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SWEETNESS OF VARIOUS COMPOUNDS AND ITS MEASUREMENT [a]

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Sweet substances are noted for their dissimilarity in chemical structure and their marked differences in intensity. The problem of the sweetness of various substances is ever present with the food scientist, especially so when formulation of a product requires substitution of one sweetener for another. The ratio of the sweetnesses of the two products must then be determined. Information in this area is available but from sources using different methods of measurement and different concentrations for comparison. There is definite evidence that the sweetness of one substance relative to another changes, depending on the concentration studied (*2*, *4*).

The studies that have been reported have generally depended on direct comparison of the two stimuli, usually by some variation on the constant stimulus differences techniques. However, many studies have shown that people are quite capable of expressing their judgments of attributes or qualities directly on the basis of an underlying subjective continuum. The purpose of this study was to determine how effectively such an underlying subjective continuum would be related to different concentrations of sweeteners so that the subjective sweetness of various compounds and hence their sweetness relative one to another could be established.

EXPERIMENTAL

The psychophysical method used was that of the single stimulus with a nine-category single-ended rating schedule of intensity. The schedule started with *no intensity* and had subsequent alternate intervals anchored by the terms *slight amount or intensity*, *moderate amount or intensity*, *strong amount or intensity* and, finally, *extreme amount or intensity*.

Materials were the purest available: many were C.P. or U.S.P.; other were specially prepared by an organic chemist. Water for preparation of solutions and for mouth rinsing by the subjects was distilled and percolated through charcoal to remove all taste and odor. The subjects did not know what substances they were testing.

Subjects consisted of 15 employees of this Institute. They were given general information on the nature of the study and their task in assigning each stimulus to a point on the rating scale. They were asked not to smoke or eat for one-half hour before a test and were instructed to rinse their mouths with water at the start of a test session and after each stimulus solution. They were also told to take the whole sample, which consisted of 6 ml., hold it in the mouth for a few seconds, and then expectorate.

Preliminary studies using two substances, sucrose and dextrose, in the same session and with the concentrations approximately arithmetically spaced showed that: (a)

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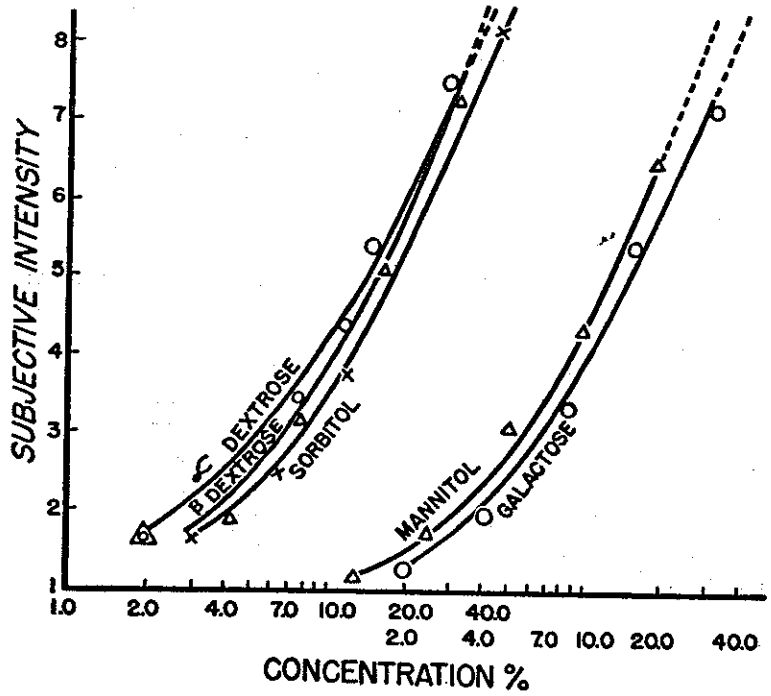

Figure 1. Relation between concentration and subjective intensity. Symbols are actual mean values obtained. Broken lines indicate extrapolation beyond obtained values. (Second line of values on abscissa refer to two compounds on the right of figure.)

mean ratings of subjective intensity plotted against concentration yielded relatively smooth curves; (b) the curves were such that logarithmic spacing should produce nearly straight lines.

For the tests proper, solutions of each substance were prepared in concentrations that were a geometric series with a factor of two; thus sucrose was 2, 4, 8, 16, and 32%. The concentrations were wt. by volume, i.e., g. per 100 ml. of solution. The middle of the series was a concentration that the experimenters judged to be approximately moderately sweet. Exceptions were made for substances that were not sufficiently soluble to fit such a series. In these cases the solubility set the highest concentration but the geometric series was maintained.

Each of 16 substances was measured at a different test session. All sessions were held between 9 and 10 a.m. on Tuesdays and Thursdays. At a session, 10 subjects, drawn as randomly as possible from the pool of 15, participated. Each subject was presented 10 stimuli, two of each of the 5 concentrations, in a random order with a 45-second interval between the time he returned the one-ounce medicine or "shot" glass and the presentation of the next.

The 9 categories of the rating scale were assigned successive integers from 1 to 9 so that the subjective intensity responses could be expressed as numerical scores for analysis. Mean intensity ratings based on 20 judgments for each concentration were obtained, and a least-squares curve was fitted to the means, by applying the method of orthogonal polynomials *(6)*. The assumption was made that the relationship between concentration and subjective intensity is not more complex than one that can be fitted by a quadratic curve. The curve equations were solved for the concentrations of a compound equivalent to mean ratings of intensity from 2 through 8. For comparisons among compounds the ratio of the concentration to sucrose concentration at each of these intensities was computed.

RESULTS AND DISCUSSION

The least squares curve and the actual mean intensities are plotted against concentrations in Figures 1, 2, and 3. Certain general characteristics are observable from these figures. First of all, it is apparent that for most substances the obtained mean ratings do not deviate much from the least squares line. Also, the lines are essentially straight with a slight positive curve in most cases and a few negative curves. It is evident that the log relationship for concentration is one which yields the closest to a straight line function, suggesting that the scale categories are relatively uniform in width. Note that there are 3 points for each concentration of sucrose (Fig. 3) since it was tested on three occasions. Since it was to be used as a standard, a more reliable measure was desirable. Examination of the variation in these points reveals the high degree of reliablity of the method employed. The line for sucrose was computed on the basis of the combined data for the 3 tests.

Mean ratings for lactose and dulcin, which could not be tested within the same range of sweetness as sucrose because of their lack of solubility, indicate that the subjects used the scale in a manner appropriate to the range of sweetness present. Thus, the method is not specific to substances which cover the whole range of intensity. This evidence has been interpreted as supporting the validity of the method.

Figures 4 and 5 show the sweetness curves relative to sucrose for all

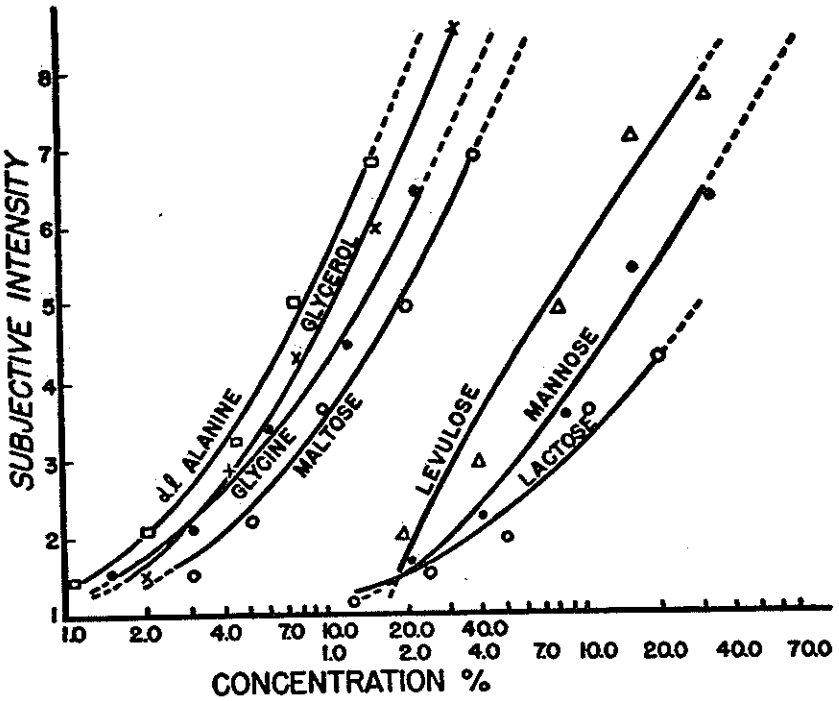

Figure 2. Relation between concentration and subjective intensity. Symbols are actual mean values obtained. Broken lines indicate extrapolation beyond obtained values. (Second line of values on abscissa refer to three compounds on the right of figure.)

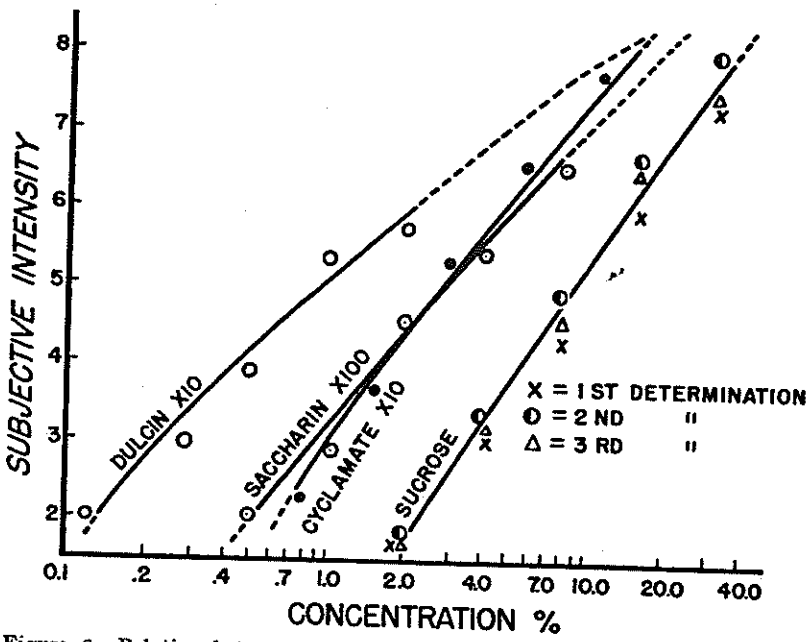

Figure 3. Relation between concentration and subjective intensity. Symbols are actual mean values obtained. Broken lines indicate extrapolation beyond obtained values.

the compounds, for intensities 2 through 8. It is immediately apparent that at first relative sweetness decreases slightly and then increases with increasing concentration. Exceptions to this tendency are levulose which has a fairly constant relative sweetness and the "artificial" sweeteners of entirely different chemical structure, dulcin, saccharin and calcium cyclamate which all decrease in relative sweetness with increasing concentration. The rationale for various types of relative sweetness curves is not easy to develop. Why some substances should become less sweet relative to sucrose as concentration changes while others become more sweet is perplexing. Certain hypotheses can be advanced to explain what may at least contribute to this effect. One possibility is that differences in structure produce differences in diffusion into the receptors. In the case of those compounds which become relatively less sweet there is the possibility that other qualities, especially bitter, may mask the sweetness. Subjective reports of bitter, particularly at the higher concentrations, give some support to this idea but these hypotheses do not explain the results for levulose and sucrose vs. the other related compounds. Changes in relative sweetness with concentration for a number of compounds have been studied by Cameron *(2)* and Dahlberg and Penczek *(4)*. Their results show the same tendency for many substances to become relatively more sweet with respect to sucrose with increasing concentration. However, if glucose were chosen as the standard then most of the natural compounds would exhibit a straight line for the relative sweetness curves and sucrose and levulose would stand out as exceptions.

Figure 1 also reveals another interesting fact. Two forms of *d* dextrose were tested, α and $\alpha\beta$. The $\alpha\beta$ form is the equilibrium mixture

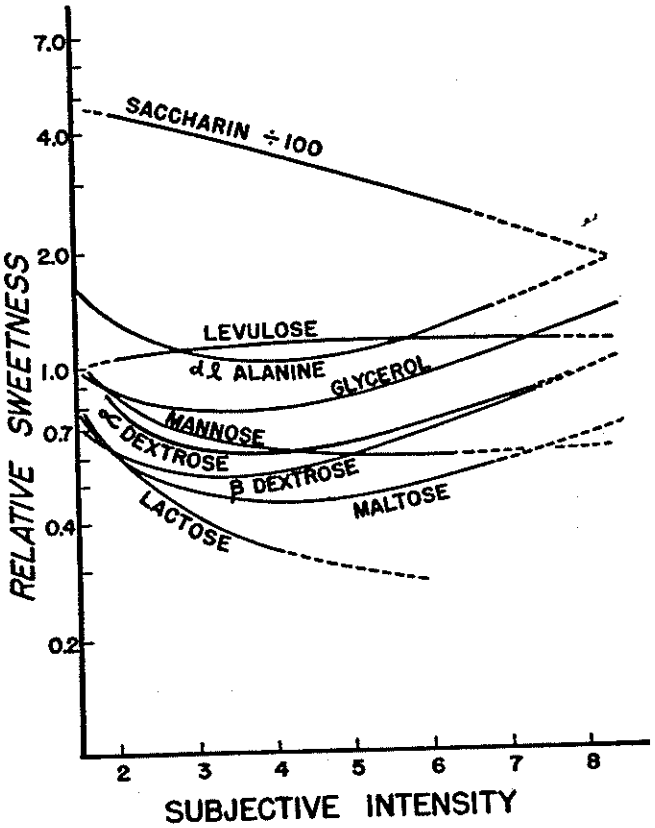

Figure 4. Relative sweetness compared to sucrose at different subjective intensities. Broken lines indicate extrapolation beyond obtained values.

which forms upon standing. Cameron *(3)* did some pilot work which indicated that the α form is the sweeter. This result is borne out by our results and can be seen in the divergence of the two dextrose curves. Note that they merge at the higher intensities.

Table 1 gives the relative sweetness values for each substance at a moderate level of sweetness (5 on the 9 category scale). This represents a subjectively common point to compare the various compounds. Sucrose at this intensity is a 9.12% concentration. The values for these compounds found by other experimenters are also given. Whenever possible the value was chosen which represents a comparison with a 10% sucrose solution. In order to give an idea of the values obtained when comparisons are made by determining absolute thresholds, several of this type are included.

Examination of Table 1 shows that the pattern of results obtained in the present experiment is comparable to that obtained by other experimenters. The actual values are in many cases very close even though the psychophysical methods used were different. The order for other levels of intensity are very much the same as can be observed by examination of Figures 4 and 5. In most cases the curves do not cross each other.

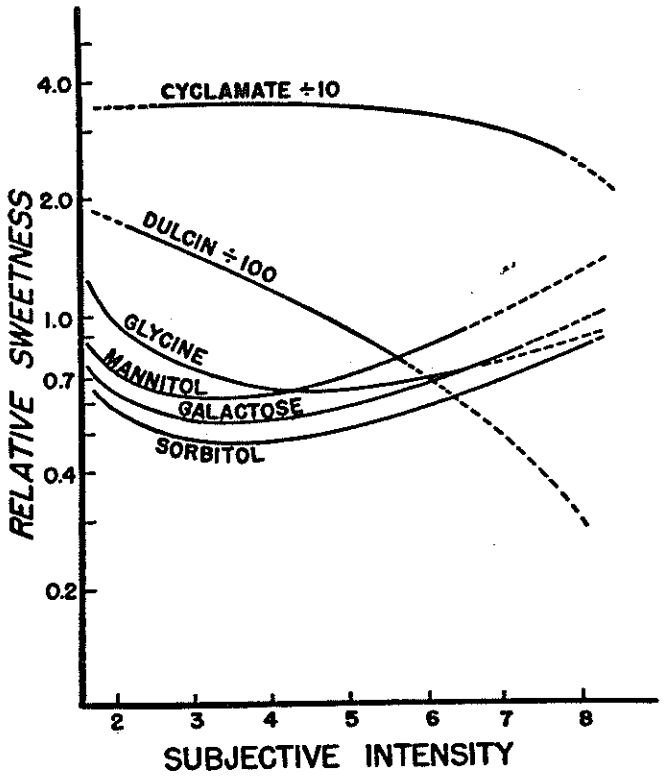

Figure 5. Relative sweetness compared to sucrose at different subjective intensities. Broken lines indicate extrapolation beyond obtained values.

TABLE 1

Sweetness relative to sucrose at moderate intensity (9.12% sucrose)

Substance	Schutz-Pilgrim	Other investigators [1]
Saccharin	306.0	675 (7)[2]
Dulcin	90.7	265 (7)[2]
Ca. Cyclamate	33.8	
Levulose	1.15	1.15 (4), 1.16 (2), 1.75 (1)[3]
DL-Alanine	1.07	.90 (10)
Glycerol	.84	.77 (2), 1.08 (3)[3]
Mannitol	.72	.62 (3)[3]
Glycine	.65	.62 (10)
α-Dextrose	.64	
α,β-Dextrose	.61	.79 (4), .68 (2), .65 (8), .76 (9), .74 (1)[3]
Galactose	.59	.67 (2), .32 (1)[3]
D-Mannose	.59	
Sorbitol	.51	.54 (3)[3]
Maltose	.46	.47 (4), .32 (1)[3]
Lactose	.30	.48 (4),[4] .38 (2), .16 (1)[3]

[1] Compared with 10% sucrose unless otherwise noted.
[2] Compared with 2% sucrose.
[3] Ratio of concentrations at absolute threshold.
[4] β-Lactose.

TABLE 2

Mean values for seven compounds in order of subjective intensity and significant differences between compounds at 1% level of significance

Compound	Mean value [1]
Levulose	4.95
Sucrose	4.92
Sucrose	4.70
Glycerol	4.58
Sucrose	4.49
α-Dextrose	4.07
D-Mannose	3.86
Galactose	3.84
α,β-Dextrose	3.83

[1] The values contained within the same bracket are not significantly different from one another.

An analysis of variance was conducted for the 7 compounds which were tested at the same concentrations. Only compounds studied at the same concentrations could be analyzed in the variance model employed. Since sucrose was tested three times a total of 9 sessions were analyzed. The over-all analysis revealed that there were significant differences among compounds (and levels of concentration, of course), but no significant interaction, indicating that the slopes were essentially the same. In order to determine which compounds contributed to the significance found in the analysis of variance a Duncan multiple range test *(5)* was applied. The results are shown in Table 2. The 3 sucroses do not differ significantly from each other, and this fact can be interpreted as indicating the reliability of the method although it is recognized that compound is confounded with session. However, if a sensitive test of the relative intensity of 2 compounds is required, they should both be rated in the same session by the same subjects. In addition, the concentration-subjective intensity relationship was tested for quadratic curvature. This curvature can be seen visually in Figures 1, 2, and 3. Glycerol, galactose, α-dextrose and α,β-dextrose were significantly curved. If the values for these compounds are used as a guide it can be estimated that of the compounds not included in the analysis, sorbitol, mannitol, and DL-alanine also have significant curvature.

SUMMARY

Sixteen compounds were rated on a subjective intensity scale for sweetness at each of five concentrations. The method of single stimuli using this subjective intensity scale yields results which are meaningful and reliable and which are more easily obtained than the more traditional methods such as paired comparisons. The relationship between subjective sweetness and concentration was established. It is basically logarithmic. The ratios of the concentration of each of 15 of the compounds to the concentration of sucrose of the same subjective intensities were computed to determine their relative sweetnesses. As subjective intensity or concentration increases relative sweetness varies in one of three patterns depending on the compound.

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