Studies on the Taste of Some Sweet Substances

Part I. Measurement of the Relative Sweetness†

By Shizuko YAMAGUCHI, Tomoko YOSHIKAWA,
Shingo IKEDA and Tsunehiko NINOMIYA

Central Research Laboratories, Ajinomoto Co., Inc.

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The sweetness of various sweet substances, such as sugars, synthetic sweeteners, and amino acids were evaluated by sensory analysis. The relative sweetness varied in many ways as the concentration increased and the quantitative relationships between the sweetness and the concentration were established. The substances were classified according to their patterns of the taste intensity curves.

As to the sweet substances most familiar to all people, many attempts have been made to express the taste quantitatively.^{1~10)} However, most of the reports so far offered are somewhat fragmentary, and since the conditions of experiment and methods of measurement are different according to each investigator, some results are in agreement with that obtained by other investigators and some are not. On the other hand, we are already told that there are some particular interactions of taste among some sweet substances^{1~4, 8~10)} and this fact deeply interests us in dealing with taste at large. It is regrettable, however, that, we have had actually only a few systematic reports^{2, 8)} on this point among many piecemeal ones.

So the present authors would like to quantify the taste of sweet substances as systematically and accurately as possible, and to give some order to the present confused me-

asurement of taste so that the foundation of the measurement of taste may be consolidated. This paper deals with the relative sweetness of various sweet substances.

MATERIALS AND METHODS

1. *Materials.* The test materials used in this experiment are listed in Table I. All compounds had a purity over 99%.

2. *Procedure.* In general, the traditional methods of measuring suprathreshold taste intensity may be summed up under one of the following two—one concerned with the psychological intensity of taste stimuli and the other concerned with relative taste effectiveness of different substances in eliciting equal taste intensity. The present experiment has been undertaken on the latter. The methods of experiment and data analysis employed here may be of the highest degree of reliability in obtaining the exact values of the relative taste intensity. However, since it takes plenty of time and needs a considerable amounts of

† The outline of this work was presented at the Symposium on the flavor of foods of the Kanto Division of the Agricultural Chemical Society of Japan, held at Tokyo, February 8, 1969.

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TABLE I. TEST MATERIALS

Abbreviation	Material	Maker	Grade
Suc	Sucrose	Junsei Pure Chemicals Co., Ltd.	J.S. ^{a)}
Fru	D-Fructose	Kokusan Chemical Works, Ltd.	J.S.
Glu	D-Glucose	Koso Chemical Co., Ltd.	J.S.
Xse	D-Xylose	Nippon Rikagakuyakuhin Co., Ltd.	J.S.
Sit	D-Sorbitol	Wako Pure Chemical Industries, Ltd.	J.S.
Xit	D-Xylitol	Nippon Kayaku Co., Ltd.	J.P. ^{b)}
Mit	D-Mannitol	Junsei Pure Chemicals Co., Ltd.	J.S.
Cyc	Sodium cyclamate	Kyowa Organic Chemicals	F.S. ^{c)}
Sacc	Sodium saccharin	Daito Chemical Industries, Ltd.	F.S.
Gly	Glycine	Ajinomoto Co., Inc.	J.S.
DL-Ala	DL-Alanine	Ajinomoto Co., Inc.	J.S.
D-Try	D-Tryptophan	Ajinomoto Co., Inc.	J.S.

^{a)} JIS Special Grade.

^{b)} Japanese Pharmacopoeia.

^{c)} Japanese Food Additive Standard.

test materials, only few investigators have made such a detailed experiment.

In this experiment, the sweetness of test sample in a given concentration was represented by the concentration of sucrose required to attain the equivalent sweetness to the test sample: A test solution was paired with a set of sucrose solutions consisting of five concentrations. Five concentrations were determined, in logarithmically equal steps, at 5% interval and ranged from clearly less sweet to clearly sweeter than the test samples. However, in the case of the samples such as glycine, alanine *etc.* whose quality of taste was considerably different from that of sucrose, the interval was extended by two times. Since the α - and β -anomers of the sugars differ in sweetness, care was taken to ensure that the solutions of fructose, glucose, and xylose, were fully mutarotated. The concentrations of the test samples are shown in Table II. Five pairs of samples were presented to each panelist in a randomized order. The panelists were asked to indicate which one in each pair had a stronger sweetness. The comparisons were conducted only on the intensity of sweetness regardless of the quality of taste. The number of replications for each pair was twenty-five or fifty. The data were obtained as dichotomous judgments which were then converted into the proportion of judgments that the control sample had a stronger sweetness than a reference, and analyzed by the probit method.

3. Panel and experimental conditions. The panel

consisted of one hundred people who were screened from approximately one thousand employees of the Ajinomoto Co., Inc. on the basis of their sensitivity of taste. The age of the panelists, both men and women, ranged from eighteen to fifty years.

Distilled water was used for preparing the solutions and for oral rinsing. The solutions were presented in 40 ml portions in randomly coded glasses. All tests were accomplished in individual taste booths which were air-conditioned and equipped with constant illumination.

RESULTS AND DISCUSSION

The data obtained are shown in Table II. Figures 1 and 2 show the sweetness curves relative to sucrose for all the compounds examined in this paper. As has already been shown by many investigators,¹⁻⁸⁾ the relative sweetness varies in many ways as the concentration increases. Fructose and sodium cyclamate have a fairly constant relative sweetness to sucrose within the limit of the experimental range. However, some substances such as glucose and xylose become sweeter relative to sucrose, while the others such as sodium saccharin and D-tryptophan become less sweet as concentration varies. In one of the most comprehensive studies published,

TABLE II. EQUIVALENT SWEETNESS OF VARIOUS SWEET SUBSTANCES
IN TERMS OF SUCROSE CONCENTRATIONS

Compound	Control sample Concentration x (g/100 ml)	No. of replications n	Equi-sweet sucrose concn. y (g/100 ml)	Standard ^{a)} deviation ($1+\Delta y$)
Fru	2.5	50	3.30	1.01
	5.0	50	6.66	1.01
	10.0	50	12.3	1.01
	20.0	25	24.7	1.02
Glu	2.5	25	1.40	1.02
	5.0	50	2.80	1.01
	10.0	50	6.32	1.01
	20.0	50	14.4	1.01
	30.0	25	23.0	1.02
	40.0	25	33.0	1.04
Xse	2.5	25	1.42	1.02
	5.0	25	2.96	1.02
	10.0	25	6.49	1.02
	20.0	25	15.7	1.02
	40.0	25	35.0	1.02
Sit	2.5	50	1.37	1.01
	5.0	50	2.71	1.01
	10.0	25	5.79	1.02
	20.0	25	14.2	1.02
	40.0	25	32.8	1.02
Xit	2.5	50	2.40	1.02
	5.0	50	5.03	1.02
	10.0	50	10.2	1.01
	20.0	50	21.6	1.01
	30.0	50	35.3	1.02
Mit	5.0	50	2.55	1.02
	10.0	50	5.60	1.01
	15.0	50	9.32	1.01
Cyc	0.05	25	1.62	1.03
	0.1	50	3.23	1.01
	0.2	50	5.84	1.02
Sacc	0.0025	25	1.24	1.03
	0.005	25	2.13	1.02
	0.01	25	3.54	1.02
	0.02	25	5.41	1.01
	0.04	25	7.40	1.02
	0.08	25	9.18	1.02
Gly	3.0	50	2.72	1.04
	6.0	25	4.44	1.03
	9.0	25	5.60	1.07
DL-Ala	2.5	25	3.29	1.02
	5.0	50	4.80	1.02
D-Try	0.025	25	1.59	1.03
	0.05	50	2.98	1.01
	0.1	50	5.11	1.02
	0.2	25	8.50	1.03
	0.4	25	11.5	1.02

^{a)} In terms of the value of a ratio, *i.e.*, the upper and the lower deviations of observed y are given as $y \times (1 + \Delta y)$ and $y \div (1 + \Delta y)$, respectively.

FIG. 1. Sweetness Curves for Various Sugars in Terms of the Equi-sweet Sucrose Concentrations.

●—● Fru, ○—○ Glu, ▲—▲ Xse,
■—■ Sit, □—□ Xit, △—△ Mit.

FIG. 2. Sweetness Curves for Synthetic Sweeteners and Amino Acids in Terms of the Equi-sweet Sucrose Concentrations.

○—○ Cyc÷50, ●—● Sacc÷100,
□—□ Gly, ▲—▲ DL-Ala,
×—× D-Try÷50

Cameron²¹ reported that the relative sweetness of the group of compounds, glucose, galactose, lactose, glycerol, and mannitol, when compared with any one of them, does not change with varying concentration, while the relative sweetness of these and of fructose and dulcin, when compared with sucrose, changes with varying concentration and the relation is of log-log nature. For the general sensations, including the taste sense, Stevens¹¹⁾ discovered that the relationship between the objective intensity of stimulus, s , and the psychological intensity, R , could be expressed by a power function, $R=ks^m$, where k and m are constants. If this power law equation holds for our sweet substances in general, the relationship between the concentration of the test material, x g/100 ml, and the equivalent concentration of sucrose, y g/100 ml, must also be expressed as $y=ax^n$, where a and n are constants. In another words, log concentration

11) S. S. Stevens, *Amer. Scientist*, **48**, 226 (1962).

of the test substance bear a linear relationship to equally sweet log concentration of sucrose as given by the equation,

$$\log y = \log a + n \log x \quad (1)$$

Figures 3 and 4 shows log-log relations of

FIG. 3. Log-log Relationships between Sucrose and other Sugars.

●—● Fru, ○—○ Glu, ▲—▲ Xse,
■—■ Sit, □—□ Xit, △—△ Mit.

FIG. 4. Log-log Relationships between Sucrose and Synthetic Sweeteners or Amino Acids.

○—○ Cyc ÷ 100, ●—● Sacc ÷ 1000,
□—□ Gly, ▲—▲ DL-Ala,
×—× D-Try ÷ 100.

our data. In most of substances tested, the relations are well represented by straight lines, and are in good agreement with the results of Cameron. However, sodium saccharin and sweet amino acids were found to be exceptional in that the plotted curves deviated apparently from straight lines. In these cases, the deviations are likely attributable to the remarkable qualitative differences in taste of the substances from sucrose. In fact, saccharin has somewhat bitter taste at higher concentrations and sweet amino acids have complicated taste in addition to sweetness. Equation (1) was applied to each of the substances which showed approximately straight lines in Figs. 3 and 4. The results are summarized in Table III.

Now, in order to classify the sweet substances according to their patterns of the taste intensity curves, we may define a concept of the term *identical* as follows: Let $f_A(x)$ and $f_B(x)$ be the values of taste intensity given in a certain scale of measurement to a concentration, x , of any given two substances A and B, respectively. If a relationship $f_A(x) = f_B(\theta x)$ (θ : constant) holds for any x in a certain range

TABLE III. FUNCTIONS RELATING THE CONCENTRATION, x , OF INDIVIDUAL SWEET SUBSTANCES TO EQUI-SWEET SUCROSE CONCENTRATION, y

Fru: $y = 1.28x$	Xit: $y = 0.908x^{1.06}$
Glu: $y = 0.451x^{1.16}$	Mit: $y = 0.394x^{1.16}$
Xse: $y = 0.473x^{1.16}$	Cyc: $y = 31.2x$
Sit: $y = 0.437x^{1.16}$	

of concentration, then the patterns of the substances A and B are called to be identical. Then, if the patterns of two substances are identical, a single numerical value, θ , can adequately represent the relative sweetness between them.

In the present experiment, among a group consisted of sucrose, fructose, and sodium cyclamate, and a group consisted of glucose, xylose, sorbitol, and mannitol, the taste intensity patterns are identical, respectively.

The pattern of xylitol is somewhat different from these two types. According to the data of Cameron, the patterns of galactose, lactose, and glycerol may also be identical to that of the glucose group. The patterns of sodium saccharin and amino acids are similar to each

other in some degree, but not always exactly identical.

Relationships between the patterns of the relative sweetness curves and the chemical structures are perplexing and not easily explained at this stage of research.