ELSEVIER

PII: S0308-8146(96)00026-X

Food Chemistry, Vol. 56, No. 3, pp. 291–302, 1996

0308-8146/96 $15.00+.00

Psychophysical characterization of new sweeteners of commercial importance for the EC food industry

Marie-Odile Portmann* & David Kilcast

Leatherhead Food Research Association, Randalls Road, Leatherhead, Surrey, UK

(Received 27 August 1995; revised version received 10 November 1995; accepted 10 November 1995)

Quantitative psychophysical information on the perceptual characteristics of sucrose (as reference), sodium cyclamate, aspartame, neohesperidin dihydrochalcone (NHDHC) and maltitol were established through the determination and the modelling of their concentration–response (*C–R*) functions according to linear, Beidler or Hill equations, the recording of the time–intensity (*T–I*) curves with the determination of the *T–I* parameters for each sweetener, and the establishment of the sensory profile of the sweetener solutions by the QDA technique. Bulk and intense sweeteners present dissimilar *C–R* functions. The *C–R* function observed for maltitol is linear while aspartame, cyclamate and NHDHC exhibit a saturation plateau around 10–13% sucrose equivalent. Temporal characteristics of aspartame and cyclamate are comparable to those of sucrose and maltitol, whereas the *T–I* characteristics of NHDHC contrast with those of the other sweeteners, essentially because of its long onset and persistence times. Bitter taste and bitter aftertaste are attributes that differentiate maltitol and sucrose from artificial sweeteners. Bitter and metallic are non-sweet aftertastes characteristic of cyclamate, while NHDHC is mainly defined by a liquorice-like and cooling/menthol flavour. Caramel flavour is associated with nutritive sweeteners, and burnt sugar flavour is related to synthetic sweeteners, except cyclamate, which is characterized by both flavours. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

Dietary and health demands are continuing to expand the market for sweeteners as alternatives to sucrose. Cyclamates, maltitol and neohesperidin dihydrochalcone (NHDHC) are approved in the UK since December 1995, when the EC Sweeteners Directive 4135/EC was ratified. However, two novel sweeteners, sucralose and alitame were not included in the EC Sweeteners Directive as they are still under evaluation.

Alternative sweeteners are successful if they match perfectly the taste quality of sucrose. This implies that alternative sweeteners should have a clean sweet taste, with a quick onset and a minimum persistence. The understanding of the various factors that produce this idealized response is still very limited for various reasons. One reason is that the sweet sensation is the result of a cascade of complex biological, physiological and chemical events starting when the sweet molecule, carried by the saliva, reaches the sweet receptors inside the lingual epithelium. How these events occur is not yet entirely elucidated. Another reason for the limited understanding of the sweetness response is that the property of sweetness is exhibited by diverse classes of natural or chemical compounds, in which it is difficult to see any common structural features.

As part of the collaborative EC project 'The mechanistic understanding of the sweetness response', the LFRA has undertaken a detailed study to quantify the psychophysical characteristics of sweeteners of current and potential commercial importance to EC food industry. The data will provide information on sweetener intensity response, temporal characteristics and sweetness quality. The studies have focused on comparing the characteristics of maltitol, neohesperidin dihydrochalcone, aspartame and cyclamate with that of sucrose.

The study is being carried out in three stages, following recruitment and training of a panel. Concentration–response (*C–R*) functions of selected sweeteners have been established after their sweetness intensities were rated according to standard sucrose references. As a

*To whom correspondence should be addressed.

result, sweeteners are classified in two categories, whether the type of the *C–R* function is linear or hyperbolic. Sweeteners represented by a linear model reach a maximal sweetness intensity equal to that of sucrose whereas sweeteners presenting a hyperbolic model deliver a maximal sweetness intensity lower than that of sucrose (Carr *et al.*, 1993; DuBois *et al.*, 1991).

Differences existing in the perception of sweetness between bulk and intense sweeteners can also be also demonstrated by recording their time–intensity (*T–I*) curves. Time–intensity profiles generate a series of temporal parameters for quantifying sweeteners and provide a valuable method for discriminating sweeteners on the basis of the onset (the time when sweet taste is first perceived), intensity and duration (the time until no sweet taste remains) of perception of a sensory attribute. However, *C–R* functions and *T–I* parameters give only a quantitative appreciation of the sweet taste of bulk and intense sweeteners. Differences and similarities among sweeteners may also be specified by descriptive analysis (Stampanoni, 1994). Specific flavour, texture and aftertaste descriptors were generated by Quantitative Descriptive Analysis (Stone *et al.*, 1974; Stone & Sidel, 1985) for each sweetener solution. Definitions of the sensory attributes and the intensity ranges were set up using standard references. Standards for developing descriptive language help to reduce the amount of time needed to train panellists (Rainey, 1986), and also help to decrease variability among judges by unifying the panel in the use of the intensity scale (Stampanoni, 1993*a*,*b*). An important aspect of the project is to maximise the internal consistency of the data, by generating all three types of data on all sweeteners with the same sensory panel.

MATERIALS AND METHODS

Sweeteners

The sweeteners tested were: aspartame (Holland Sweetener Compagny, Maastricht, NL); cyclamate (Jan Dekker BV, Wormerveer, NL); maltitol [Roquette (UK) Limited, Tunbridge Wells, UK]; NHDHC (Exquim SA, Barcelona, SP); and sucrose (Tate & Lyle, London, UK).

Panel screening and training

Twelve female panellists, who were members of the Leatherhead Food RA's sensory panel, took part in this study. They already had experience in sweetener assessment and were familiar with the time–intensity and descriptive analysis techniques. Panellists were trained over 2 weeks (four 4-h sessions) to become acquainted with the sensory techniques used for the concentration–intensity assessment. Sweetness intensities of sucrose, aspartame, acesulfame-K and caffeine solutions were evaluated by magnitude estimation. Six sucrose references (2, 5, 7.5, 10, 12 and 16% w/v) were used to normalize sweetness intensity ratings on a 15 cm scale. These sucrose standards were allotted the intensity values 2, 5, 7.5, 10, 12 and 15, respectively. Two caffeine solutions were used as reference for bitterness with 0.05% assigned a bitterness value of 2 and 0.08% a bitterness value of 5 (Carr *et al.*, 1993; DuBois *et al.*, 1991).

For time–intensity evaluation, practice sessions were held using 5 and 10% sucrose solutions and 5 and 10% SEV (sucrose equivalent value) sweetener solutions to give panellists an awareness of various taste intensities and degree of lingering tastes.

For the sensory characterization of sweetener solutions, training sessions were held to elicit profile terminology. Panellists were asked to write down terms describing flavour, mouthfeel, aftertaste and aftereffects. A discussion session followed to agree on the terms, their definitions and their anchor points. During the discussion, panellists had the use of some reference samples to help them to decide on the term definition. As a result of the discussion, 17 terms were defined and a glossary of terms was established. Further training sessions were carried out on these terms and the panel data were checked for sample scoring consistency.

Determination of the sweetener concentrations

Sweetness levels were chosen to permit assessment of the temporal, qualitative and quantitative characteristics of sweeteners at a sweetness level commonly encountered in foods. For the *C–R* relationships, sweetener concentrations were determined within a concentration range 2–15%, on the sucrose equivalence scale (DuBois *et al.*, 1991). The dilution ranges investigated are given in Table 1. To facilitate the comparison of the temporal profiles, time–intensity parameters were determined at 5 and 10% SEV. Sensory profile characteristics were determined at 10% SEV. A paired comparison, constant stimulus, forced-choice method (Amerine *et al.*, 1965) was conducted to establish the concentration of sweeteners equi-sweet at 5 and 10% sucrose. Data were analysed according to Larson-Powers & Pangborn (1978). Equivalent sweetener concentrations are given in Table 2.

Sample preparation

Samples were dried in a desiccator with silical gel granules for 48–72 h and dissolved in still mineral water (Ballygowan Spring Water Co. Ltd, Newcastle

Table 1. Concentration ranges investigated for *C–R* relationships of bulk and intense sweeteners

Sweeteners	Concentration ranges
Sucrose	2–15%[a]
Maltitol	2–18%
Aspartame	100–2000 ppm
NHDHC	50–800 ppm
Sodium cyclamate	750–9000 ppm

[a] % denotes weight/volume %.

Table 2. SEVs (5 and 10%) for aspartame, maltitol, sodium cyclamate and NHDHC

Sweeteners	5% SEV[a]	10% SEV
Maltitol	8.0	13.5
Aspartame	0.075	0.12
Cyclamate	0.18	0.44
NHDHC	0.02	0.06

[a] % denotes weight/volume %.

West,Co. Limerick, Ireland) 24 h before the evaluation and stored at 4°C overnight. Concentrations were reported on a weight/volume basis. Panellists received 15 ml aliquots of test stimuli, served at room temperature (22°C) in 30 ml odour-free plastic cups coded with randomly selected three-digit numbers.

Sensory procedures

The tasting was conducted, in individual tasting booths, under red filter lights to minimize appearance differences essentially concerning the yellow colour of the NHDHC solutions. Panellists were given a brief outline of the objectives of the work, but with no information on the type of sweeteners. Basic instructions and requested information (e.g. judge identification), data acquisition and collection are monitored through the 'Taste' computerized data acquisition system (Reading Scientific Services, Reading, UK). Panellists with extensive training in the practice of *T–I* procedures use a mouse to move a marker on an unstructured line scale displayed on a computer screen. Panellists tasted the samples using a sip-and-spit method. They cleansed their palates with water and crackers and waited at least 1 min before tasting the next sample. All the assessments were carried out in triplicate. Between sessions panellists observed a break of 10–15 min to cut down the effect of fatigue.

C–R relationships

The *C–R* data were obtained by presenting seven concentrations in one session. An eighth sample containing sucrose, at low concentration (2%), was presented as an unidentified control. The order of sample presentation was randomized. In each session the panellists began by tasting the sucrose references: 2, 5, 7.5, 10, 12 and 16% (w/v). Retasting of the reference samples was not permitted. Panellists assessed the first of the eight samples, holding and swirling it in the mouth for few seconds before expectoration. They were instructed to score sweetness intensity at the point of maximal sweetness perception on an unstructured scale, by moving the arrow along the scale with the 'mouse'. The left-hand end of the scale was labelled 0 and was defined as having a sweetness equivalent to a 0% sucrose solution. The right-hand end of the scale was labelled 15 and was represented by a sweetness equivalent to a 16% sucrose solution. Evaluation of the remaining samples was conducted in a similar fashion. After the fourth sample, panellists took a break of 10 min to reduce the effect of fatigue.

Temporal experiments

Panellists were presented with three 15 ml samples. Two solutions were the test sweeteners at 5 and 10% SEV. The third was a 7.5% sucrose solution used as a reference to standardise an intensity value of 50 on the 0–100 scale. Sweetener samples were presented in a randomized order across the panel but the panellists always started with the reference. They were instructed to rate the sweetness intensity continuously over time from sipping the whole sample, through expectoration at 15 s until extinction of the sweet sensation. The beginning and end of each evaluation were indicated on the screen by a countdown clock. The allocated time was 120 s for sucrose, maltitol, cyclamate and aspartame and 180 s for NHDHC, owing to its longer aftertaste.

Sensory profile characteristics

The samples were presented in sets of three in a semi-balanced design. In order to minimize sweetness carry-over effects, NHDHC solutions were always the last sample tasted in the set. Panellists had to evaluate each flavour attribute, for each sweetener solution, using an unstructured scale with appropriate anchors. The extreme ends of these line scales were scored as 0 (left) and 100 (right).

Data analysis

C–R data

Individual data points on the *C–R* graphs represented the average of all panellists' intensity scores. Statistical analyses were performed using Microsoft Excel 5.0. (Microsoft Corporation, Redmond, WA, USA). The linear regression models were fitted with MINITAB 10 (MINITAB, Inc. State College, PA, USA), whereas the non-linear models were resolved, using least squares as a fitting criterion, with Mathcad 5.0 (Mathsoft, Inc. Cambridge, MA, USA) software.

T–I data

The data are collected in a format that is unsuitable for further analysis. They are reformatted using a BASIC program written at the Food RA. *T–I* curve parameters are defined as follows. I_{max}: maximum intensity of response; T_{max}: time to reach the maximum intensity of response; area: area under the curve or total amplitude; T_{fin}: total duration time of response (with $T_{fin} = I_{max}/\text{rate}$); T_r: time at which the curve starts to decline from maximum intensity; Lag: onset time of response; rate: rate of release (maximum intensity/time to reach maximum intensity).

Mean values were calculated across all parameters by averaging the panellist individual scores. The main and interactive effect of three variability factors, concentration, assessors, and replications and their interactions, were analysed by ANOVA. Analysis of variance (ANOVA) was also applied to determine whether the

T–I parameters were statistically different, among sweeteners, at a significant level of 5%. A Least Significant Difference (LSD) procedure was used to separate the differences between means. Data were analysed with MINITAB 10 and STATISTICA (StatSoft, Inc. Tulsa, OK, USA) data analysis software.

Sensory profile data

Attribute scores were analysed using analysis of variance (ANOVA) and multiple comparison testing in the form of least significant differences (LSD). Visual comparisons of the sensory characteristics were made using star diagrams, generated with Microsoft Excel 5.0 (Microsoft Corporation, Redmond, WA, USA).

RESULTS

Relationships

The mathematical functions examined for determination of the concentration–response (C–R) relationships of a sweetener relative to sucrose (Carr *et al.*, 1993) were

(a) Linear equation : $R = R_0 + (P')(C)$

(b) Beidler equation : $R = (R_m)(C)/(1/K) + (C)$

(c) Hill equation : $R = (R_m)(C)^n / (1/K)^n + (C)^n$

where R is the observed response, C is the sweetener concentration, P' is the potency of the sweeteners relative to sucrose, n is the apparent number of binding sites per receptor molecule, R_0 is the response for a sweetener concentration of zero (typically with a value near zero for aqueous solutions), R_m is the maximal response that can be attained for the taste stimulus, and $1/K$ is the concentration for half of the maximal response. The relative sweetness potency of intense sweeteners was measured through P' for bulk sweeteners and through the ratio R_m/K (Roczniak & Walters, 1991) for intense sweeteners.

Intensity concentration responses of bulk and intense sweeteners are summarized in Table 3, with their corresponding LSD (5%) values and the concentration–intensity curves are presented in Figs 1–5. Concentration–response equations and stimulus parameters n, K, R_m and ratio R_m/K are presented in Table 4 and Table 5. The data for sucrose and maltitol were subjected to a linear analysis only, following previous published work (DuBois *et al.*, 1991), although the sucrose data showed some evidence for slight non-linearity.

Temporal characteristics

Mean values of each *T–I* parameter together with the SEM and LSD (5%) values are presented in Table 6 and Table 7.

Subject consistency/panel reproducibility data are not shown. In common with most sensory experiments (Pangborn *et al.*, 1983; Schmitt *et al.*, 1984; Leach & Noble, 1986; Lynch *et al.*, 1993), significant assessor

Table 3. Intensity concentration response of bulk and intense sweeteners

	Sucrose concentration (g/100 ml)							
	1	2	3	4.5	6.75	10.12	12	15.18
Intensity response	1.36	2.31	3.74	5.04	6.56	11.6	13.26	13.83
LSD (5%)	0.59	0.73	1.01	0.74	1.03	1.37	1.15	1
	Maltitol concentration (g/100 ml)							
	2.22	5.55	8.33	11.11	13.33	17.77		
Intensity response	1.68	3.62	5.8	7.86	9.44	12.35		
LSD (5%)	0.83	0.92	1.06	1.16	1.45	1.53		
	Aspartame concentration (ppm)							
	100	200	500	750	1000	1500	2000	
Intensity response	0.26	0.65	2.57	4.54	7.52	11.21	12.35	
LSD (5%)	0.23	0.27	0.91	1.36	1.61	1.14	1.68	
	Sodium cyclamate concentration (ppm)							
	750	1000	3000	5000	6500	7000	7500	9000
Intensity response	2.09	2.72	7.47	9.51	11.81	12.67	12.88	12.66
LSD (5%)	0.62	0.7	1.64	1.65	1.21	1.51	1.36	1.52
	NHDHC concentration (ppm)							
	50	75	100	150	200	500	800	
Intensity response	2.17	3.7	3.9	4.4	6.8	9.9	10.8	
LSD (5%)	0.92	1.26	1.4	1.5	2.81	2.12	3.08	

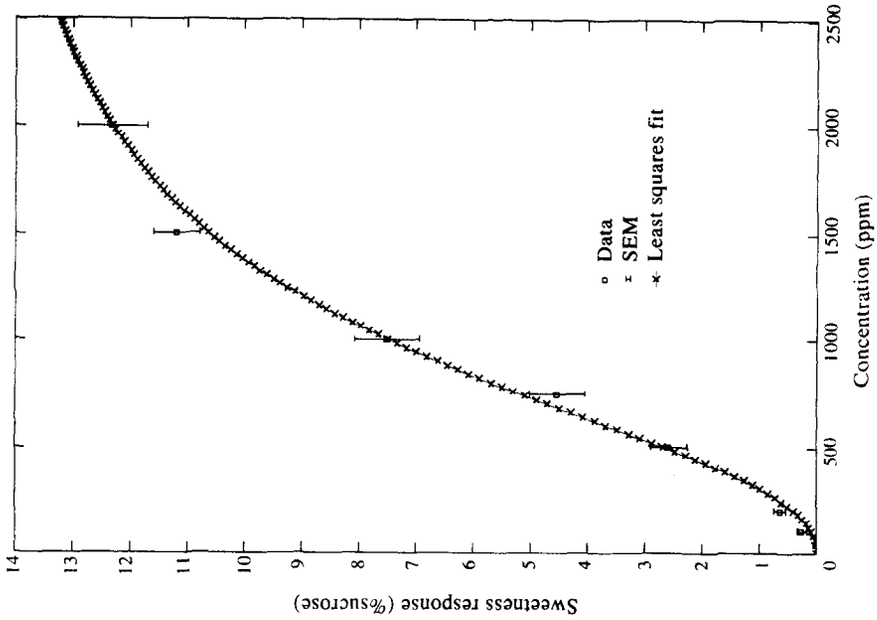

Fig. 3. Concentration–intensity response for aspartame.

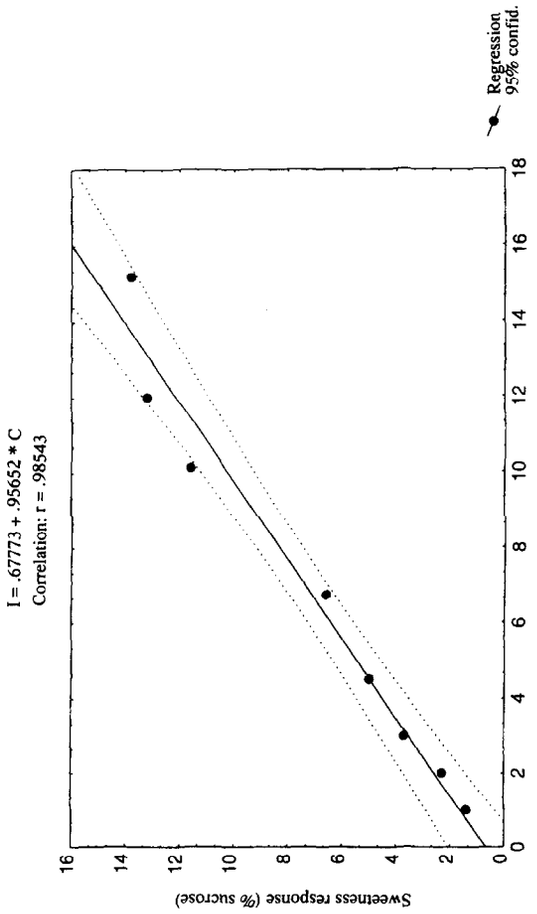

Fig. 1. Concentration–intensity response for sucrose.

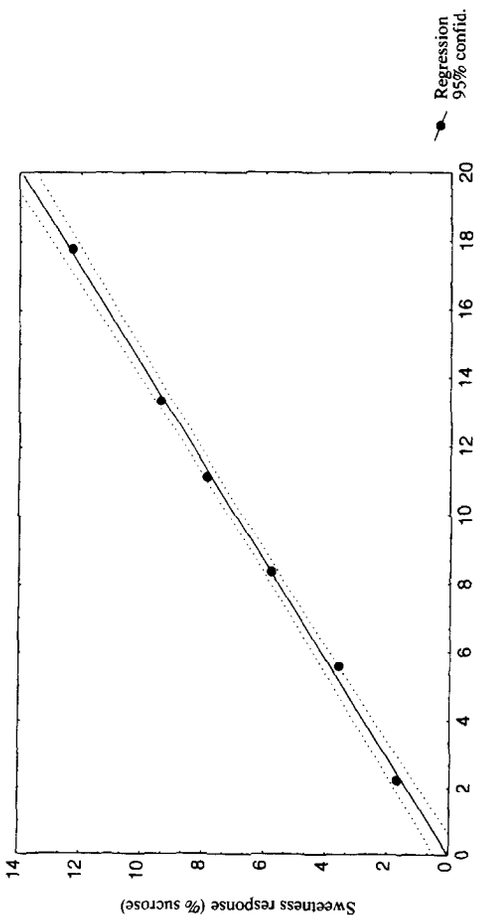

Fig. 2. Concentration–intensity response for maltitol.

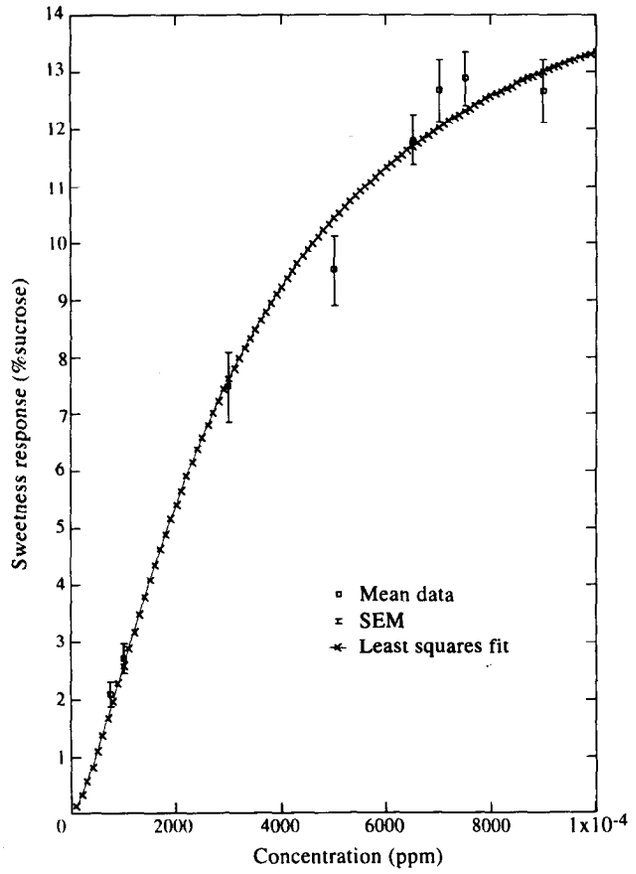

Fig. 4. Concentration–intensity response for cyclamate.

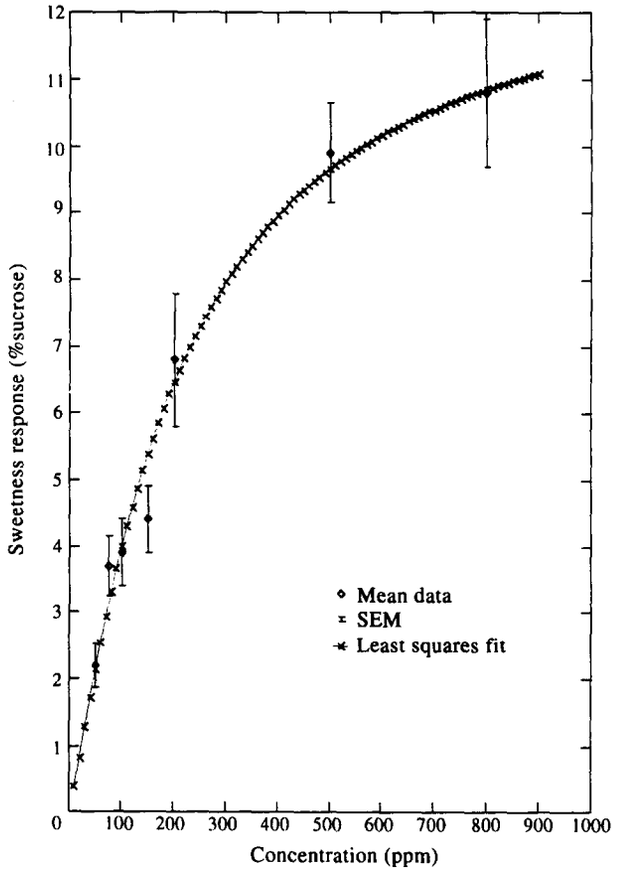

Fig. 5. Concentration–intensity response for NHDHC.

Table 4. *C–R* function equations, type of equation, correlation coefficient *r* and slope *n* for sucrose, maltitol, cyclamate, NHDHC and aspartame

Sweeteners	Type of equation	*C–R* equation	*r*	*n*
Sucrose	Linear	$R = 0.67 + 0.95C$	0.98	1.0
Maltitol	Linear	$R = 0.015 + 0.69C$	0.99	0.7
Aspartame	Hill	$R = \frac{14.6(C)^{2.51}}{(979)^{2.51}+(C)^{2.51}}$	0.99	2.5
Cyclamate	Hill	$R = \frac{16.1(C)^{1.4}}{(3300)^{1.4}+(C)^{1.4}}$	0.98	1.4
NHDHC	Beidler	$R = \frac{13.1(C)}{204+C}$	0.97	1.0

Table 5. Stimulus parameters $1/K$ and R_m and sweetness potencies for cyclamate, NHDHC and aspartame

Sweeteners	$1/K$ (ppm)	R_m	Sweetness potency
Sucrose	—	—	1.0[a]
Maltitol	—	—	0.7[a]
Aspartame	1000	15	150[b]
Cyclamate	3300	16	50[b]
NHDHC	204	13	637[b]

[a] Sweetness potency derived from P' (linear equation).
[b] Sweetness potency derived from the ratio R_m/K.

differences were found beween *T–I* parameters. According to Swartz (1980), these differences may have occurred because each panellist evaluated the sweet taste in an individual manner. Subject × replication interaction was not significant, except for aspartame. Increasing concentration led to a statistically significant effect of I_{max} and area responses for all the sweeteners. However, assessor × concentration interaction was not significant for NHDHC and sodium cyclamate but significant differences were found for the I_{max} and area parameters of aspartame, for I_{max} and lag time parameters of maltitol, and for all *T–I* parameters of sucrose, except lag time and rate time. The implication of such results is that the trend for higher ratings to be given to higher concentrations was not consistent over subjects.

I_{max}: This is dependent on the sweetener concentration. I_{max} varied between sweeteners, both for 5% SEV [$F(4,14) = 32.6$, $p < 0.001$] and at 10% SEV [$F(4,14) = 6.7$, $p < 0.01$]. For 5% SEV, the LSD test

Table 6. *T–I* parameters for sucrose, maltitol, aspartame, cyclamate and NHDHC (concentration equi-sweet at 5% sucrose)

T–I parameters	Sweeteners (%w/v)										LSD (5%)
	Sucrose (5%)		Maltitol (8%)		Aspartame (0.075%)		Cyclamate (0.18%)		NHDHC (0.02%)		
	mean	sem	mean	sem	mean	sem	mean	sem	mean	sem	
I_{max}	40.9	0.31	47.1	0.84	55.3	2.6	48	1.8	67.3	2.2	5.6
T_{max}	26.8	2.4	23.7	0.55	30.1	0.9	21.9	1.2	89	10.8	15.8
Area	2307	140.5	2433.3	65.5	3898.3	152	1482.2	100.9	7159.7	547.8	827
T_r	32.7	2.8	30.3	0.8	39.6	2.6	31.5	1.4	127.9	14.1	20.7
Lag	1.9	0.45	3.1	0.36	2.9	0.12	1.0	0.3	6.5	2.5	3.6
Rate	0.5	0.003	0.6	0.03	0.5	0.001	0.6	0.03	0.14	0.03	0.07
T_{fin}	81.8	—	78.5	—	100	—	80	—	480	—	—

Table 7. *T–I* parameters for sucrose, maltitol, aspartame, cyclamate and NHDHC (concentrations equi-sweet at 10% sucrose)

T–I parameters	Sweeteners (%w/v)										LSD (5%)
	Sucrose (10%)		Maltitol (13.5%)		Aspartame (0.12%)		Cyclamate (0.44%)		NHDHC (0.06%)		
	mean	sem	mean	sem	mean	sem	mean	sem	mean	sem	
I_{max}	78.2	2.1	76.6	1.3	74.7	0.7	88.5	1.7	84.8	3.9	7.1
T_{max}	26.2	1.0	25.3	0.2	32.0	1.3	27.3	0.5	90.6	15.3	21.7
Area	5351.9	164	4444	228.4	5633	123	3372.8	55.2	9819.4	674.1	1021
T_r	32.9	1.2	30.5	0.8	42.6	1.8	34.6	2.7	151.1	16.0	23.1
Lag	1.7	0.2	1.5	0.4	1.9	0.2	0.6	0.4	6.5	2.1	3.1
Rate	0.6	0.09	0.8	0.02	0.6	0.02	0.8	0.003	0.1	0.01	0.1
T_{fin}	120	—	95.7	—	123	—	110	—	706	—	—

Note: time unit (s); $T_{fin} = I_{max/rate}$.

disclosed that only maltitol and cyclamate were not significantly different, and, for 10% SEV, that there were no significant differences between aspartame, cyclamate and maltitol or between NHDHC and cyclamate. The interaction between subjects (data not shown) indicated inconsistency in panellists' evaluation of I_{max} for each sweetener. Ott *et al.* (1991) reported similar results for the *T–I* evaluation of aspartame, acesulfame-K and alitame. These results were supported by other investigators (Swartz, 1980; Schmitt *et al.*, 1984; Yoshida, 1986). Cyclamate has its maximum intensity at, respectively, 11 s (5% SEV) and 13.6 s (10% SEV), prior to expectoration (15 s), whereas sweetness was still developing after expectoration for sucrose, maltitol, aspartame and NHDHC. These results were in contrast to those of Ott *et al.* (1991), who found sucrose and aspartame intensities maximal around 10 s and prior to expectoration.

T_{max}: For 5 and 10% SEV, analysis of variance of the data indicated a significant difference between the sweeteners [$F(4,14) = 32.7$, $p < 0.001$ and $F(4,14) = 16.8$, $p < 0.001$]. However, the LSD tests showed that this variation between sweeteners is essentially due to the NHDHC. These results are consistent with the *T–I* profile of NHDHC given in the literature (Bär *et al.*, 1990). At high concentration, NHDHC was reported to have a delayed onset and a rather long duration of sweetness perception. Significant differences were found for T_{max} values for cyclamate between 5 and 10% [$F(1,83) = 6.5$, $p < 0.05$].

Lag time: Values were independent of the concentration, except in the case of aspartame [$F(1,65) = 10.7$, $p < 0.001$]. Apart from aspartame, above a 5% SEV, all the sweet receptors, including the less readily available receptor sites, were rapidly saturated, resulting in no difference between 5 and 10% SEV. The cyclamate had the shorter onset time, and the longer onset time was observed for NHDHC, for 5 and 10% SEV. At 5% SEV, analysis of variance showed no significant difference between the sweeteners [$F(4,14) = 3.23$, $p > 0.05$]. According to the LSD test, lag time was statistically different between NHDHC and cyclamate ($p < 0.01$) and NHDHC and sucrose ($p < 0.05$). At 10% SEV, lag time was significantly different [$F(4,14) = 5.52$, $p < 0.01$]. The LSD test indicated that lag time values observed for NHDHC were statistically different from those of all other sweeteners.

These results are consistent with Birch (1986), who stated that intensely sweet substances seemed to have a slow 'reaction time'. In general, sweeteners, such as sucrose, cyclamate or even saccharin are characterized by a rapid taste onset and short persistence, whereas NHDHC is characterized by a slow taste onset and a lingering aftertaste (DuBois *et al.*, 1977). An explanation for the slow taste onset of NHDHC is that some modifications of the molecule must occur within the oral cavity before the active glucophore is produced. Other explanations for the lingering taste of NHDHC would involve a strong and slowly reversible binding to

the sweet receptor site with the NHDHC molecule adopting a 'bent' active conformation in elicitation of sweet taste (DuBois *et al.*, 1977).

Rate: The values are highly significantly different, for 5% SEV [$F(4,14)=61.74$, $p<0.001$] and 10% SEV [$F(4,14)=35.41$, $p<0.01$] between non-nutritive and nutritive sweeteners except cyclamate. For 5% SEV, the LSD test revealed that the main differences were between NHDHC and the other sweeteners. This result was consistent with the greater perceived intensity of NHDHC, which exhibits a more prolonged sweet taste than the other sweeteners. For 10% SEV, significant differences were found between NHDHC and the other sweeteners, between maltitol and aspartame ($p<0.05$), and between maltitol and sucrose ($p<0.05$). Rate values were found to be dependent on the concentration of maltitol [$F(1,71)=19.5$, $p<0.001$], aspartame [$F(1,65)=6.8$, $p<0.05$] and cyclamate [$F(1,83)=16.1$, $p<0.001$].

T_r: Differences observed for T_r values between sweeteners are more significant for the assessment at 10% SEV [$F(4,14)=4.99$, $p<0.05$] than at 5% SEV [$F=(4,14)=50.5$, $p<0.001$]. The LSD test showed that NHDHC sweet intensity lasted significantly longer. Sweet intensity of NHDHC started to decline more than one minute after the maximal intensity had been reached ($T_r-T_{max}=38$ s at 5% SEV and 60.5 s at 10% SEV). At 5 and 10% SEV, the sweetness intensity of sucrose and maltitol started to decrease slightly before that of aspartame and cyclamate. The plateauing effect is around 6 s for sucrose and maltitol and 9 s for aspartame and cyclamate. These results were consistent with the conclusion of Birch (1986), who stated that intensely sweet substances had pronounced duration of taste.

T_{fin}: Duration time or persistence of sweet taste is dependent upon the sweetener concentration and is thus also a function of maximum intensity (Swartz, 1980; DuBois & Lee, 1983; Ketelsen *et al.*, 1993). T_{fin} values were extrapolated from the ratio I_{max}/rate. Longest T_{fin} values were observed for NHDHC, followed by aspartame and cyclamate. T_{fin} values of the non-nutritive sweeteners, cyclamate and aspartame, were close to those of the nutritive sweeteners, maltitol and sucrose. Literature data reported that, at high concentration the bitter aftertaste of cyclamate could impact on the sweetness of cyclamate (Larson-Powers & Pangborn, 1978; Redlinger & Setser, 1987). Aspartame was described has having a longer aftertaste than alitame, acesulfame-K or sucrose (Ott *et al.*, 1991). Samundsen (1985) cited aspartame as having a lingering sweetness with a bitter–sweet aftertaste.

Area: Area parameter represents the amplitude of the sweet solution. Significant differences were found between the amplitudes of all tastants, for 5% SEV [$F=(4,14)=73.4$, $p<0.001$] as well as 10% [$F(4,14)=57.34$, $p<0.001$]. However, the LSD test has shown no significant difference between the amplitudes of sucrose and maltitol ($p>0.7$) or sucrose and cyclamate ($p>0.05$) for 5% SEV, and also no significant difference between the amplitudes of aspartame and sucrose ($p>0.48$), for 10% SEV. Results found for cyclamate are different from the conclusion of Ketelsen *et al.* (1993), who stipulated that, regarding the area parameter, cyclamate exhibited longer lingering characteristics than sucrose. Area parameters were dependent on the concentration for sucrose [$F(2,98)=38.5$, $p<0.001$], aspartame [$F(1,65)=13.9$, $p<0.01$] and cyclamate [$F(1,83)=100$, $p<0.001$]. Among the intense sweeteners, NHDHC has the greatest sweetness amplitude, followed by aspartame. These data agreed with the longer duration for aspartame and with NHDHC sweetness persistence.

Table 8. Attribute means for bulk and intense sweeteners

Attributes	Sucrose	Maltitol	Aspartame	Cyclamate	NHDHC	LSD (5%)
Flavour and aftertaste attributes:						
Sweet	61.5	59.1	55.7	54.3	57.3	10.0
Liquorice[a]	3.7	0.5	10.9	4.1	68.1	4.0
Caramel[a]	17.6	14.6	7.8	12.5	5.1	5.8
Burnt sugar[a]	7.0	3.9	8.6	19.2	12.2	5.0
Bitter[a]	4.6	2.3	11.0	23.5	30.2	4.8
Acid[a]	1.4	0.7	1.2	3.1	2.6	2.2
Menthol[a]	3.7	5.9	6.6	2.0	18.6	3.1
Liquorice-at[a]	3.1	1.2	10.2	4.5	63.4	3.5
Bitter-at[a]	5.2	5.9	12.5	28.2	33.0	3.7
Sweet-at	45.4	40.4	40.4	41.1	43.8	9.5
Metallic[a]	3.2	4.0	6.2	13.6	9.5	4.2
Mouthfeel attributes:						
Body[a]	39.0	37.4	28.2	31.8	35.5	7.8
Drying[a]	20.0	19.0	21.4	19.8	23.5	3.5
Astringent[a]	25.2	21.8	24.6	26.5	26.6	4.6
Smoothness[a]	33.1	37.6	29.5	31.0	31.9	6.3
Irritant	4.9	8.4	8.1	9.2	9.3	4.8
Cooling[a]	8.6	10.1	13.6	6.5	22.0	4.8

[a]Attributes with significant LSD values.

Sweetener profiling

Sample means for all attributes, together with the 5% LSD values, are shown in Table 8 for flavour, aftertaste and mouthfeel attributes. Asterisks indicate those attributes with significant differences at the 5% level. The results are represented by star diagrams in Fig. 6 and Fig. 7. The absence of any statistical differences in sweetness intensity between any of the five sweeteners confirms the validity of the equisweet relationships used. No statistical differences were found for sweet persistence or irritancy.

DISCUSSION

Maltitol exhibits a linear *C–R* function with a slope less than 1. This indicates that maltitol has a maximal intensity equivalent to that of sucrose but that it is less potent. In general, polyols (e.g. isomalt, lactitol, maltitol) fit the *C–R* linear model over a concentration range with an initial slope lower than 1. They achieve the same maximal intensity as sucrose but have a lower sweetness potency (DuBois *et al.*, 1991; Carr *et al.*, 1993). High-potency sweeteners approach the maximal sweetness response asymptotically. Aspartame and sodium cyclamate values were fitted by the Hill relationship, whereas, NHDHC exhibited the Beidler type. For all the substances that have a higher sweetness potency than sucrose, increasing the concentration led to a decrease in the rate of change of relative sweetness. There is not yet a clear answer to explain this different behaviour between sugars and intense sweeteners.

According to DuBois *et al.* (1993), high-potency sweeteners and sugars may bind to the same receptor population, but sugars may activate taste cells by an alternative mechanism from that of intense sweeteners. For Shallenberger (1993), sugars and high-potency sweeteners may have a common recognition mechanism and a common receptor set. Thus, the different types of sweetness score vs concentration curves for different compounds are the result of a combination of factors such as perceived intensity, onset time, duration and other tastes (Shallenberger, 1993). R_m values observed for NHDHC, aspartame and cyclamate are high. These sweeteners are able to match the sweetness

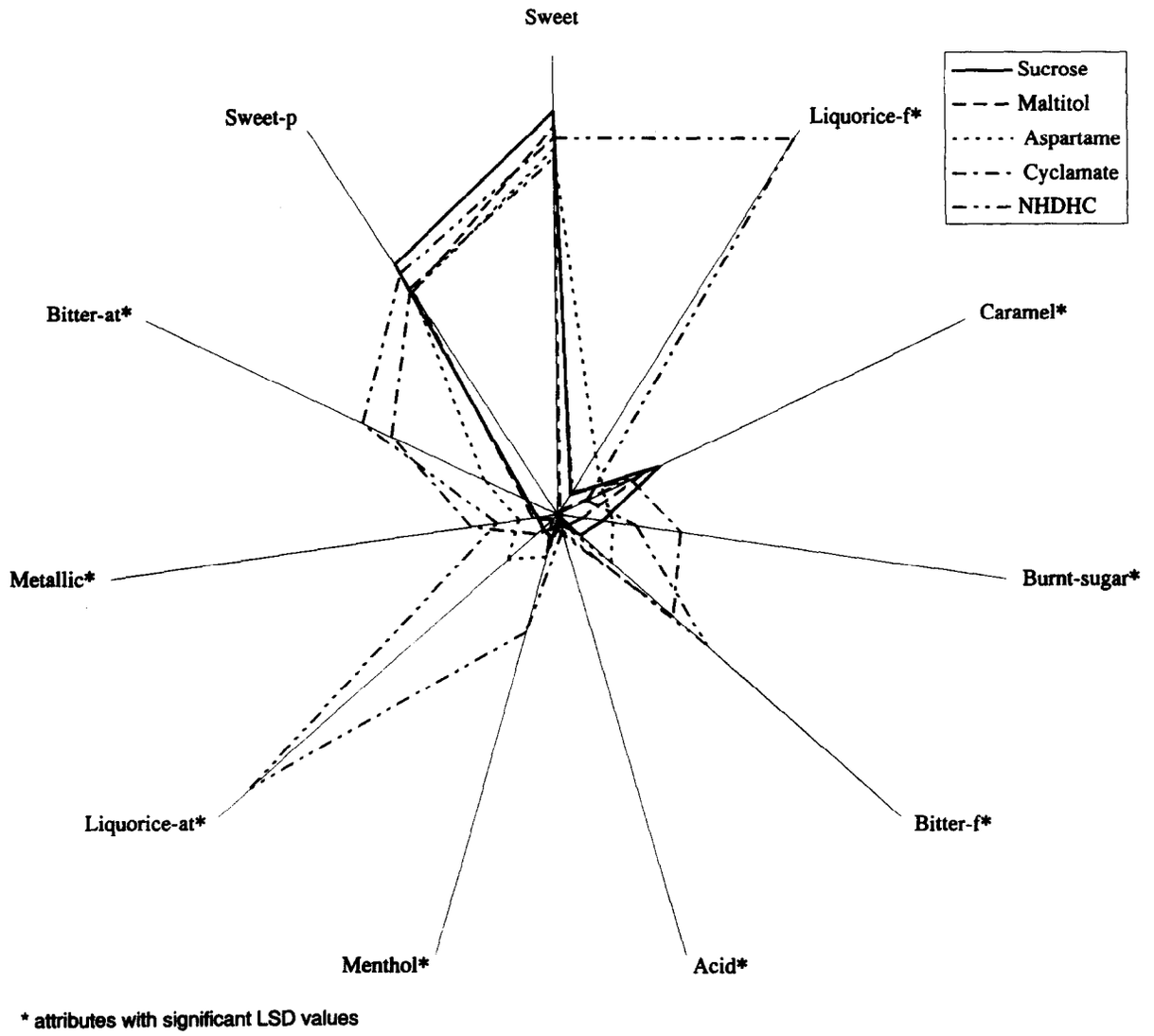

Fig. 6. Flavour and aftertaste attributes for bulk and intense sweeteners.

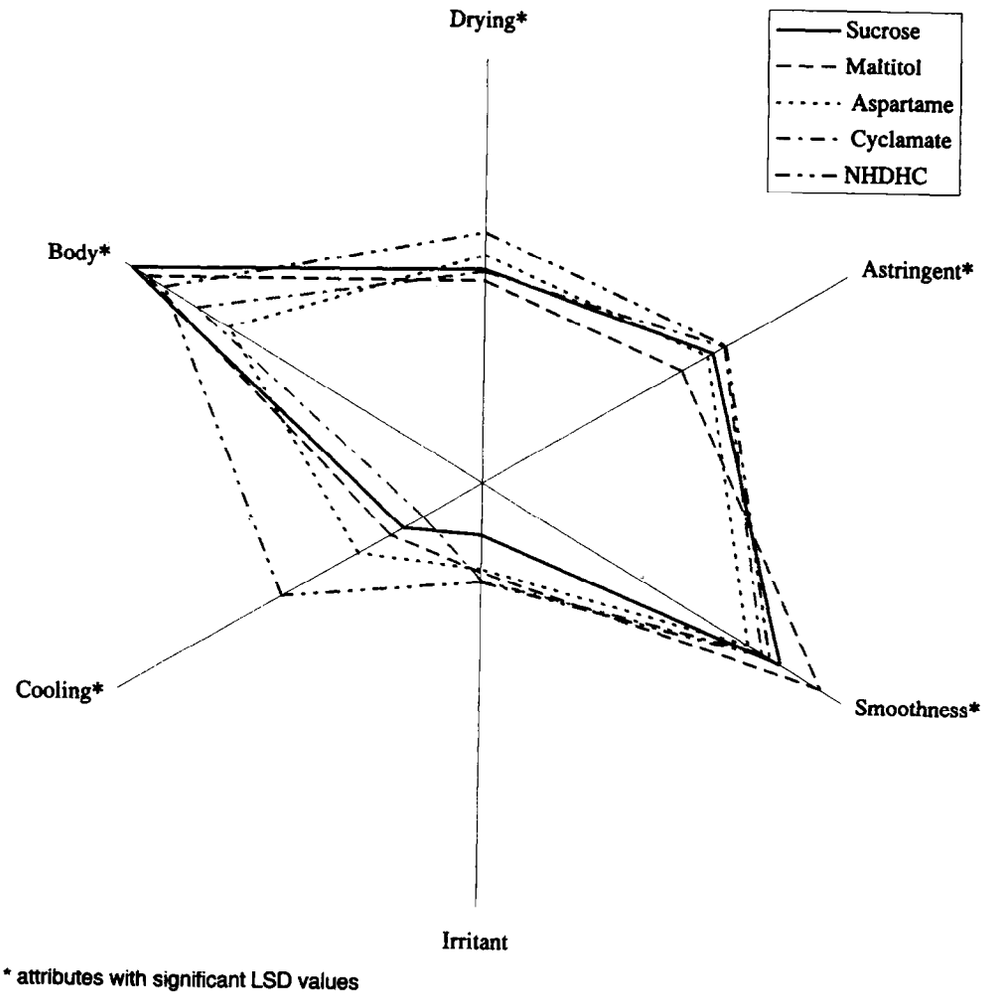

Fig. 7. Mouthfeel attributes for bulk and intense sweeteners.

level of 10–15% equivalent sucrose normally required in many food systems such as carbonated soft drinks and still beverages. However, in contrast to sugars and sugar alcohols, which have an invariable potency, relative to sucrose, the potency of intense sweeteners is highly concentration-dependent. For food formulation purposes, therefore, the potency values for intense sweeteners need to be quoted at appropriate sucrose concentrations.

Differences exist among sweeteners for initial and residual sweet intensities and non-sweet aftertaste (Ott *et al.*, 1991). Aspartame and sucrose have similar intensity profiles, with the exception of duration of aftertaste characteristics, whereas cyclamate had a profile comparable to that of saccharin and acesulfame-K (Ott *et al.*, 1991; Ketelsen *et al.*, 1993). DuBois & Lee (1983) found the temporal characteristics of cyclamate and aspartame to be indistinguishable from those of sucrose. Ketelsen *et al.* (1993) stipulated that direct comparisons between time–intensity parameters of cyclamate and other sweeteners (except fructose) might not be valid at 9% SEV in water. Birch & Lee (1979) explained the intensity of the sweet response by the rapid occupation and vacation of the binding site and the persistence by the time for the sweet molecules to diffuse from oral fluid to the ionophore trigger (Birch *et al.*, 1980; Birch, 1991).

Sucrose and maltitol develop an identical sweetness quality. None of the intense sweeteners was perceived exactly as sucrose. Aspartame sweetness has been described as 'sucrose-like' (Inglett, 1981; Holmer, 1984; Samundsen, 1985). However, sensory profiles have revealed that aspartame was found to be different from sucrose for liquorice flavour and liquorice aftertaste, caramel flavour, bitter flavour and bitter aftertaste, cooling effect and body. Previous studies (Wiet & Beyts, 1992) have suggested that panellists perceived artificial sweeteners and sucrose as similar in 'body', despite a difference in physical viscosity. Bitter aftertaste has been reported for sucrose (DuBois *et al.*, 1977), associated with a drying effect (Redlinger & Setser, 1987). Intensity scores for metallic and bitter aftertastes, were lower for sucrose and aspartame. Non-sweet aftertastes were much reduced for sucrose and aspartame compared with any other sweeteners in solution. Aftertaste for aspartame has been described as bitter–sweet with a slightly powdery sensation (Redlinger & Setser, 1987). Yoshida (1986) found that aspartame resembled several natural sweeteners in terms of secondary bitter taste. Sweeteners such as aspartame and sucrose that elicit a slight bitterness are qualified as 'sweet clean' in comparison with cyclamate, labelled 'sweet chemical' (Larson-Powers & Pangborn, 1978). Both natural and synthetic

sweeteners have been described as having some bitter characters (Ott *et al.*, 1991) although O'Brien & Gelardi (1981) claim than cyclamate is 'almost free from aftertaste'. The non-sweet flavours (bitterness, metallic and dryness) usually associated with saccharin or acesulfame-K (Redlinger & Setser, 1987; Rader *et al.*, 1967) were also noted for cyclamate. Bitterness can impair or even change the sweetness perception of cyclamate at high concentration (Redlinger & Setser, 1987). Bitter flavour and bitter aftertaste are attributes that differentiate sucrose and maltitol from artificial sweeteners. NHDHC solutions were mainly characterised by a liquorice-like and cooling/menthol flavour. This result was consistent with the literature data (Lindley *et al.*, 1991; Crosby & Furia, 1980). This lingering aftertaste appears to be typical of the DHC sweeteners. Caramel flavour was associated with nutritive sweeteners, whereas burnt sugar flavour was related to synthetic sweeteners except cyclamate, which was characterized by both flavours.

CONCLUSIONS

C–R functions represent an accurate method to estimate the concentration of sweetener require to elicit a specific level of sweetness. *C–R* equations are indicative of two different classes of tasting stimuli. Maltitol, representative of the polyols, is distinct from the high-potency sweeteners aspartame, sodium cyclamate and NHDHC. This difference may be rationalized by a difference in the mechanism of activation of the sweet receptors rather than by a difference in the type of receptors.

Quantification of time–intensity profiles represents another option for discriminating among bulk and intense sweeteners, temporal qualities being related to the structural and physical properties of sweeteners. Concentration influences the degree to which sweetener differences can be perceived. Sweetener differences become more evident at high concentrations. Application of the *T–I* data to a complex food system is not so simple, because in foods simple stimuli are rare (Moskowitz, 1977) and because of the taste interactions and masking effects (Pangborn, 1960; Stone & Oliver, 1969).

Bulk sweeteners maltitol and sucrose, and high-potency sweeteners aspartame, cyclamate and NHDHC, present dissimilar sensory profiles. If the sweetness quality of aspartame can be described as clean, like the sweetness of sucrose, cyclamate and NHDHC are characterized by a strong bitter flavour that is also associated with a liquorice note for NHDHC. These non-sweet flavours can impair the use of cyclamate and NHDHC in food formulation unless they are used in appropriate combinations with other sweeteners.

ACKNOWLEDGEMENTS

This work was funded by the Ministry of Agriculture Food and Fisheries (MAFF) and is part of the EU AIR programme 3.CT94.2107 on the investigation of the sweet taste mechanism and the role of water in the perception of sweetness.

The authors wish to thank Mrs S. Jenkinson, Ms C. L. Dray and Ms S. Nally for coordinating and conducting all sensory tests. Special thanks are due to Mr C. Roberts for his help in fitting the mathematical equations.

REFERENCES

Amerine, M. A., Pangborn, R. M. & Roessler, E. B. (1965). *Principles of Sensory Evaluation of Food.* Academic Press, New York.

Baïr, A., Borrego, F., Benavente, O., Castillo, J. & del Rio, J. A. (1990). Neohesperidin dihydrochalcone: properties and applications. *Lebensm.-Wiss. Technol.*, **23,** 371–6.

Birch, G. G. & Lee, C. K. (1979). The theory of sweetness. In *Development in Sweetness,* eds C. A. M. Hough, K. J. Parker & A. J. Vlitos. Applied Science, London, pp. 165–86.

Birch, G. G., Latymer, Z. & Holloway, M. R. (1980). Intensity/time relationships in sweetness: evidence for a queue hypothesis in taste chemoreception. *Chem. Senses,* **5(1),** 63–78.

Birch, G. G. (1986). Sweetness. *Arch. Dis. Childhood,* **61,** 1153.

Birch, G. G. (1991). Chemical and biochemical mechanisms of sweetness. *Food Techol.*, **Nov,** 114, 116, 119–20.

Carr, B. T., Pecore, S. D., Gibes, K. M. & DuBois G. E. (1993). Sensory methods for sweetener evaluation. In *Flavour Measurement,* eds C. T. Ho & C. H. Manley, Marcel Dekker Inc., pp. 219–56.

Crosby, G. A. & Furia, T. E. (1980). New sweeteners. In *CRC Handbook of Food Additives,* ed. T. E. Furia. CRC Press, pp. 203–216.

DuBois, G. E., Crosby, G. A., Stephenson, R. A. & Wingard, R. E. (1977). Dihydrochalcone sweeteners, synthesis and sensory evaluation of sulfonate derivatives. *J Agric. Food Chem.*, **25(4),** 763–71.

DuBois, G. E. & Lee, J. F. (1983). A simple technique for the evaluation of temporal taste properties. *Chem. Senses,* **7(3/4),** 234–47.

DuBois, G. E., Waiters, D. E., Schiffman, S. S., Warwick, Z. S., Booth, B. J., Pecore, S. D., Gibes, K., Carr, B. T. & Brands, L. M. (1991). Concentration–response relationships of sweeteners – a systematic study. In *Sweeteners: Discovery, Molecular Design and Chemoreception,* eds D. E. Walters, F. T. Orthoefer & G. E. DuBois. American Chemical Society, Washington DC, pp. 271–6.

DuBois, G. E., Walters, D. E. & Kelloggs, M. S. (1993). The rational design of ultra-high-potency sweeteners. In *Sweet-Taste Chemoreception,* eds M. Mathlouthi, J. A. Kanters & G. G. Birch. Elsevier Applied Science, London, pp. 237–65.

Holmer, B. (1984). Properties & stability of aspartame. *Food Technol.*, **38(7),** 50–5.

Inglett, G. E. (1981). Sweeteners — a review. *Food Technol.*, **35(3),** 37–41.

Ketelsen, S. M., Keay, C. L. & Wiet, S. G. (1993). Time–intensity parameters of selected carbohydrate and high potency sweeteners. *J. Food Sci.*, **58(6),** 1418–21.

Larson-Powers, N. & Pangborn, R. M. (1978). Paired comparison and time–intensity measurements of sensory properties of beverages and gelatins containing sucrose and synthetic sweeteners. *J. Food Sci.*, **43,** 41–6.

Leach, E., & Noble, A. C. (1986). Comparison of bitterness of cafeine and quinine by time–intensity sensory procedure. *Chem. Senses,* **11(3),** 339–45.

Lindley, M. G., Canales, I. & Borrego, F. (1991). A technical re-appraisal of the intense sweetener neohesperidine dihydrochalcone. In *Food Ingredients Europe Conference Proceed-ings.* Expoconsult Publishers, Maarsen, The Netherlands, pp. 48–51.

Lynch, J., Liu, Y.-H., Mela, D. & MacFie, H. J. H. (1993). A time–intensity study of the effect of oil mouthcoating on taste reception. *Chem. Senses*, **18(2),** 121–9.

Moskowitz, H. R. (1977). Intensity and hedonic functions for chemosensory stimuli. In *The Chemical Senses*, eds M. R. Kare & O. Maller. Academic Press, New York, p. 71.

O'Brien, L. & Gelardi, R. (1981). Alternative sweeteners. *Chem. Technol.*, **11,** 274.

Ott, D. B., Edwards, C. L. & Palmer, S. J. (1991). Perceived taste intensity and duration of nutritive and non-nutritive sweeteners in water using time–intensity (T–I) evaluations. *J. Food Sci.*, **56(2),** 535–42.

Pangborn, R. M. (1960). Taste interrelationships. *Food Res.* **25,** 245–56.

Pangborn, R. M., Lewis, M. J. & Yamashita, J. F. (1983). Comparison of time–intensity with category scalling of bitterness of iso-α-acid in model systems and in beer. *J. Inst. Brew.*, **89,** 349–55.

Rader, C. P., Tihanyl, S. G. & Zienty, F. B. (1967). A study of the true taste of saccharin. *J. Food Sci.*, **32,** 357–60.

Rainey, B. A. (1986). Importance of reference standards in training panelists. *J. Sens. Stud.*, **1,** 149–54.

Redlinger, P. A. & Setser, C. S. (1987). Sensory quality of selected sweeteners: aqueous and lipid model system. *J. Food Sci.*, **52(2),** 451–4.

Roczniak, S. & Walters, D. E. (1991). Use of the specific constant R_{max} /K, for rigorous comparison of sweeteners potencies. *Chem. Senses*, **16(5),** 491–5.

Samundsen, J. A. (1985). Has aspartame an aftertaste? *J. Food Sci.*, **50,** 1510.

Schmitt, D. J., Thompson, L. J., Malek, D. M. & Munroe, J. H. (1984). A improved method for evaluating time–intensity data. *J. Food Sci.*, **49,** 539–42.

Shallenberger, R. S. (1993). The initial chemistry of taste. In *Taste Chemistry*. Blackie Academic and Professional, London, pp. 377–448.

Stampanoni, C. R. (1993*a*). The 'Quantitative Flavor Profiling' technique. *Perf. Flav.*, **18,** Nov/Dec, 19–24.

Stampanoni, C. R. (1993*b*). Quantitative Flavor Profiling. An effective tool in flavor perception. *Int. Food Market. Technol.*, **2,** 4–6, 8.

Stampanoni, C. R. (1994). The use of standardized flavor languages and quantitative flavor profiling technique for flavored dairy products. *J. Sens. Stud.*, **9,** 383–400.

Stone, H. & Oliver, S. M. (1969). Measurement of the relative sweetness of selected sweeteners and selected mixtures. *J. Food Sci.*, **34,** 215–22.

Stone, H., Sidel, J., Oliver, S., Wolley, A. & Singleton, R. (1974). Sensory evaluation by quantitative descriptive analysis. *Food Technol.*, **11,** 24–34.

Stone, H. & Sidel, J. J. (1985) *Sensory Evaluation Practices*. Academic Press, London.

Swartz, M. (1980). Sensory screening of synthetic sweeteners using time–intensity evaluations. *J. Food Sci.*, **45,** 577–81.

Wiet, S. G. & Beyts, P. M. (1992). Sensory characteristics of sucralose and other high intensity sweeteners. *J. Food Sci.*, **57,** 1014–9.

Yoshida, M. (1986). A microcomputer (PC 9801/MS mouse) system to record and analyze time–intensity curves of sweetness. *Chem. Senses*, **11(1),** 105–18.