POTENCY OF SWEETNESS OF ASPARTAME, D-TRYPTOPHAN AND THAUMATIN EVALUATED BY SINGLE VALUE AND TIME-INTENSITY MEASUREMENTS

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ABSTRACT

Perceived sweetness of sucrose, aspartame, D-tryptophan and thaumatin in a sour, citric acid background was analyzed in terms of the potency of these compounds relative to sucrose-water combinations. Potencies of the sweeteners were determined from (1) maximum intensity using single value and time-intensity (T-I) measurements and (2) average intensity calculated as the ratio of area under the T-I curve and total perceived time. Stevens' law was applied to sweet responses, either in static or dynamic conditions. It was found that the exponent of the concentration-response function reflected the relative capacity of a compound to sweeten a given food and stressed differences of potency among sweeteners. Aspartame, D-tryptophan and thaumatin exhibited a decrease in sweetness potency relative to sucrose as sweetness increased from 10 to 100% of the full scale of response. Across the entire sweetness range, thaumatin showed the greatest potency but its long persistence time led to differentiate this intense sweetener from the other sweeteners evaluated.

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INTRODUCTION

The potency of sweeteners is a very useful index for food technologists to answer the question concerning the amount of sweetener A that tastes as sweet as sweetener B in a given food. Usually, the unit of sweetness is the concentration of sucrose as the reference sweetener. Alternatively, a given concentration of the sweetener served as a reference to determine the concentration of sucrose required to obtain the equivalent sweetness (Yamaguchi *et al.* 1970). Relative sweetness potencies could be derived from detection or recognition thresholds as well as from typical suprathreshold levels. Further, kinetic parameters as maximal response attained by a sweetener (Rmax) and the apparent dissociation constant for the taste stimulus-receptor complex (K) extrapolated from the entire dose-response curve allow another way to obtain relative measurements of sweetness. The Beidler equation yielded Rmax and K values for taste (Beidler 1961; Stone 1967; Calviño 1986; DuBois *et al.* 1991) and irritant perception (Cliff and Heymann 1994), but is limited to represent sweetness potency because Rmax offers valuable information only at saturating concentration of the sweetener and comparisons of K values are worthless if sweeteners have different maximal intensities.

Rmax/K was also proposed as a meaningful index of the relative sweetness potencies of the compounds. Although Rmax/K derives from the whole range of sweetener concentrations, it relates sweetener potency to sweetener concentration as the concentration of the sweetener approaches zero, i.e., similarly to the reported threshold potency (Roczniak and Walters 1991).

Stevens' law gives reliable predictions of relative sweetness. Stevens (1969) reported that log concentration (C) of the test sweetener bears a linear relationship to log sweetness (S) as given by the equation: $\log S = \log K + n \log C$ where K and n are constants. It is possible to estimate the potency (P) at a given response extrapolated from the power function. Previously, power functions of several sweeteners determined a single equisweetness point equivalent to a 4.5% sucrose sweetened beverage (Yau *et al.* 1989) or multiple equisweet points at 2, 5, and 10% of sucrose (Schiffman *et al.* 1995).

Single intensity ratings do not completely account for the differences in potency reported among sweeteners. Time intensity (T-I) measures are preferable if sweetness is conceived as emerging by significant contributions from events at receptors and further subsequent processing at central nervous system. Consistent with this approach, different studies have shown that the strength or sensory impact for a specific compound is a function of both time and stimulus concentration (Dubois *et al.* 1991; DeRovira 1996). Thus, the potency of the sweeteners could be predicted from the temporal profiles of several concentrations of both, test and reference sweeteners.

Typically, T-I parameters as maximum intensity, time to extinct perception and area under the curve are suitable for examining the functionality of the sweeteners. We propose to explore the quotient of area under the curve and total persistence time as a measure to average intensity across the entire temporal course of sweetness. This derived parameter may be tested as another measure of dynamic potency of sweeteners.

Multivariate statistical techniques such as principal component analysis (PCA) simplify the relationships among multiple variables (Resurrección 1988; Calviño *et al.* 1996). This approach was recently applied to describe the relative sweetness of fructose versus sucrose (Zamora *et al.* 1998). Guinard *et al.* (1995) have previously studied the time-intensity profiles of 23 stimuli covering extensively sweet and bitter taste qualities. A PCA on the T-I data supported the separation of the sweeteners which do not share common mechanisms of chemoreception.

Since concentration influences T-I profiles, different concentrations may be studied in order to expand the database regarding T-I properties of a selected set of sweeteners. The aim of this research focuses on peptide-family sweetener potencies versus sucrose as reference. D-tryptophan, aspartame, and thaumatin were selected as examples of amino acids, peptide derivates and proteins, respectively. Sweet formulations, using citric acid, resembled noncarbonated soft drinks. Specific objectives of this research were: (1) to examine the effectiveness of each sweetener by multiple measures of sweet potency along the entire range of response of both, the test compound and sucrose; (2) to test two data collection methods (single- point and T-I measurements) for description of sweetness potencies; (3) to measure potencies of sweeteners from derived T-I parameters as maximum intensity and average intensity and (4) to ascertain differences among sweeteners by multivariate analysis of the T-I parameters.

MATERIALS AND METHODS

Single-point Measurements of Sweetness

Thirty students, from the University of Buenos Aires, ages ranging from 19 to 35 years participated in the experiment. Each sweetener was evaluated by a subgroup of 10 panelists in three replicated sessions.

Solutions of sucrose (commercial grade, 0.09; 0.18; 0.37 and 0.73M), aspartame (Nutra Sweet, 0.5; 1; 2 and 4mM), D-tryptophan (Sigma, 2.5; 5; 10 and 20mM), dissolved in distilled water as well as in citric acid (Parafarm, 2.5; 5 and 10mM) were evaluated sensorially. Solutions, prepared at least 24 h before tasting, were stored at 4C for a period not longer than one week. Samples were served at room temperature in coded plastic cups and sample volume was set at 4.0 mL to minimize fatigue and taste carryover.

Judgments of sweetness were made using a 21-point category scale as described by Frank and Archambo (1986). The scale ranged from 0 to 20 and had three labels: very weak and very strong at the extremes, and medium in the middle. Before testing, the subjects tasted samples of water and the highest sweetener level. They were told that the sweetness of these stimuli approximately matched the range of sweetness they might encounter in the test stimuli. The samples were not swallowed, and the assessors were asked to rinse well between each sample using distilled water.

Data Analysis

Individual data points on the C/R graph represented the average of the intensity scores of all panelists. A linear regression analysis performed on the mean data of sweet intensity (log perceived intensity versus log concentration) afforded the sweet intensity function for each sweetener. From each regression line concentrations were estimated at ratings of 2, 4, 8, 12, 16 and 20 representing 10, 20, 40, 60, 80 and 100% of the full response scale respectively. Potency of sweeteners relative to sucrose was calculated as P = Suc/Sw, where Suc is the estimated concentration of the reference sucrose and Sw is the estimated concentration of the test sweetener. Thus, the ratio between equisweet sucrose and sweetener concentrations on a molar basis defined the potency. Further, multiple potencies (equisweet points) were obtained at the percentages reported above.

There is not a suitable nonparametric test equivalent to the analysis of variance required for this experimental design. Thus, a three-way analysis of variance (type of sweetener, levels of sweetener and levels of citric acid) with repeated measures in two factors (sweetener and citric acid levels) was applied to determine if there were significant differences among concentrations of taste stimuli.

Time-intensity Measurements

Temporal properties were evaluated using a software "T-I.exe" (Garrido *et al.* 1999). This computerized data collection system was used by panelists to rate sweet intensity of the samples on a line scale (0-100). After clicking the mouse button to initiate data acquisition (collected every 0.1 s) a bar appeared on the screen representing the entire scale for sweetness evaluation. This box, which is 20 pixels high and more than 600 pixels wide presents five labels as references at 0, 25, 50, 75 and 100% of full scale.

From an initial panel of 30 judges, nine of those judges, five females, four males, ages ranging from 23 to 48 years, were selected to perform T-I measurements. This selection was based on (1) their performance on basic taste recognition tasks and (2) their ability to ascertain degrees of difference for sweet

stimuli in aqueous and acidic solutions using R-index (O'Mahony 1992; Calviño *et al.* 1997).

Samples were sweetened either with aspartame (Nutrasweet, 1; 2; 4 and 8mM) or D-tryptophan (Sigma, 5; 10; 20 and 40mM) or thaumatin (Talin; 1.1; 2.3; 4.5 and 9.1μM), dissolved in 4mM citric acid (monohydrate Parafarm). Furthermore four levels of sucrose (commercial grade, 0.15; 0.39; 0.58 and 1.17M) in aqueous and acid solutions (4 mM citric acid) were also evaluated. Stimuli were prepared and presented in the same way as for single point measurements.

Prior to participation in the experiment, the subjects took a training session to evaluate the sweet intensity continuously, from onset to extinction of the response. Judges had the opportunity for an additional practice session before the data collection.

Collection of T-I data included an initial measurement of intensity followed by the T-I measurement (Larson-Powers and Pangborn 1978). Judges sipped a first aliquot, swirled it around the mouth and spat when they listened to the prompt of the PC at five seconds. Sliding the mouse the panelists drove the rightmost end of the highlighted bar in the box which appeared on the monitor. After clicking the mouse, the program registered this maximum intensity (Imax stat). In a second step panelists received another sample of the same stimulus. Again, after 5 s the computer prompted the judge to spit and to continue rating the sweet intensity along time. During the recording, the lateral motion of the mouse sliding it to the right signaled the increase of sweetness until the perception of maximum intensity and sliding it to the left reflected the decrease of sweetness until the sweet sensation had dissipated. Judges were instructed to spit periodically the saliva to avoid artificial persistence when saliva mixed with residual solution is swallowed.

At the beginning of each session panelists were presented with standard sweet solutions (10, 20 and 30% W/V sucrose) to define intensities equivalent to 25, 50 and 75% of the full scale. Each session consisted in the evaluation of the four concentrations of one sweetener in random order. Consequently, the whole experiment consisted of 10 sessions, during which two T-I replicates were obtained for each concentration and sweetener.

Data Analysis

T-I parameters were defined as follows: Imax stat: maximum intensity obtained by single point determination, without time measurement, Imax dyn: maximum intensity over a time period, Tlag: onset time and Tdur: total duration of the sweet response. Additional parameters encompassed representative variables of total gustatory response, such as Area (the area under the curve)

and Imed (an average intensity calculated as the area divided by the time taken to finish sweet perception, i.e., Area/Tdur).

Individual scores of each T-I parameter were submitted to four-way analysis of variance (ANOVA) with panelists, sweeteners, concentrations and replicates as factors. When sweeteners and concentrations were significant sources of variation, multiple comparisons were conducted, using a least significant difference (LSD) procedure to search significant differences between means. For all sweeteners, a linear regression analysis evaluated the concentration dependency of Imax dyn and Imed. Principal component analysis (PCA) applied to the sweeteners x T-I parameters matrices of average data allowed to examine if sweeteners fell into a differentiated pattern of responses.

RESULTS AND DISCUSSION

Comparisons of Sweet Potency by Single-point Measurements

No differences in sweetness were seen between sweeteners in aqueous solutions ($F2,27 = 1.00$, n.s.). Similar average values for sucrose (2.3 - 15.1), aspartame (1.9 - 12.9) and D-tryptophan (2.0 - 14.1) suggest an adequate matching of the concentrations of sweeteners. ANOVA showed no significant interaction between the type of sweetener and the concentration of citric acid ($F6,81 = 0.93$, n.s.). Particularly, aspartame and sucrose revealed similar taste onset and persistence time (DuBois and Lee 1983) and similar degree of sweetness suppression by citric acid (Bonnans and Noble 1993). Sweetness was equally affected by acid at all sweetener levels as previously reported (Frank and Archambo 1986). No significant interaction between citric acid and sweetener concentrations was observed. As sweetness was equally affected by all citric acid levels, concentration-intensity relationships for sweetness ratings were averaged across citric acid concentrations. As is shown in Fig. 1 the sweeteners did not behave as one. ANOVA results showed a significant interaction between type and concentration of the sweetener ($F8,108 = 3.13$, $p < 0.01$). The difference was dictated by the highest level of sucrose which showed a more pronounced sweetness than that of aspartame or D-trypthophan.

A general power law, fitted to the averaged sweetness data, gave an exponent close to 1.0 for sucrose ($\beta \pm SEM = 0.93 \pm 0.09$, $r^2 = 0.98$) indicating that perceived sweetness intensity grew proportionally with the increase in physical concentration. The respective sweetness functions for aspartame ($\beta \pm SEM = 0.76 \pm 0.05$, $r^2 = 0.99$) and D-tryptophan ($\beta \pm SEM = 0.75 \pm 0.06$, $r^2 = 0.99$) displayed compression, i.e., perceived sweetness growth was slower than concentration growth.

Both sweeteners in a sour context depicted a clear abatement of potency as percentage of sweetness increases. Literature data reporting sweetness data in aqueous context showed similar trends of relative potencies across an extended range of sweetness intensity (Schiffman *et al.* 1995; Portmann and Kilcast 1996).

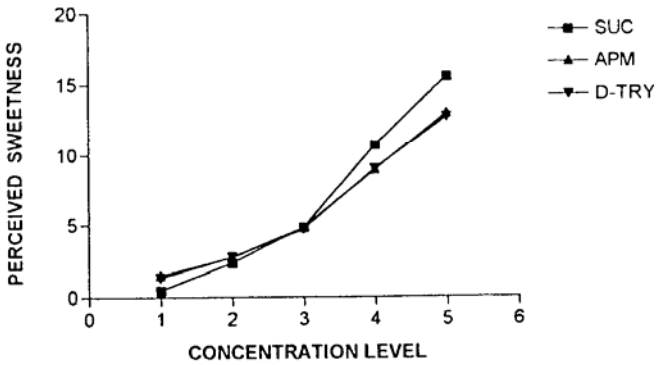


FIG. 1. CONCENTRATION-INTENSITY RELATIONSHIPS FOR SUCROSE, ASPARTAME AND D-TRYPTOPHAN

Sweetness data are averaged across citric acid levels. The means are depicted as a function of sweetener concentration where level 1 means water and citric acid solutions and levels 2, 3, 4 and 5 represent the increasing levels of sweeteners.

The hypothesis that different exponents characterize different sweet potency ranges seems to hold either in aqueous or acid solutions. As a rule, for nutritive sweeteners, with exponents close to 1 or greater than 1, increases in sweetness ratings were accompanied by slight changes in potency. In return, high potency sweeteners, with exponents lower than 1, tend to become less potent when ratings of sweetness increase. Therefore, in contrast to sugars and sugar alcohols which have an invariable potency, the potency of intense sweeteners is highly response-dependent and doubtlessly concentration-dependent.

Figure 2 showed sweetness potency curves developed for the sweeteners evaluated in acid background. Note that the x-axis in Fig. 2 represents a psychological scale of sweetness intensities rather than a physical scale of concentrations. Aspartame was about 230 times more potent than sucrose at a sweetness equivalent to 10% of total scale and about 130 times more potent than sucrose at 100% of full scale of response. D-tryptophan was less potent than aspartame, in coincidence with ANOVA results.

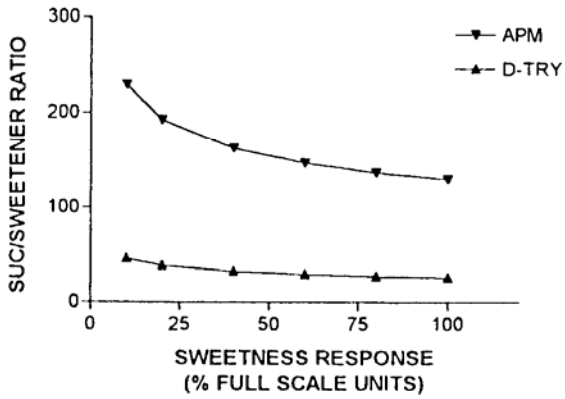


FIG. 2. POTENCIES OF ASPARTAME AND D-TRYPTOPHAN AS A FUNCTION OF SWEET RESPONSE EXPRESSED IN PERCENTAGES OF THE FULL SCALE OF SWEETNESS

ANOVA of the Time-intensity Parameters

To compare the temporal characteristics of the sweeteners, F-values of main effects and binary interactions are given in Table 1. Concentration and judges were highly significant sources of variation for all T-I parameters. The large degree of differences observed among individual panelists is in agreement with previous results for sweeteners (Yoshida 1986; Guinard *et al.* 1995; Zamora *et al.* 1998). Ott *et al.* (1991) reported that each judge displays a unique T-I curve, whose tracing was comparable to a signature, and the variability was inherent to the employed range of intensity scores, and inter-individual variations in the use of the scale. For all parameters (except Tlag), ANOVA also detected judges inconsistencies among sweeteners, as indicated by the significant judge x sweetener interaction ($p<0.001$). Previous research (Guinard *et al.* 1995; Zamora *et al.* 1998) suggested the presence of inter-individual differences in sensitivity.

For Imax dyn, as well as Imax stat and Imed, significant sweetener by concentration interaction reflects that differences between concentrations were not rated in the same way for all sweeteners. Further, replicates were not a significant source of variation for any T-I parameter except Tdur, which revealed a shift on the criterion for terminating a T-I curve.

Good overall panel reproducibility across sessions was obtained for Imax stat, Imax dyn and Imed, because judge x replicate was not a significant source of variation. However, there were significant judge x replicate interactions for Tlag, Tdur and area implying that some subjects responded differently across replicates. Individual Tdur values showed that sweeteners were less persistent

in the second session for 4 out of a total of 9 panelists. Three panelists also tended to produce curves with smaller areas than the ones obtained in the first session. The way these panelists may have shifted their criteria (such as the rate at which the mouse was brought back to zero) probably accounts for the observed differences.

TABLE 1.
ANALYSIS OF VARIANCE OF THE TIME-INTENSITY PARAMETERS. DEGREES OF FREEDOM (df) AND F-RATIOS ARE SHOWN WITH SIGNIFICANCE LEVELS

	df	I Stat	I Dyn	I med	Tlag	T dur	Area
Sweetener	4	1.7	1.6	1.0	1.0	4.2**	0.8
Concentration	3	320.5***	225.1***	140.5***	95.0***	36.4***	26.8***
Judge	8	59.7***	45.9***	68.7***	26.7***	37.8***	37.0***
Replicate	1	2.8	1.7	0.1	1.7	13.5**	1.4
Sweetener x Concentration	12	5.0***	6.4***	3.3***	0.3	0.9	1.4
Sweetener x Judge	32	7.1***	4.8***	7.1***	1.6	2.5***	3.0***
Sweetener x Replicate	4	0.3	0.4	0.5	1.0	1.3	1.8
Concentration x Judge	24	1.6	1.5	2.8***	0.6	2.5***	5.5***
Concentration x Replicate	3	0.6	1.4	1.1	0.5	2.5	6.1**
Judge x Replicate	8	1.7	1.6	1.6	3.3**	3.5**	4.3**
Error	96	87.7	121.4	43.2	0.18	52.59	10.04

*, **, *** significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

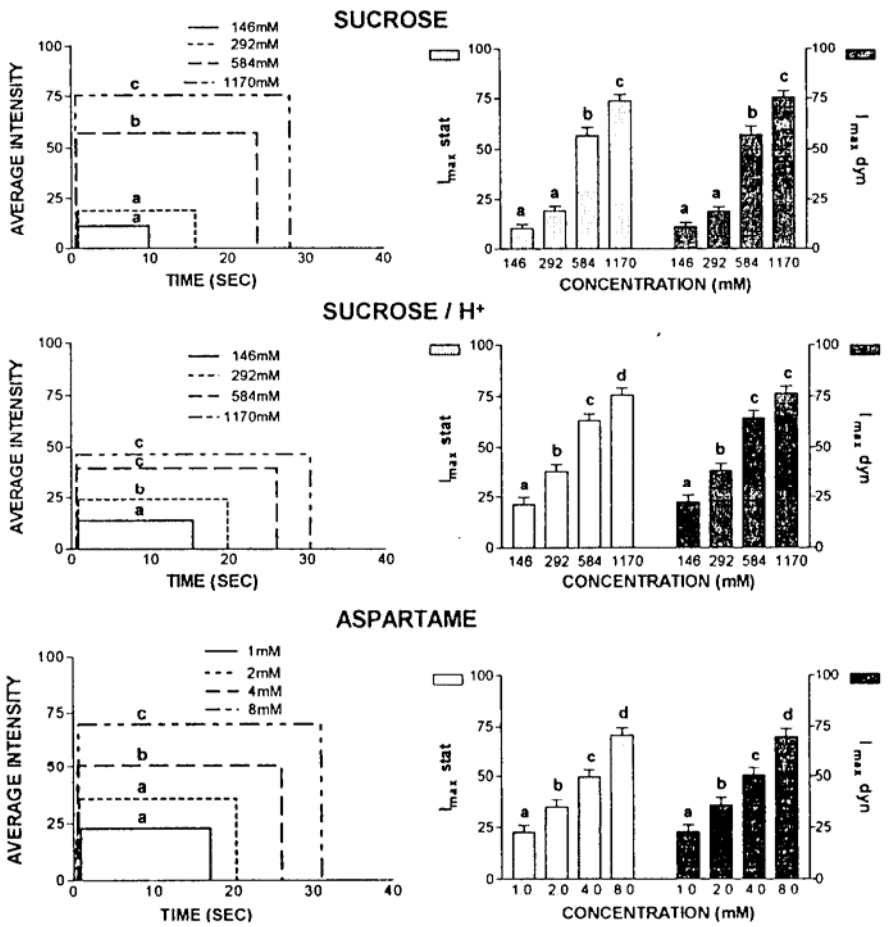
Area under the curve T-I is another useful index of overall gustatory response. Although mean values showed a clear dependence of concentration, there were no significant differences among sweeteners regarding area as there were found previously in aqueous solutions (Ott *et al.* 1991).

ANOVA failed to detect inter-sweeteners differences for five of the six parameters analyzed, consequently with previous results for several sweeteners evaluated in sodium citrate-citric acid buffered solutions (Ketelsen *et al.* 1993). Only the persistence of sweetness (Tdur) discriminated successfully among sweeteners. Consistent with the results of Birch *et al.* (1980), sweetness of thaumatin was longer than that of both sucrose/water and sucrose/citric acid mixtures. The differences in temporal properties between sucrose and thaumatin as an example of nonsucrose like sweeteners may be explained by the following mechanism hypothesized by Du Bois and Lee (1983): molecules of sucrose-like compounds diffused in a specific and quick way to the sweet taste receptor site and bind efficiently to this type of receptor. On the other hand, molecules of nonsucrose like sweeteners diffused rapidly and predominantly to nonreceptor

binding sites on the receptor protein and a secondary diffusion to a sweet taste receptor site evoked a delayed sweetness. Furthermore, the prolonged persistence may be explained because release of the molecule by the receptor promotes a predominant diffusion to the nonreceptor site rather than to the receptor site.

Temporal Measurements of Sweet Potency

Mean values of static, dynamic and average maximum intensities are presented in Fig. 3 for each sweetener. The three measures discriminated significantly among concentrations.



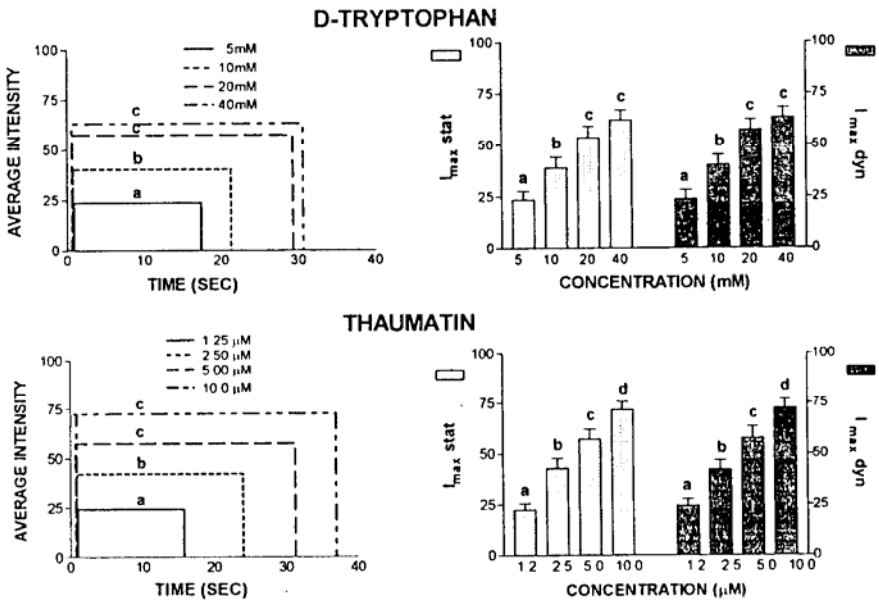


FIG. 3. LEFT SIDE: AVERAGE INTENSITY OF SWEET RESPONSE (IMED) CALCULATED AS THE RATIO AREA/TDUR AS A FUNCTION OF TIME, FROM ONSET (TLAG) UNTIL EXTINCTION TIME (TDUR). IN A GRAPH ARE DEPICTED THE FOUR LEVELS FOR EACH SWEETENER. DIFFERENT SUPERSCRIPTS SHOWED SIGNIFICANT DIFFERENCES FOR IMED IN THE NEIGHBORING CONCENTRATIONS ($P < 0.05$). RIGHT SIDE: MEAN RATINGS FOR BOTH, IMAX DYN AND IMAX STAT AS A FUNCTION OF CONCENTRATION

Different superscripts in adjacent bars indicated significant differences ($p < 0.05$).

Combined measures as the product of intensity and persistence, IT or the expression IT/2 as overall gustatory response gave a good assessment of the temporal taste properties (López Chavez and Birch 1997). Consistent with this view the quotient of area and Tdur was analyzed as an average of sweetness intensity from onset through extinction time. It must be noted that, as occurred in other combined measures, similar values may arise from different combinations of original parameters. Thus, curves having similar ratios of area to Tdur values will yield the same value of Imed.

Relative sweetness changed with the percentage of the full scale response (see Table 2). Both, Imax dyn and Imed measures showed again the decrease of potencies as sweetness magnitude increased.

The potencies calculated by T-I measurements are greater than the ones obtained in single-point ratings and this effect may be ascribable to a major

range of concentration covered in the T-I experiment. The decay of potency with the increase in sweetness level supports again a highly response-dependent process for aspartame, D-tryptophan or thaumatin. Figures 4 and 5 illustrated this effect for Imax dyn and Imed values. Clearly, a correct estimate of sweetness potency would require knowing the magnitude of the dynamic range of responses.

TABLE 2.
EXPONENTS (β) AND CORRELATION COEFFICIENTS (r^2) OF THE POWER RELATION FOR SWEET RESPONSE AND SWEET POTENCIES CALCULATED FROM T-I DATA

			POTENCY					
	β	r^2	10%	20%	40%	60%	80%	100%
DYNAMIC MAXIMUM INTENSITY (I_{max} dyn)								
SUCROSE	0.61	0.96	3.8	2.4	1.6	1.2	1.0	0.9
D-TRYPTOPHAN	0.47	0.92	202	94.8	44.5	28.6	20.9	16.4
ASPARTAME	0.54	0.99	648	360	200	142	112	92.4
THAUMATIN	0.51	0.96	$7x10^5$	$4x10^5$	$2x10^5$	$1.5x10^5$	$1x10^5$	$9x10^4$
AVERAGE INTENSITY (I_{med})								
SUCROSE	0.60	0.95	2.6	1.7	1.2	0.9	0.8	0.7
D-TRYPTOPHAN	0.50	0.93	102	53.3	28	19.2	14.7	11.9
ASPARTAME	0.51	1.00	413	223	121	84.2	65.3	53.5
THAUMATIN	0.51	0.95	$4x10^5$	$2x10^5$	$1x10^5$	$8x10^4$	$6x10^4$	$5x10^4$

Sucrose in acid media exhibits a relative sweetness 3-4 times greater than in neutral aqueous solutions. Both, aspartame and D-tryptophan depicted a similar pattern as stated in single point measurement. Finally, as can be seen from both graphs, thaumatin displayed extremely high potencies as a function of sweetness intensity. These values revealed the strong affinity of thaumatin for the receptor. The intimate binding of the receptor site to the thaumatin macromolecule is in accord with intensification and prolonged sweetness of this protein (Suami *et al.* 1997). However, reported sweet potencies for thaumatin are 'unrealistic' because the fitting procedure on maximum intensity values ignores other sensory characteristics of this intense sweetener. This bias will be examined within the framework of the PCA.

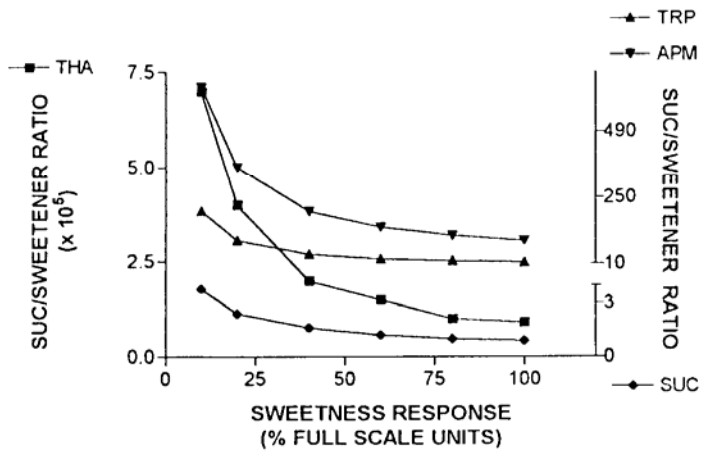


FIG. 4. POTENCIES OF SUCROSE, ASPARTAME, D-TRYPTOPHAN AND THAUMATIN AS A FUNCTION OF SWEET RESPONSE EXPRESSED IN PERCENTAGES OF THE FULL SCALE OF SWEETNESS

Sweetness potencies were developed for Imax dyn measures calculated from T-I curves.

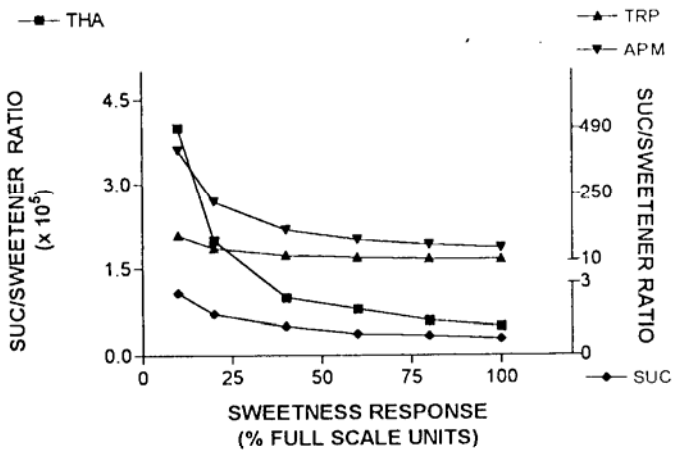


FIG. 5. POTENCIES OF SUCROSE, ASPARTAME, D-TRYPTOPHAN AND THAUMATIN AS A FUNCTION OF SWEET RESPONSE EXPRESSED IN PERCENTAGES OF THE FULL SCALE OF SWEETNESS

Sweetness potencies were developed for Imed measures calculated from T-I curves.

Principal Component Analysis of the Time-intensity Parameters

PCA should tell us which of the parameters of the T-I curve were relevant to provide a perceptual map of the sweeteners as well as to establish the variability among the sweeteners and concentrations. The first principal component (PC 1) with an eigen value greater than one (5.43) accounted for the 90% of the variance associated with the data. Mainly, a unidimensional solution explained the variation among sweeteners and concentrations. T-I parameters showed that Imax stat, Imax dyn, Imed and their original parameters area and Tdur had the highest factor loadings on the positive half of the first PC (see Fig. 6) and are tightly associated among them. Such correlations are given in Table 3. Thus, these T-I parameters described slightly different aspects of the same underlying dimension.

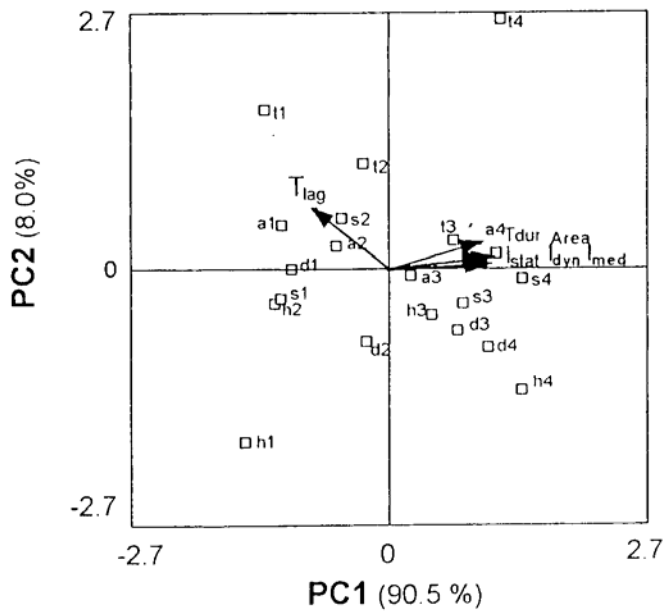


FIG. 6. PRINCIPAL COMPONENT ANALYSIS OF SWEETNESS T-I DATA
Representation of the sample scores is displayed in the space of the first two components where a: aspartame, d: D-tryptophan, h: sucrose in citric acid solutions, s: sucrose in water solutions and t: thaumatin. The arrows represented the projection of T-I parameter loadings (vectors).

TABLE 3.
CORRELATIONS AMONG TI PARAMETERS WITH HIGH FACTOR LOADINGS IN PC1

	Istat	Idyn	Tdur	Area
Idyn	0.99			
Tdur	0.94	0.93		
Area	0.99	0.99	0.95	
Imed	0.99	1.00	0.92	0.98

PC 1 was only negatively weighted with Tlag. The highest level of sucrose in water and acidic solutions showed the lowest Tlag and the more diluted solution of thaumatin had the highest Tlag confirming again the temporal contrast between both sweeteners.

As to be expected, Fig. 6 exhibits a separation of the sweeteners on the basis of their concentrations. Increase of the concentration works in the same way whatever the sweetener, yielding a displacement from the negative to the positive half of the first PC. This representation confirms the ANOVA results where differences among concentrations were found for all parameters. Cliff and Noble (1990) observed that the first PC, which accounted for a great amount of the total variance of sweetness data (76%), was heavily loaded with highly correlated parameters as Imax and area. As observed in the present results, they found also that the first PC separated the samples on the basis of glucose concentration.

Additionally, PCA provided evidence that thaumatin is the outlier among sweeteners. The second PC did not explain a significant amount of the variance of the data, but an inspection of sweeteners scattered in Fig. 6 revealed the separation of the set of samples of thaumatin. The results of this study must be interpreted within the constraints of the narrow context of the sweet-sour model analyzed. In terms of the practical significance of the present research the evaluation of strength of sweeteners warrants additional research, amplifying the food context in which sweetness is a prominent component.

CONCLUSIONS

The sensory evaluation of sweeteners indicated that it is not acceptable to extrapolate potency relative to a given sucrose level to other levels because the dependence of intensity on concentration may not necessarily be proportional. Reliable estimates of the potency of a sweetener may require the examination of a wide concentration range of both the sweetener and sucrose as reference.

The results confirmed that several sensory methods are appropriate to assess sweetness potency in beverages and food systems. One approach, assuming a very close relationship between events at receptor and taste perception, represented the taste intensity by a single numerical description. If sweetness is conceived as emerging by significant contributions from events at receptor and further subsequent processing at central nervous system, measurements of sweetness over time must be performed (T-I). Both approaches supported sweet potency variations and proved that sweetness potency should be examined over a wide concentration range.

The evaluation of sweeteners in citric acid solutions derived knowledge of sweeteners' potency in solutions like noncarbonated soft drinks. However, as models become more complex by addition of other food additives, differences in time-intensity parameters become less obvious. The present results showed that only duration differs among sweeteners and this effect was only important in samples sweetened with thaumatin. PCA also showed how thaumatin is differentiated from the other sweeteners and these differences might be related to different transduction mechanisms.

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