheyer 1926
	5.0	Threshold	Scholl and Munch 1937
Caffeine	4		Crocker 1945
	0.4	Threshold	Gertz 1923
Aloin	3.3	Threshold	Scholl and Munch 1937
Cinchonine	2.5	Threshold	Cohn 1914
Veratrine	2	Threshold	Cohn 1914
Pilocarpine	1.6	Threshold	Cohn 1914
Atropine	1.3	Threshold	Cohn 1914
2,3,5,6-tetraacetyl-β-phenol glucoside	0.97	[a]	Brigl and Sheyer 1926
Aconitine	0.9	Threshold	Cohn 1914
3,5,6-tribenzoyl-glucose carbon tetrachloride	0.53	[a]	Brigl and Sheyer 1926
Theobromine	0.5	Threshold	Gertz 1923, Scholl and Munch 1937
Maltose octaacetate	0.5	[a]	Brigl and Sheyer 1926
3-benzoyldiacetone-glucose	0.40	[a]	Brigl and Sheyer 1926
β-phenol glucoside	0.25	[a]	Brigl and Sheyer 1926
2,3,5,6-tetraacetyl-β-methylglucoside	0.23	[a]	Brigl and Sheyer 1926
2,3,5,6-tetraacetyl-α-phenol glucoside	0.23	[a]	Brigl and Sheyer 1926
β-glucose pentaacetate	0.22	[a]	Brigl and Sheyer 1926
Cocaine	0.2	Threshold	Cohn 1914
Morphine	0.2	Threshold	Cohn 1914
2,3,5,6-tetraacetyl-glucose	0.11	[a]	Brigl and Sheyer 1926
3-acetyldiacetone-glucose	0.097	[a]	Brigl and Sheyer 1926
α-glucose pentaacetate	0.088	[a]	Brigl and Sheyer 1926
6(?)-benzoyl-monoacetoneglucose	0.088	[a]	Brigl and Sheyer 1926
2,3,5,6-tetraacetyl-α-methylglucoside	0.038	[a]	Brigl and Sheyer 1926

Substances	Relative bitterness	Method	Reference
Diacetoneglucose	0.032	a	Brigl and Sheyer 1926
α-phenol glucoside	0.031	a	Brigl and Sheyer 1926
β(?)-acetylmonoacetone glucose	0.019	a	Brigl and Sheyer 1926

---

[a] By comparison with 0.02 M α-glucose pentaacetate; rated in terms of quinine by the intermediacy of sucrose octaacetate, and calculated from weight (not molar).

TABLE III

Relative sweetness of various substances

Substance	Relative sweetness	Method	Reference
1-propoxy-2-amino-4-nitrobenzene	5000	-----------	Blanksma 1946
	4100	1% sucrose	Verkade, van Dijk, and Meerburg 1946; cf. Verkade, van Dijk and Meerburg 1942
	3300	1% sucrose	Blanksma and von der Weyden 1940
1-allyloxy-2-amino-4-nitrobenzene	2000	1% sucrose	Verkade, van Dijk, and Meerburg 1946
α-*anti*-perillaldoxime	2006	-----------	Furukawa 1921
1-ethoxy-2-amino-4-nitrobenzene	1400	1% sucrose	Blanksma and von der Weyden 1940
	1000	-----------	Blanksma 1946
	950	-----------	Verkade, van Dijk, and Meerburg 1946
6-iodo-3-nitroaniline	1250	1% sucrose	Blanksma, van den Broek, and Hoegen 1946
1-*n*-butoxy-2-amino-4-nitrobenzene	1000	1% sucrose	Verkade, van Dijk, and Meerburg 1946
6-bromo-3-nitroaniline	800	1% sucrose	Blanksma, van den Broek, and Hoegen 1946
syn-5-benzyl-2-furfuraldoxime	690	2% sucrose	Gilman and Dickey 1930
Saccharin, as sodium salt	675	2% sucrose	Gilman and Hewlett 1929
	200-700	Varied sucrose	Paul 1922
	190-675	Varied sucrose	Magidson and Gorbachov 1923
1-isopropoxy-2-amino-4-nitrobenzene	600	1% sucrose	Verkade, van Dijk, Meerburg 1946
n-amylchloromalonamide	400	2% sucrose	Dox and Jones 1928
6-chloro-3-nitroaniline	400	-----------	Blanksma 1946
6-chlorosaccharin	ca. 340	-----------	Davies 1921
4-nitro-2-aminotoluene	330	1% sucrose	Blanksma and Hoegen 1946
1-methoxy-2-amino-4-nitrobenzene	330	1% sucrose	Blanksma and von der Weyden 1940
	300	-----------	Blanksma 1946
	220	1% surcose	Verkade, van Dijk, and Meerburg 1946

Substance	Relative sweetness	Method	Reference
1-propoxy-2-amino-4-nitro-6-methylbenzene	310	1% sucrose	Verkade, van Dijk, and Meerburg 1946
n-hexylchloromalonamide	310	6% sucrose	Dox and Houston 1924
N-methyl-*N*-*p*-ethoxyphenylurea	ca. 265	-----------	Bergmann, Camacho, and Dreyer 1922
p-ethoxyphenylurea	265	2% sucrose	Gilman and Hewlett 1929
	70-350	Varied sucrose	Paul 1922
Furylacrylonitrile	200	2% sucrose	Gilman and Hewlett 1929
2-amino-4-nitrophenol	200	1% sucrose	Blanksma and von der Weyden 1940
"*p*-methylsaccharin"	200	-----------	Holleman 1923
Sodium *N*-cyclohexylsulfamate	170	-----------	Hurd and Kharasch 1946
	70	Threshold	Audrieth and Sveda 1944
2-nitro-4-aminobenzoic acid	120	1% sucrose	Blanksma and Hoegen 1946
Sodium aminotriazinesulfonate	100	-----------	Dox and Houston 1924
anti-5-benzyl-2-furfuraldoxime	ca. 100	2% sucrose	Gilman and Dickey 1930
Furonitrile	100	2% sucrose	Gilman and Hewlett 1929
Sodium 2-thiazolylsulfamate	55	-----------	Hurd and Kharasch 1946
anti-phenylacetaldoxime	50	-----------	Asahina and Fujita 1922
m-nitroaniline	40	1% sucrose	Blanksma and von der Weyden 1940
6-fluoro-3-nitroaniline	40	1% sucrose	Blanksma, van der Broek, and Hoegen 1946
Chloroform	40	-----------	Cohn 1914
Ammonium *N*-cyclohexylsulfamate	35	-----------	Audrieth and Sveda 1944
Sodium salicylate	28	1% sucrose	Blanksma and Hoegen 1946
4-nitro-2-aminobenzoic acid	25	1% sucrose	Blanksma and Hoegen 1946
syn-phenylacetaldoxime	25	-----------	Asahina and Fujita 1922
p-methoxyphenylurea	18	-----------	Boedecker and Rosenbusch 1920
Sodium *N*-(2-methylcyclohexyl) sulfamate	17	-----------	Audrieth and Sveda 1944
Dichloromalonamide	9	6% sucrose	Dox and Houston
Ethylchloromalonamide	9	6% sucrose	Dox and Houston
n-propylchloromalonamide	9	6% sucrose	Dox and Houston
Isopropylchloromalonamide	9	6% sucrose	Dox and Houston
n-butylchloromalonamide	9	6% sucrose	Dox and Houston
Salicylic acid	4	1% sucrose	Blanksma and Hoegen 1946
Chloromalonamide	3	6% sucrose	Dox and Houston
Methylchloromalonamide	3	6% sucrose	Dox and Houston

Substance	Relative sweetness	Method	Reference
Furfuraldoxime	2.5	2% sucrose	Gilman and Hewlett 1929
dl-erythritol	2.4	Threshold	Carr, Beck, and Krantz 1930
Fructose	1.7	Threshold	Biester, Wood, and Wahlin 1925; Willaman 1927; cf. Deerr 1922
	1.35	Threshold	Fabian and Blum 1943
	1.03	3% sucrose	Paul 1921; cf. Sale and Skinner 1922
	1.08	3% sucrose	Spengler and Traegel 1927
	1.11-1.20	Varied sucrose	Dahlberg and Penczek 1941; Cameron 1943
Ethylene glycol	1.3	Threshold	Carr, Beck, and Krantz 1936
	0.49	3% sucrose	Paul 1922
dl-alanine	0.93-1.70	Varied sucrose	Heiduschka, Komm, and Simeons 1925
	0.92	3% sucrose	Heiduschka and Komm 1925
Pentaerythritol	1.1	Threshold	Carr, Beck, and Krantz 1936
Glycerol	1.08	Threshold	Carr, Beck, and Krantz 1936
	0.56-0.74	Varied sucrose	Cameron 1944
	0.48	3% sucrose	Paul 1922
Sucrose	1.00	(the	standard)
l-arabitol	1.0	Threshold	Carr, Beck, and Krantz 1936
Glycine	0.46-1.19	Varied sucrose	Heiduschka, Komm, and Simeons 1925
Glucose	0.62-1.00	Varied sucrose	Dahlberg and Penczek 1941
	0.53-0.88	Varied sucrose	Renner 1939
	0.53-0.80	Varied sucrose	Cameron 1943, 1944
	0.52	3% sucrose	Paul 1922; cf. Deerr 1922 and Sale and Skinner 1922
	0.80	Threshold	Fabian and Blum 1943
	0.75	Threshold	Carr, Beck, and Krantz 1936
	0.74	Threshold	Biester, Wood, and Wahlin 1925
i-dulcitol	0.74	Threshold	Carr, Beck, and Krantz 1936
	0.41	3% sucrose	Paul 1922
d-alanine	0.73	3% sucrose	Heiduschka and Komm 1925
Sarcosine	0.62	3% sucrose	Heiduschka and Komm 1925
d-mannitol	0.57	Threshold	Carr, Beck and Krantz 1936
	0.45	3% sucrose	Paul 1922

Substance	Relative Sweetness	Method	Reference
dl-sorbitol	0.54	Threshold	Carr, Beck, and Krantz 1936
	0.48	3% sucrose	Paul 1922
Inositol	0.50	Threshold	Carr, Beck, and Krantz 1936
d-xylose	0.40	Threshold	Carr, Beck, and Krantz 1936
Maltose	0.36-0.57	Varied sucrose	Dahlberg and Penczek 1941
	0.45	Threshold	Fabian and Blum 1943
	0.32	Threshold	Biester, Wood, and Wahlin 1925
Rhamnose	0.32	Threshold	Biester, Wood, and Wahlin 1925
Galactose	0.32	Threshold	Biester, Wood, and Wahlin 1925
Lactose	0.31-0.37	Varied sucrose	Cameron 1944
	0.33-0.60	Varied sucrose	Dahlberg and Penczek 1941
	0.27-0.28	3% sucrose	Paul 1922
	0.31	Threshold	Fabian and Blum 1943
	0.16	Threshold	Biester, Wood, and Wahlin 1925
Quebrachitol	ca. 0.3-0.5	----------	McCance and Lawrence 1933
Raffinose	0.22	Threshold	Biester, Wood, and Wahlin 1925

LITERATURE CITED

Allen and Weinberg. 1925. The gustatory sensory reflex. J. Expt. Physiol. *15*: 385-420.

Anonymous. 1946. Georgia's second meeting-in-miniature. Ind. Eng. News *24*:2917.

Asahina, Y., and A. Fujita. 1922. Furylethylamine. J. Pharm. Soc. Japan *490*:1084-1090.

Audrieth, L. F., and M. Sveda. 1944. Preparation and properties of some N-substituted sulfamic acids. J. Org. Chem. 9:89-101.

Beatty, R. M., and L. H. Cragg. 1935. The sourness of acids. J. Am. Chem. Soc. *57*:2347-2351.

Bergmann, M., F. Camacho, and F. Dreyer. 1922. New derivatives of *p*-phenetylurea (dulcin). Ber. Pharm. Ges. *32*:249-258.

Biester, A., M. W. Wood, and C. S. Wahlin. 1925. Carbohydrate studies. I. The relative sweetness of pure sugars. Am. J. Physiol. *73*:387-396.

Blakeslee, A. F. 1939. Poll of 3121 persons shows wide variation in tastes. Sc. News Letter *35*:51.

Blanksma, J. J. 1946. Preparation of 1-alkoxy-2-amino-4-nitrobenzenes in aqueous solution. Rec. Trav. Chim. *65*:203-206.

Blanksma, J. J. 1946. 1-Halo- and 1-alkoxy-2-amino-4-nitrobenzenes. Rec. Trav. Chim. 65:207-210.

Blanksma, J. J., and D. Hoegen. 1946. Sweet taste of 4-nitro-2-aminotoluene, 4-nitro-2-aminobenzoic acid, and 2-nitro-4-aminobenzoic acid. Rec. Trav. Chim. 65:333-337.

Blanksma, J. J., and P. W. M. van der Weyden. 1940. Relation between taste and structure in some derivatives of *m*-nitroaniline. Rec. Trav. Chim. *59*:629-632.

Blanksma, J. J., W. J. van den Broek, and D. Hoegen. 1946. Sweet taste of the 1-halo-2-amino-4-nitrobenzenes. Rec. Trav. Chim. *65*:329-332.

Boedecker, F., and R. Rosenbusch. 1920. Sweetening power of *p*-hydroxyphenylurea derivatives. Ber. Pharm. Ges. *30*:251-258.

Brigl, P., and W. Scheyer. 1926. Carbohydrates. V. The bitter taste of sugar derivatives. Z. Physiol. Chem. *160*:214-233.

Cameron, A. T. 1943. Relative sweetness of sucrose, glucose and fructose. Trans. Roy. Soc. Canada *37V*:11-27.

Cameron, A. T. 1944. The relative sweetness of certain sugars, mixtures of sugars and glycerol. Can. J. Research *22E*:45-63.

Carr, C. J., F. F. Beck, and J. C. Krantz, Jr. 1936. Sugar alcohols. V. Chemical constitution and sweet taste. J. Am. Chem. Soc. *58*:1394-1395.

Cohn, G. 1914. Die organische Geschmacksstoffe. Berlin. F. Siemenroth.

Crocker, E. C. 1945. Flavor. New York: McGraw-Hill Book Co.

Dahlberg, A. C., and E. S. Penczek. 1941. Relative sweetness of sugars as affected by concentration. Tech. Bull. N. Y. (Geneva) Agr. Expt. Sta. *258*:1-12.

Davies, W. 1921. Cumulative effect of the chlorine atom and the methyl and sulfonyl chloride groups on substitution in the benzene nucleus. J. Chem. Soc. *119*:853-875, 876-887.

Deerr. 1922. Relative sweetness of sucrose, levulose and dextrose. Intern. Sugar J. *24*:481.

Dox, A. W., and B. Houston. 1924. Alkylchloromalonamides. The influence of homology on taste. J. Am. Chem. Soc. *46*:1278-1281.

Dox, A. W., and E. G. Jones. 1928. New derivatives of barbituric acid. J. Am. Chem. Soc. *50*:2033-2036.

Fabian, F. W., and H. B. Blum. 1943. Relative taste potencies of some basic food constituents and their competitive compensatory action. Food Research *8*:179-193.

Furukawa, S. 1920. Relation between the chemical constitution and taste of perfumes (especially aldehydes, ketones, and their derivatives). A new perfume with sweet taste. J. Tokyo Chem. Soc. *41*:706-728.

Gertz, E. 1923. Studies on the liminal stimulation with caffeine and theobromine. Skand. Arch. Physiol. *44*:129-142.

Gilman, H., and J. B. Dickey. 1930. Attempted correlations of constitution with sweet taste in the furan series. J. Am. Chem. Soc. *52*:2010-2013.

Gilman, H., and A. P. Hewlett. 1929. Some correlations of constitution with sweet taste in the furan series. Iowa State Coll. J. Sc. *4*:27-33.

Hartridge, H. 1945. The importance of taste and smell in nutrition. J. Physiol. *103*:34-35.

Heiduschka, A., E. Komm, and A. Simeons. 1925. Relation between constitution and taste of alpha-amino acids. II. The dependence of degree of sweetness of aqueous amino acid solutions on concentration. Z. Angew. Chem. *38*:941-945.

Heiduschka, A., and E. Komm. 1925. Relation between constitution and taste of alpha-amino acids. Z. Angew. Chem. *38*:291-294.

Holleman, A. F. 1923. On some derivatives of saccharin. Rec. Trav. Chim. *42*:839-845.

Hurd, C. D., and N. Kharasch. 1946. Dipolar ion structures of the 2-thiazolylsulfamic acids. J. Am. Chem. Soc. *68*:653-658.

Komm, E., and H. Lämmer. 1940. Intensity of the sour taste of acids used in the confectionery industry. Z. Untersuch. Lebens. *79*:433-454.

McCance, R. A., and R. D. Lawrence. 1933. An investigation of quebrachitol as a sweetening agent for diabetics. Biochem. J. *27*:986-989.

Moncrieff, R. W. 1944. The chemical senses. New York: John Wiley and Sons, Inc.

Paul, T. 1921. Definitions and units of measure in the chemistry of sweeteners. Chem.-Ztg. *45*:705-706.

Paul, T. 1922. The sour taste sensation. Die Umschau *39*:610-612.

Paul, T. 1922. The degree of sweetness of sweet substances. Z. Nahr. Genussm. *43*:137-149.

Renner, H. D. 1939. Some distinctions in the sweetness of sugar. Confectionery Production *1939*:255-256.

Sale, J. W., and W. W. Skinner. 1922. Relative sweetness of invert sugar. J. Ind. Eng. Chem. *14*:522-526.

Scholl, F. M., and J. C. Munch. 1937. Taste tests. IV. Relative bitterness. J. Am. Pharm. Assoc. *26*:127-129.

Spengler, O., and A. Traegel. 1927. Degree of sweetness of fructose as compared with that of sucrose. Z. Ver. Deut. Zuckerind. *77*:1-12.

Täufel, K. 1925. The relation between the chemical structure and taste of sweet-tasting substances (sugars and alcohols). Biochem. Z. *165*: 96-101.

Verkade, P. E., C. P. van Dijk, and W. Meerburg. 1942. New sweet compounds and new local anesthetics. Proc. Nederland Akad. Wetensch. *45*:630-635.

Verkade, P. E., C. P. van Dijk, and W. Meerburg. 1946. Alkoxyaminonitrobenzenes. I. Partial reduction of 1-alkoxy-2,4-dinitrobenzenes with sodium disulfide. The taste of the alkoxyaminobenzenes thus obtained. Rec. Trav. Chim. *65*:346-360.

Wasicky, R., E. Barbieri, and H. Weber. 1942-43. Method of determining the active principle in drugs and preparations by their bitterness. Anais Faculdade Farm. Odontol. Univ. Sao Paulo *3*:113-119.

Wells, H. G., J. S. Huxley, and G. P. Wells. 1934. The science of life. New York: The Literary Guild.

Willaman, J. J. 1927. Tests on the relative sweetness of sucrose and levulose. Z. Ver. Deut. Zuckerind. *77*:365-367.

Willaman, J. J., C. S. Wahlin, and A. Biester. 1925. Carbohydrate studies. II. The relative sweetness of invert sugars. Am. J. Physiol. *73*:397-400.