Temperature and pH effects on the relative sweetness of suprathreshold mixtures of dextrose fructose¹

HERBERT STONE,² SHIRLEY OLIVER AND JOAN KLOEHN
LIFE SCIENCES DIVISION, STANFORD RESEARCH INSTITUTE

Increasing the temperature from 5 deg to 50 deg C did not significantly alter the relative sweetness of aqueous solutions of dextrose, fructose, and their combination, as measured by the method of magnitude estimation, with a panel of 12 experienced Ss. Reducing pH from 5.8 to 2.7 caused about a 50% reduction in relative sweetness for all stimuli tested. The slopes of these lines tended to decrease slightly, whereas the Y-intercept values showed the greatest change. In all experiments the slopes of the lines were reasonably stable, averaging 1.40 vs 1.3 reported by Stevens (1961) for sucrose. The results of these experiments are discussed in relation to previously reported data on taste interactions.

In a study reported earlier (Stone & Oliver, 1968), it was observed that mixtures of selected sugars were significantly sweeter than the simple addition of their individual sweetness as measured by the method of magnitude estimation. Of all the sugars and sugar mixture combinations studied, the largest effect, about 35%, was noted with dextrose-fructose mixtures. It was of interest to investigate to what extent such factors as temperature and pH influenced the estimates of relative sweetness intensity for this sugar mixture. Sato (1967), in a recent review on the effect of temperature on gustatory response, summarized the human evidence as somewhat contradictory, depending on the stimuli (sweet, sour, salty, or bitter), and the experimental temperatures. In experiments with mammals other than man, Sato reported that when the tongue was preadapted to the experimental temperature the response to various taste stimuli was greatest when the stimulus was at the temperature of the tongue (approximately 30 deg C). This response usually decreased in magnitude at either extreme (10 deg or 50 deg C), although he cautioned against simple extrapolation from one animal species to another and from one taste quality to another. In man, the situation appears to be no less confusing. Pfaffmann (1959) summarized much of the work by pointing out that temperature effects were variable, citing Goudrian (1930) as reporting apparent taste intensity of sugar solutions increasing with temperatures changing from 10 deg to 40 deg C. Tsuzuki and Yamazaki (1953) reported the relative sweetness intensity of fructose decreased going from 5 deg to 60 deg C.

The effect of pH on the relative sweetness of sugars is generally conceded to be one of depression. In a series of studies with acetic, citric, lactic, and tartaric acids, Pangborn (1961, 1965) found all four depressed the sweetness intensity of the four test sugars (sucrose, fructose, glucose, lactose).

Since previous investigators had employed single sugars and not mixtures, we felt it desirable to report our results using suprathreshold mixtures of dextrose-fructose solutions.

METHOD

Subjects

Twelve persons, all of whom had prior experience with taste testing, were used as the panel. Each S participated in every experiment and missed sessions were made up as soon as possible. The Ss were tested individually approximately the same time of day throughout the experiment.

Stimuli

This study was divided into two parts; the first part

considered the effect of temperature and the second the effect of pH.

The test stimuli for both experiments were dextrose (highest purity, Corn Products Company) and fructose (Mann Assayed, CP, S1290). The pH was adjusted with citric acid. All compounds had a purity in excess of 99%.

Glass-distilled, charcoal-filtered water was used to prepare the solutions and was available to Ss for rinsing purposes. All solutions were prepared approximately 24 h before testing and were discarded after 48 h. Fresh solutions were prepared for make-up tests. Distilled water also was prepared fresh every three days.

Each solution was prepared on a wt/vol basis. All solutions were stored and tested at 21 deg $\pm$ 2 deg C except for those used in the temperature experiment. For each single-sugar and sugar-mixture experiment, a series of four (and sometimes five) solutions (usually $\log_2$) were prepared.

For the temperature experiments care was taken to minimize moisture loss and temperature variations. Stock solutions were maintained at the elevated temperature by means of a covered, heated tray and removed only for the time required to pour out a sample. For the lower temperature we used a small cooling unit. To adjust pH, we used citric acid in either crystalline or aqueous form, depending on the amounts required. Corrections were made for the dilution caused when water was used.

Procedures

The method of magnitude estimation was used to obtain the relative sweetness of the individual sugars and the sugar mixtures (Stevens, 1961). S was informed of the test procedure and that he would receive a reference of identified intensity (10). The reference always was 0.25-M sucrose, although Ss were not informed of this fact. The reference was usually at the geometric mean of the series. The rationale for our procedure has been described elsewhere (Stone & Oliver, 1968).

Initially the relative sweetness was established for the single sugars and then for the mixtures. The second sugar always was the fructose, added at two different concentrations (0.0625 and 0.125 M).

Test solutions were presented in a random sequence and each of the 12 Ss was tested five times at each concentration.

Analysis

Analysis of the data was accomplished making use of the "Psychofit" program (kindly provided by Professor Trygg Engen and Mr. Alan Kalikow, Brown University). Data input included individual responses and stimulus concentrations, and, where appropriate, reference estimations. Output included pooled geometric means for each stimulus, variance, standard deviations, medians, first and third quartile values, equations of the line through the geometric means, least-square line through the medians (for normalized and nonnormalized data), and Pearson R and R². Other data also were available.

RESULTS

In the first experiment, increasing or decreasing the temperature did not significantly alter the relative sweetness of

Table 1
Magnitude Estimates of the Relative Sweetness of Dextrose and Fructose and
Their Mixtures as a Function of Temperature^a

	Sugar (Molar concentration)					
	0.0625	0.125	0.25	0.50	1.0	2.0
At Temperature of 5 deg C (± 1 deg C)						
Dextrose	—	0.19	0.48	2.21	14.11	27.91
	—	(0.06-0.6)	(0.38-0.97)	(1.4-2.9)	(5.8-33.6)	(13.4-55.8)
Fructose	0.43	1.06	3.68	12.05	23.71	—
	(0.18-1.0)	(0.86-1.9)	(2.6-4.9)	(6.9-14.7)	(14.9-25.7)	—
Dextrose + 0.0625-M Fructose	—	0.79	4.01	7.13	21.31	—
	—	(0.4-1.6)	(3.3-5.7)	(5.4-9.2)	(14.2-23.7)	—
Dextrose + 0.125-M Fructose	—	1.55	3.01	10.07	19.43	—
	—	(0.84-4.8)	(1.8-6.4)	(8.6-13.1)	(16.8-22.2)	—
At Temperature of 22 deg C (± 2 deg C)						
Dextrose	—	0.44	1.07	4.29	15.73	32.53
	—	(0.22-0.89)	(0.88-1.7)	(3.1-5.3)	(8.4-21.1)	(20.8-43.3)
Fructose	0.59	1.66	3.99	12.69	24.17	—
	(0.7-1.5)	(1.4-1.9)	(2.9-4.3)	(8.6-16.6)	(17.4-30.8)	—
Dextrose + 0.0625-M Fructose	—	1.33	2.65	7.46	22.09	—
	—	(0.89-2.2)	(2.2-3.0)	(5.9-9.5)	(14.8-32.2)	—
Dextrose + 0.125-M Fructose	—	2.03	4.14	10.59	26.88	—
	—	(1.4-2.7)	(3.2-5.3)	(8.9-12.0)	(20.4-31.1)	—
At Temperature of 50 deg C (± 5 deg C)						
Dextrose	—	0.70	1.69	5.56	16.65	29.12
	—	(0.49-1.2)	(1.3-2.1)	(4.4-6.5)	(12.1-19.2)	(20.2-33.6)
Fructose	0.84	1.72	5.18	13.33	25.69	—
	(0.75-1.5)	(1.5-2.4)	(3.8-6.1)	(9.5-12.9)	(17.4-27.2)	—
Dextrose + 0.0625-M Fructose	—	1.50	3.01	9.95	21.42	—
	—	(1.6-2.1)	(2.4-4.3)	(7.7-9.9)	(14.8-26.6)	—
Dextrose + 0.125-M Fructose	—	2.46	4.60	12.13	22.63	—
	—	(2.1-3.5)	(4.1-5.4)	(9.5-13.9)	(14.6-29.4)	—

^a In all experiments the reference, 0.25-M sucrose was designated as 10 and was served at room temperature (22 deg C). Each entry is the geometric mean of 60 responses. Entries in parenthesis are the first and third quartile values.

the single sugars or of the mixtures. These data are summarized in Tables 1 and 2. Although the relative sweetness intensity values were slightly greater at the higher temperature, these differences were not statistically significant.

Results of changing pH are summarized in Tables 3 and 4. In these experiments, adjusting pH to 2.7 produced a not unexpected decrease in the relative sweetness. Changing the pH to 4.0 did not influence the relative sweetness.

It was of interest to find that the slopes of the lines in these experiments were consistent with our previously reported

results using an entirely different panel (Stone & Oliver, 1968). In the present study the average slope value was 1.40 vs 1.16 in that experiment. In general, we found that the slope values varied between Ss in an experiment, but were less variable between experiments for any one S.

DISCUSSION

The fact that no significant changes in relative sweetness occurred after changing the temperature was quite surprising in view of previously reported results. The two previously

Table 2
Summary Statistics—Slope Values, Variances, Standard Deviations, Y-Intercepts, and
Correlation Coefficients (R) for the Temperature Experiments

	Slope	Variance	SD	Y-intercept	R
At Temperature of 5 deg C (± 1 deg C)					
Dextrose	1.9318	1.1774	1.0851	-0.0396	0.9603
Fructose	1.5061	0.5988	0.7738	0.4438	0.9665
Dextrose + 0.0625-M Fructose	1.5076	0.5094	0.7137	0.3517	0.9680
Dextrose + 0.125-M Fructose	1.2690	0.4350	0.6595	0.3130	0.9795
At Temperature of 22 deg C (± 2 deg C)					
Dextrose	1.6491	0.4576	0.6765	0.0935	0.9745
Fructose	1.3675	0.4120	0.6418	0.4384	0.9684
Dextrose + 0.0625-M Fructose	1.3642	0.1977	0.4446	0.7183	0.9829
Dextrose + 0.125-M Fructose	1.2534	0.0995	0.3155	0.7881	0.9797
At Temperature of 50 deg C (± 5 deg C)					
Dextrose	1.4186	0.5060	0.7114	0.1240	0.9797
Fructose	1.2820	0.6723	0.8199	0.4538	0.9821
Dextrose + 0.0625-M Fructose	1.3218	0.4319	0.6572	0.3431	0.9774
Dextrose + 0.125-M Fructose	1.1000	0.2358	0.4856	0.3698	0.9830

Table 3
Magnitude Estimates of the Relative Sweetness of Dextrose and Fructose and
Their Mixtures as a Function of pH^a

	Sugar (Molar concentration)					
	0.0625	0.125	0.25	0.50	1.0	2.0
At pH 5.8						
Dextrose	—	0.44	1.07	4.29	15.73	32.53
	—	(0.22-0.89)	(0.88-1.7)	(3.1-5.3)	(8.4-21.1)	(20.8-43.3)
Fructose	0.59	1.68	3.99	12.69	24.17	—
	(0.7-1.5)	(1.4-1.9)	(2.9-4.3)	(8.6-16.6)	(17.4-30.8)	—
Dextrose + 0.0625-M Fructose	—	1.33	2.65	7.46	22.09	—
	—	(0.89-2.2)	(2.2-3.0)	(5.9-9.5)	(14.8-32.2)	—
Dextrose + 0.125-M Fructose	—	2.03	4.14	10.59	26.88	—
	—	(1.4-2.7)	(3.4-5.3)	(8.9-12.0)	(20.4-31.1)	—
At pH 4.0						
Dextrose	—	0.42	1.12	3.99	15.46	33.29
	—	(0.14-0.98)	(0.96-1.9)	(3.2-5.0)	(9.6-20.7)	(17.3-50.4)
Fructose	0.79	1.60	4.21	14.38	28.06	—
	(0.4-1.5)	(1.2-2.2)	(3.7-4.6)	(8.8-18.7)	(16.3-39.4)	—
Dextrose + 0.0625-M Fructose	—	1.42	2.66	7.61	21.48	—
	—	(1.2-2.1)	(2.1-3.4)	(5.8-9.8)	(15.9-27.2)	—
Dextrose + 0.125-M Fructose	—	2.70	4.68	11.78	24.75	—
	—	(1.8-3.8)	(4.6-5.2)	(9.2-14.9)	(18.9-32.1)	—
At pH 2.7						
Dextrose	—	0.30	0.61	1.98	9.68	18.64
	—	(0.19-0.78)	(0.51-1.3)	(1.6-2.3)	(4.2-13.6)	(6.2-23.6)
Fructose	0.28	0.55	2.27	10.69	18.69	—
	(0.09-0.76)	(0.35-1.4)	(1.8-2.7)	(4.4-16.3)	(8.4-25.4)	—
Dextrose + 0.125-M Fructose	—	1.54	3.08	8.51	17.91	—
	—	(1.3-2.4)	(2.9-3.9)	(6.4-9.9)	(11.9-21.4)	—

^a In all experiments the reference, 0.25-M sucrose, was designated as 10 and was served at pH 5.8. Each entry is the geometric mean of 60 responses. Entries in parenthesis are the first and third quartile values.

cited reports (Goudrian, 1930; Tsuzuki & Kamazaki, 1953) were in disagreement suggesting that the higher temperature would produce both an increase and a decrease in the relative sweetness for a sugar. In the present study, the relative sweetness tended to increase with increasing temperature; however, the differences were quite small and did not approach statistical significance. In fact, we are impressed by the remarkable stability of the responses over this wide temperature range.

At the higher temperature, 50 deg C, we reported a maximum range of ± 5 deg which was the exception. In most cases the temperature range was less than ± 2 deg; however, occasionally this became larger in spite of our efforts so we

have reported the maximum values. Observation of the responses for individual Ss did not reveal any inconsistencies in their data when these variations occurred.

The failure to demonstrate a decrease in the relative sweetness of the solutions adjusted to pH 4.0 was unexpected. It is hypothesized that this pH is not sufficiently acidic and Ss may have confused this level of sourness with sweetness. Such occurrences have been reported by other investigators (Pangborn, 1961; Pangborn & Trabue, 1967). Interestingly, Ss commented that the solutions were pleasant and preferred over the test stimuli used in previous experiments.

Recently, Gregson (1968) hypothesized that taste interactions such as the one reported here between the citric acid

Table 4
Summary Statistics—Slope Values, Variances, Standard Deviations, Y-Intercepts, and
Correlation Coefficients (R) for the pH Experiments

	Slope	Variance	SD	Y-intercept	R
At pH 5.8					
Dextrose	1.6491	0.4576	0.6765	0.0935	0.9745
Fructose	1.3675	0.4120	0.6418	0.4384	0.9684
Dextrose + 0.0625-M Fructose	1.3642	0.1977	0.4446	0.7183	0.9829
Dextrose + 0.125-M Fructose	1.2534	0.0995	0.3155	0.7881	0.9797
At pH 4.0					
Dextrose	1.6374	0.4560	0.6753	0.5838	0.9823
Fructose	1.3453	0.2813	0.5304	0.4770	0.9749
Dextrose + 0.0625-M Fructose	1.3280	0.3626	0.6022	0.2972	0.9735
Dextrose + 0.125-M Fructose	1.0916	0.1273	0.3568	0.3846	0.9795
At pH 2.7					
Dextrose	1.5917	1.2607	1.1228	-0.1582	0.9644
Fructose	1.6442	1.2613	1.1231	0.3571	0.9583
Dextrose + 0.125-M Fructose	1.2073	0.4613	0.6792	0.2603	0.9814

and dextrose-fructose mixtures may be artifacts of the response measure employed by the E. Since our experiments were only concerned with intensity of perceived sweetness, it is not possible to consider whether, in fact, this taste interaction is artifactual or not. It would be most interesting to reconsider these pH experiments (especially at pH 4.0) using methods as described by Gregson (Cases i to v, p. 127).

The fact that the reference always was sucrose did not appear to cause any difficulty on the part of the panel. In our previous study (Stone & Oliver, 1968) changing the reference or the stimulus tended to shift the Y-intercept but not necessarily the slope of the line.

One additional aspect of this study worth mentioning is the remarkable stability of the synergistic effect described earlier for dextrose-fructose mixtures. The addition of a small amount of the fructose to dextrose produced a mixture sweeter than what one expects from a simple addition of their respective relative sweetness values. Where relative sweetness intensity was depressed, all solutions were affected equally.

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NOTES

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2. Address: Life Sciences Division, Stanford Research Institute, Menlo Park, Calif. 94025

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