Solute–solvent interactions and the sweet taste of small carbohydrates. Part II: Sweetness intensity and persistence in ethanol–water mixtures

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Intensity and persistence of sweet taste of sugars (glucose, fructose, xylose and sucrose) and polyols (sorbitol, xylitol) were determined in ethanol–water mixtures using a sensory measuring unit for recording flux (SMURF) device. In all cases sweetness intensity and persistence were decreased when ethanol concentration was increased from 10% to 30%. Assessing intensity/time responses for varied (from 2·3% to 9·2%, w/v) concentrations of D-glucose, D-fructose and sucrose in 5% ethanol mixture shows that persistence is more affected by the presence of ethanol than intensity. These results are interpreted by the solution properties in the ethanol–water binary solvent.

INTRODUCTION

Since the stimulus–receptor interaction at the origin of sweet sensation takes place in water (saliva), it is of relevance to study the effect of 'water structure' on the intensity and duration of this sensation. The effects of temperature and viscosity have already been demonstrated (Portmann *et al.*, 1991). Among factors influencing solution properties of small carbohydrates and water structure, the polarity of the solvent modified by ethanol has been reported in Part I of this study (Serghat *et al.*, 1991). Analysis of the Raman spectra in the OH stretching region provided information on the effect of traces of D-glucose, D-fructose and sucrose on the structure of water and helped in defining the role of water in the sweet taste mechanism (Mathlouthi & Seuvre, 1988). Increased hydrophobicity of sweeteners was found to enhance their sweet taste (Kier, 1972), whereas an increased opposition of hydrophobic and hydrophilic sides of a sweet molecule seems to contribute to an increase in water mobility in aqueous solutions of intense sweeteners (Mathlouthi & Portmann, 1990). It is evident that sensory evaluation could not be performed in a solvent other than water. The only way the authors have found to study the effect of solvent structure on intensity/time response to sugars has been the addition of different percentages of ethanol to

water. The comparison of thermodynamic results and laser-Raman data of these sugar–ethanol–water ternary solutions to their sweetness intensity and persistence values should help in answering some of the questions remaining unanswered in the field of sweet taste chemoreception. Among these is the possibility that carbohydrates may activate the receptor indirectly simply by provoking membrane depolarization as their concentration and the polarity of their solvent are changed.

MATERIALS AND METHODS

D-Glucose and D-fructose were obtained from BDH Chemicals, Poole, UK. Sorbitol is a Sigma product (Sigma, Poole, Dorset, UK). D-Xylose and xylitol were obtained from Aldrich, Gillingham, Dorset, UK. These sugars together with commercial sucrose were used for sensory analysis. The water used was natural mineral water from Buxton Mineral Water Company, Derby, and the ethanol was fermented ethanol (96%, v/v) obtained from Hayman Ltd, Witham, Essex, UK.

Intensity/time responses were recorded for sugars in ethanol–water mixtures using the SMURF (sensory measuring unit for recording flux) device (Birch & Munton, 1981).

The solutions were assessed by 22 panellists from departmental personnel (9 males, 13 females, aged

23–60). Selection of assessors was based on their aptitude to detect sweetness and classify in the correct order sucrose solutions of 0%, 1%, 1·5% and 2% (w/v) on the one hand and 5%, 10% and 15% (w/v) on the other. Training of the panellists in using the SMURF technique was done in one session and, where necessary, a second session was carried out.

Solutions for assessing the ethanol concentration effect were 10% (w/w) of sugar in 10%, 20% or 30% (w/w) ethanol in water. These solutions were stored overnight at 7°C and allowed to warm up at room temperature one hour before tasting. Solutions used in the comparative study of the ethanol effect on sweetness intensity and persistence as a function of sugar concentration were 2·3%, 4·6%, 6·9% and 9·2% (w/v) of D-glucose, D-fructose or sucrose in 5% (v/v) ethanol–water solvent. The results of the study were treated statistically using the STATIT-CF program (Danzart, 1990) and Student's *t*-test. The effect of various levels of ethanol on the sweetness of

10% (w/w) sugar solution was analyzed using analysis of variance.

RESULTS AND DISCUSSION

Effect of ethanol concentration on sweetness

Figure 1 shows the effect of ethanol concentration on the sweetness intensity of each of the monosaccharides (D-glucose, D-fructose and D-xylose) with the standard deviations for a confidence interval of 95%. The variation of intensity as a function of ethanol concentration with the standard error is given in Figs 2 and 3 respectively for sucrose and the polyols, sorbitol and xylitol. The persistence results are reported in Figs 4, 5 and 6 respectively for monosaccharides, sucrose and polyols. The overall effect of ethanol concentration on the sweetness intensity and persistence of the studied sugars is shown in Figs 7 and 8. It is obtained from the mean of the scores of intensity and time of all the sugars taken together. Figures 1–8 show that both intensity and persistence are decreased when ethanol concentration is increased. However, it was also found that the 10% ethanol level gives higher intensity and persistence values than the zero level (pure water) for glucose, sorbitol and xylitol. For fructose, xylose and sucrose these results are fairly similar. In all cases the 30% level is significantly lower than the zero ethanol level. In Table 1, it can be seen that the influence of ethanol concentration is more apparent for intensity than for persistence.

For intensity, the difference between 0% and 20% ethanol is highly significant but the difference in persistence is not. Some of the physicochemical properties of sugar in the EtOH–water binary solvent (e.g. intrinsic viscosity) show a minimum at about 20–25% of EtOH in the mixture (Serghat *et al.*, 1991). This minimum is also reported for the excess of enthalpy of mixing of water with ethanol (Franks & Ives, 1966). The preponderant effect in these mixtures seems to be that of
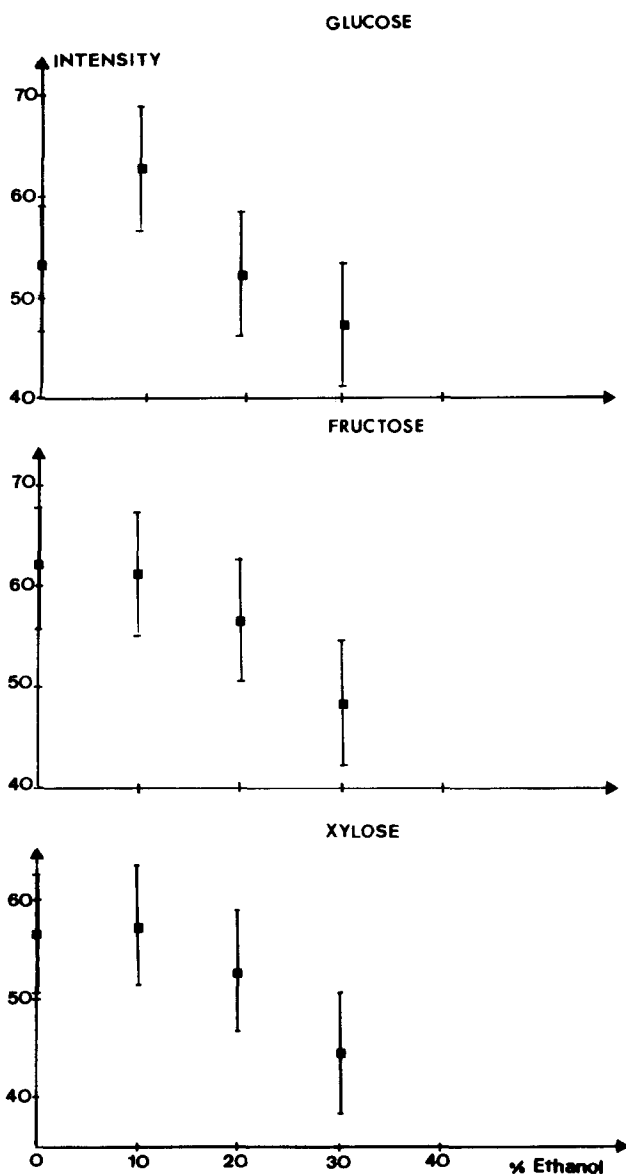

Fig. 1. Mean intensity and standard error (95% CI) for monosaccharides (D-glucose, D-fructose and xylose) in various concentrations of ethanol.
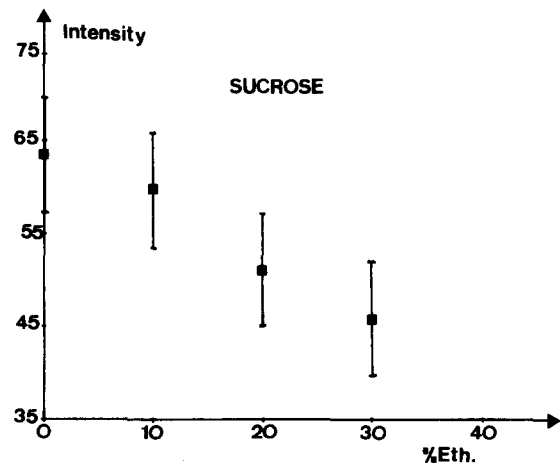

Fig. 2. Mean intensity and standard error (95% CI) for sucrose in various concentrations of ethanol.
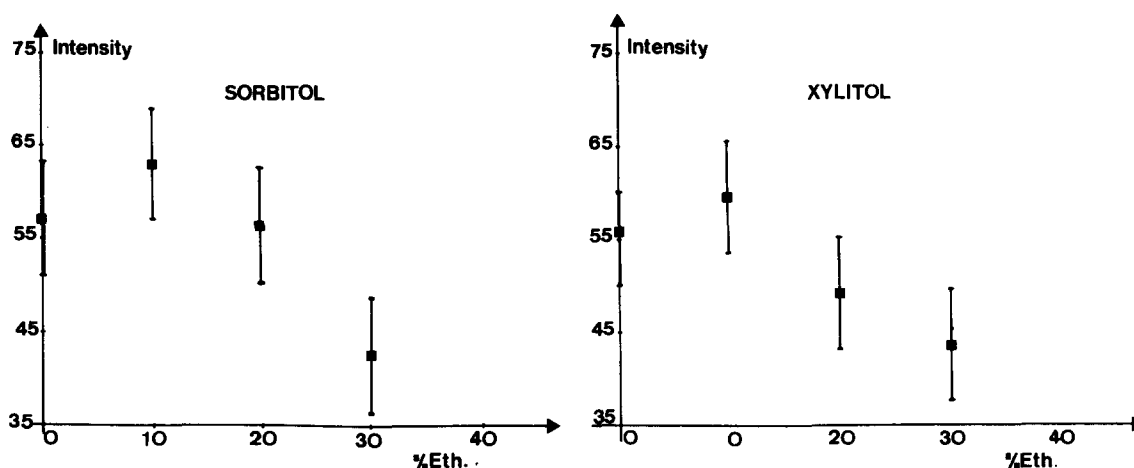
Fig. 3. Mean intensity and standard error (95% CI) for polyols in various concentrations of ethanol.
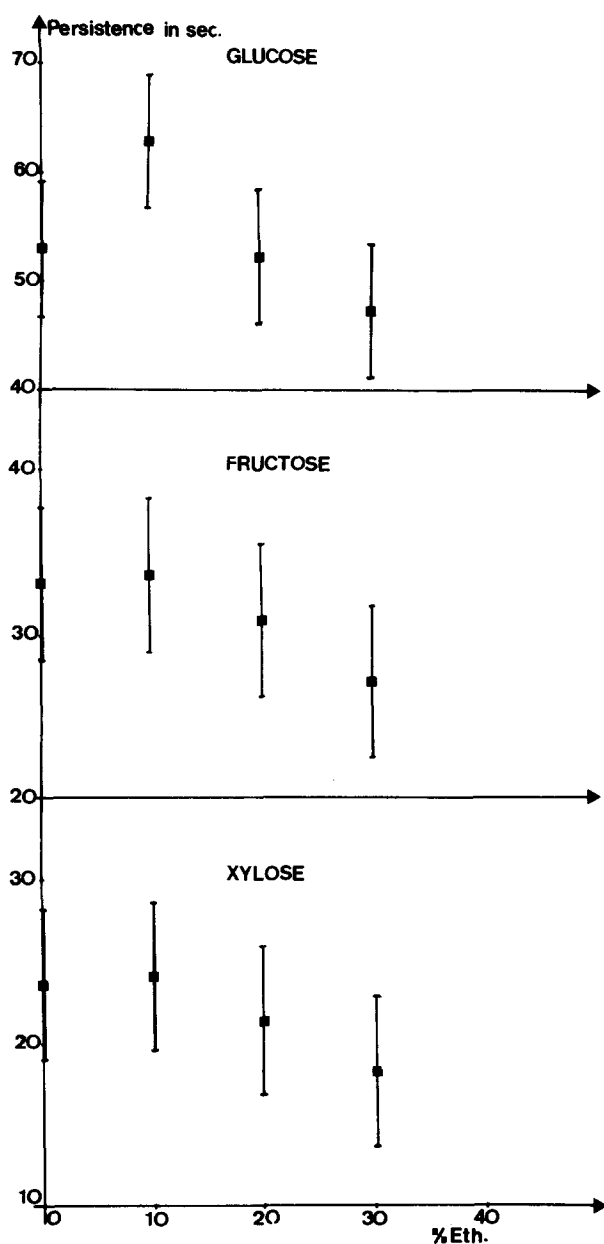

Fig. 4. Mean persistence and standard error (95% CI) for monosaccharides (D-glucose, D-fructose and D-xylose) in various concentrations of ethanol.

Table 1. Significant differences of sweet taste in a comparison of each pair of solutions for perceived intensity and persistence

% Sucrose	% EtOH							
	Intensity				Persistence			
	0	10	20	30	0	10	20	30
0	—	ns	**	***	—	ns	ns	***
10	—	—	***	***	—	—	**	***
20	—	—	—	***	—	—	—	***

ns, Not significant; *, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$.

entropy. Mixing of water with ethanol provokes an enhancement of the packing of water molecules in clusters. It was shown in Part I of this work (Serghat *et al.*, 1991) that the addition of EtOH to water provokes the shift of the frequency corresponding to the more organized species towards higher frequencies and that of the less organized clusters towards lower frequencies. It was also found (Nakanishi *et al.*, 1967) that ethanol stabilizes the structure of water. It is probable that accession of sugars to the receptor site in such mixtures is hindered. Moreover, it was shown
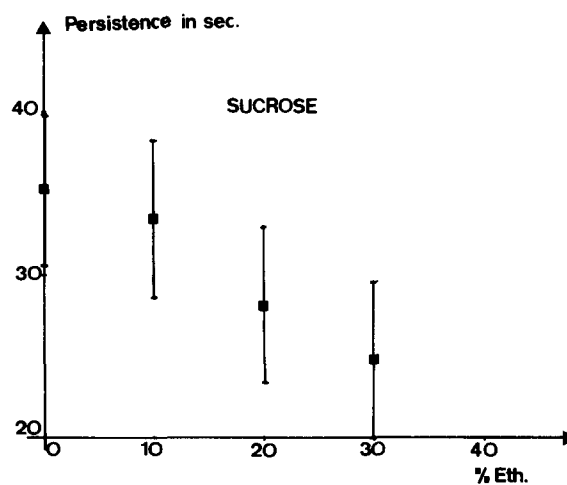

Fig. 5. Mean persistence and standard error (95% CI) for sucrose in various concentrations of ethanol.
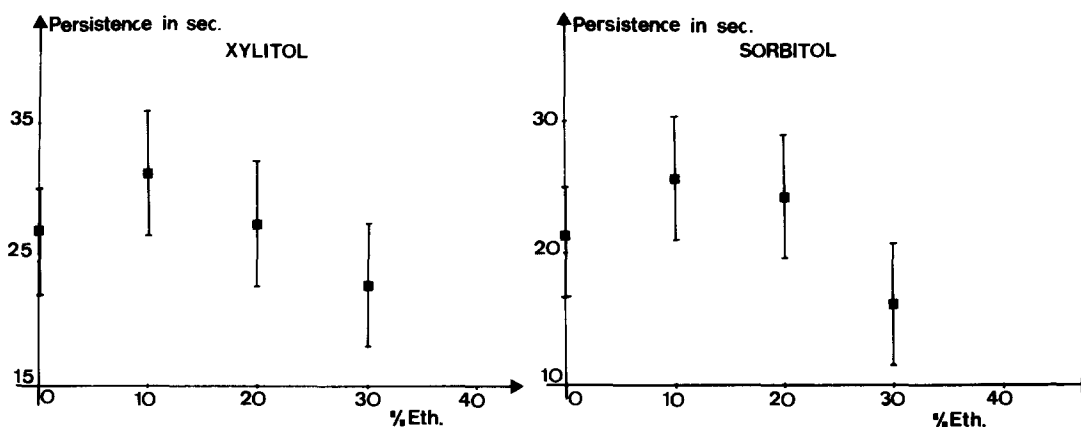
Fig. 6. Mean persistence and standard error (95% CI) for polyols (D-sorbitol and xylitol) in various concentrations of ethanol.
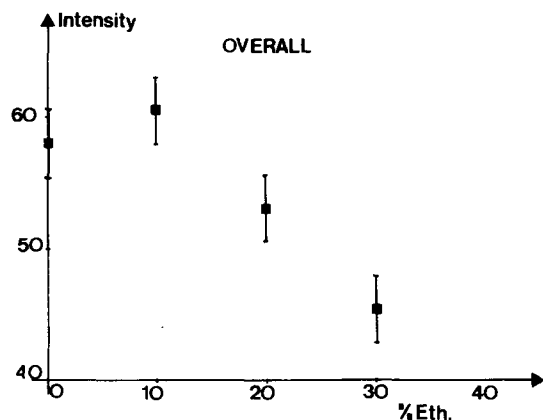

Fig. 7. Mean intensity and standard error (95% CI) for six sugars together in various concentrations of ethanol.
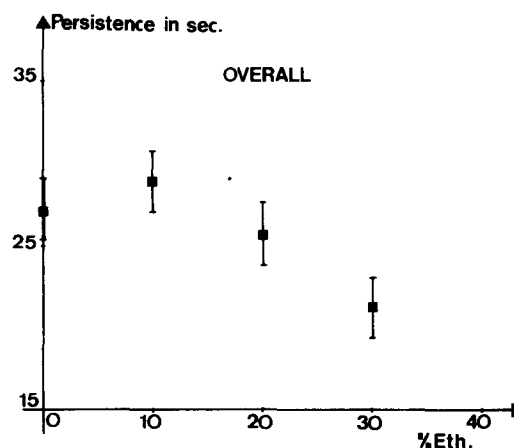

Fig. 8. Mean persistence and standard error (95% CI) for six sugars in various concentrations of ethanol.

(Mathlouthi, 1984; Mathlouthi & Seuvre, 1988) that water mobility is needed for sweetness to be intense and persistent. The enhanced 'water structure' under the hydrophobic effect of ethanol is opposed to the ease of ion (Na^+/K^+) transport across the receptor membrane; hence it causes a decrease in sweetness response. The persistence response seems to depend on the assessed sugar.

Comparison of the sweetness of sugars at different concentrations in water and 5% ethanol

The variation of sweetness intensity for D-glucose, D-fructose and sucrose in water and 5% ethanol as a function of concentration is reported in Fig. 9. Persistence results are reported in Fig. 10. Comparison of intensity values for the three sugars in water and 5% ethanol does not reveal any significant difference except for sucrose at 9·2% (w/v) when the Student's t-test is applied (see Table 2).

Figure 10 shows that almost all values of persistence are shorter in ethanol solutions than in water. Table 2 shows that the short duration of sensation in ethanol mixtures is especially important for fructose solutions.

Another approach to the sweetness–concentration relationship is the power function treatment. Intensity and persistence are related to concentration by these relations:

$$S = k_S C^{nS}$$

and

$$P = k_P C^{nP}$$

where S is intensity, P is persistence, n is the exponent and k a constant. The parameters n and k were interpreted as representative of accession to receptor and of interactions between the stimuli and the receptor (Moskowitz, 1970). They are derived from the regression line of $\log S$ and $\log P = f(C)$ and are listed in

Table 2. Level of significance of sensory results in 5% ethanol using Student's t-test with CI = 95%

	Concentration (w/v)			
	2·3	4·6	6·9	9·2
Glucose				
Intensity	ns	ns	*	ns
Persistence	ns	ns	ns	ns
Fructose				
Intensity	ns	ns	*	ns
Persistence	*	ns	*	ns
Sucrose				
Intensity	ns	ns	ns	*
Persistence	*	ns	ns	ns

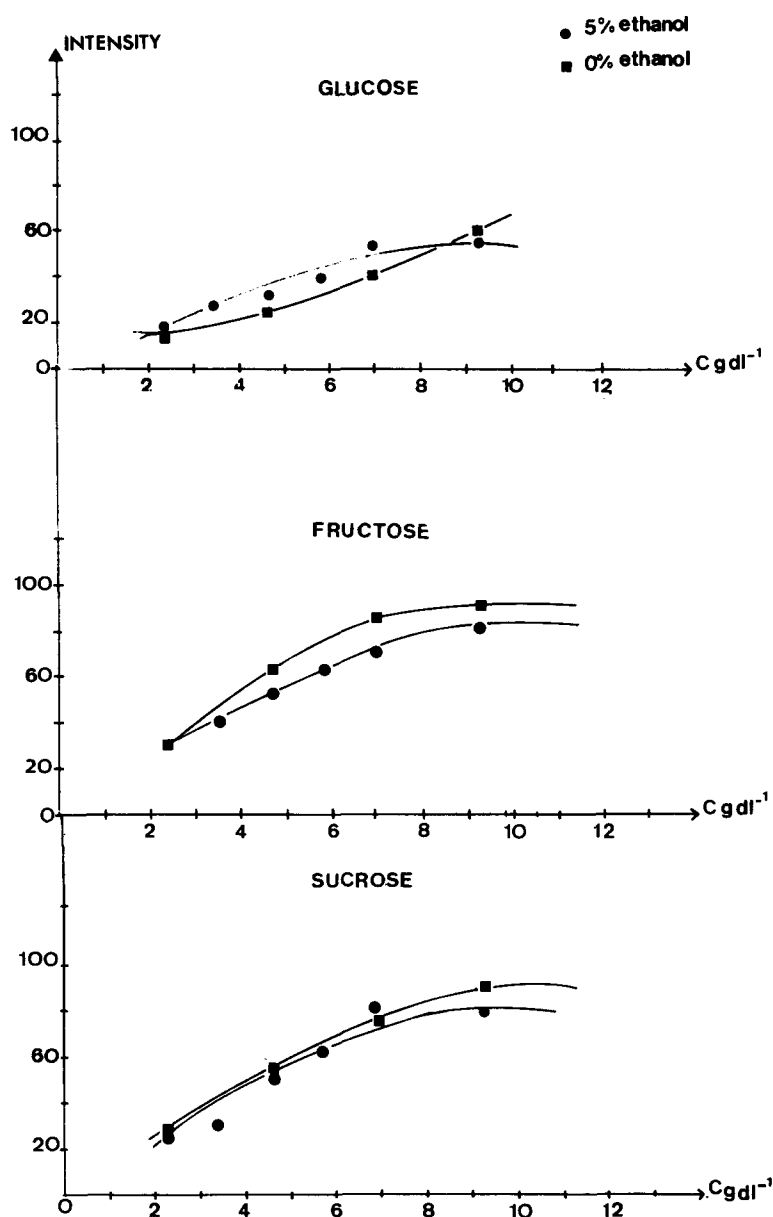ns, Not significant; *, $p \leq 0.05$.

Fig. 9. Intensity of sweetness taste versus sugar concentrations (D-glucose, D-fructose and sucrose) with and without ethanol.

Table 3 for the intensity of the three sugars in 5% ethanol mixture and Table 4 for persistence.

Results for aqueous solutions at 22°C have already been given in a previous paper (Portmann *et al.*, 1991). Comparison of n_S, k_S, n_P and k_P for water and ethanol mixture solutions is shown in Table 5. Both k_S and k_P are decreased in ethanol solutions whereas almost no change occurs in the values of n_S and n_P for fructose and sucrose.

The values obtained for glucose show an increase of k_S and k_P and a decrease of n_S and n_P. The presence of 5% of ethanol in solution does not seem to affect sugar–receptor interactions for fructose and sucrose (similar n values), but their accession to sites is made more difficult (decrease of k values, see Table 5). For D-glucose, it seems that binding to the site is favoured if the interpretation of n and k values (Table 5) according to Moskowitz (1970) is adopted. It may also be noticed

Table 3. Linear regression equations (log (intensity) = $f(C)$), correlation coefficient, r, and coefficients k_S and n_S for sugar ethanol (5%) mixtures at 22°C

Sugar	Linear regression equation	r	k_S	n_S
Glucose	$y = 0.94 + 0.87x$	0.97	8.70	0.87
Fructose	$y = 1.13 + 0.84x$	0.98	13.45	0.82
Sucrose	$y = 1.03 + 0.97x$	0.96	10.71	0.87

Table 4. Linear regression equations (log (persistence) = $f(C)$), correlation coefficient, r, and coefficients k_S and n_S for sugar ethanol (5%) mixtures at 22°C

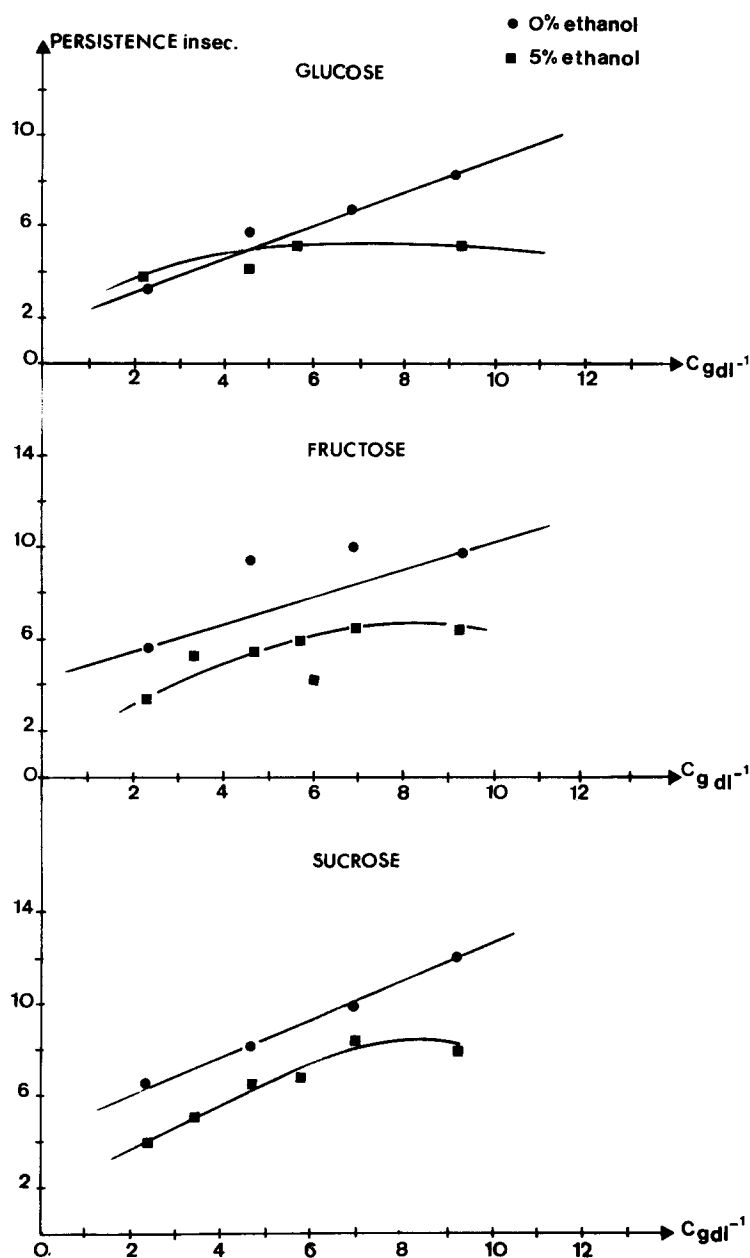| Sugar	Linear regression equation	r	k_P	n_P
Glucose	$y = 0.45 + 0.43x$	0.94	2.81	0.42
Fructose	$y = 0.41 + 0.45x$	0.91	2.56	0.45
Sucrose	$y = 0.41 + 1.55x$	0.96	2.57	0.50

Fig. 10. Persistence of sweetness taste versus sugar concentrations (D-glucose, D-fructose and sucrose) with and without ethanol.

that the tendency of the D-glucose sweetness intensity to exhibit expansion when concentration is increased (Portmann *et al.*, 1991) is not repeated for ethanol solutions. Figure 10 rather shows compression behaviour for D-glucose in the aqueous ethanol mixture.

The results for the effect of ethanol concentration on sweetness and the comparison of water and 5% ethanol

Table 5. Coefficients k_S, k_P, n_S and n_P for solutions of D-glucose, D-fructose and sucrose with and without ethanol at 22°C

Sugar	In water				In 5% ethanol			
	k_S	n_S	k_P	n_P	k_S	n_S	k_P	n_P
Glucose	5·75	1·12	2·00	0·87	8·70	0·87	2·81	0·42
Fructose	15·24	0·85	4·16	0·45	13·45	0·82	2·56	0·45
Sucrose	14·12	0·46	14·46	0·83	10·71	0·87	2·57	0·50

solutions both show that sweetness decreases when ethanol is added to the tasting medium. This can be explained by physicochemical properties, especially apparent specific volume. The compatibility of the solute seems to decrease with increasing ethanol concentration. Therefore, the solute cannot reach, in concentrated ethanol solutions, the deeper layers of the sweet taste bud and the perceived sweet taste is decreased. In terms of the 'orderly queue', as proposed by Birch and Lee (1979), this will mean that less queues will operate. The queues situated in deeper layers of the taste bud are not reached. Therefore, there will be less overlap between queues operating and the time of sweetness perception will be shorter. This is at the origin of the more pronounced effect of ethanol on persistence than on intensity. Ethanol itself has a taste which competes with the sweet taste. An adaptation of panellists to ethanol solutions was obtained and the

panel booth where assessments were made was well ventilated. Nevertheless, some people accustomed to drinking spirits could have been better judges of solutions with higher concentrations of ethanol because of their ability to distinguish between alcohol taste and all other tastes. Indeed, the 20% ethanol concentration was found to elicit a low sweet sensation.

Other descriptions were mentioned by panellists, such as 'dehydrating', 'bitter' or 'astringent taste' for solutions of ethanol in water. The lower level (5%) used for comparative study did not markedly influence the judgement of panellists. At this level, the differentiation of D-glucose on the one hand and D-fructose and sucrose on the other seems much more related to their interactions in water and the ethanol mixture than to specific effects of the alcohol.

CONCLUSION

Results of sweet taste evaluation for ethanol–water mixtures show a decrease in response, especially significant as regards persistence. The decrease in sweetness intensity and persistence of small carbohydrates in EtOH–water mixture may have different origins. The interference of ethanol taste and the anaesthetic effect of alcohol, described as a 'dehydrating' sensation by panellists, are possible explanations. However, it may be recalled that the hydrophobic effect of anaesthetics and the repelling of water molecules was proposed by Pauling (1961) to explain anaesthesy. The enhancement of packing of water molecules under the effect of ethanol was previously shown (Franks & Ives, 1966; Serghat *et al.*, 1991). It is then reasonable to relate the sensory results observed in this paper to the packing of water provoked by the addition of ethanol. The sugars are also differentiated in the ethanol mixture by their effect on water mobility. The results reported here and in Part I of this work (Serghat *et al.*, 1991) could be taken as arguments to support the preponderant role of water structure in sweet taste chemoreception.

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