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Sweetness of bulk sweeteners in aqueous solution in the presence of salts

David Kilcast *, Marie-Odile Portmann [1], Briege E. Byrne

Sensory and Consumer Science, Leatherhead Food Research Association, Randalls Road, Leatherhead, Surrey, KT22 7RY, UK

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Abstract

The perceived effect of adding salts on the sweetness of bulk sweeteners (sucrose, glucose, fructose, sorbitol and xylitol) depends on the sweetener type and concentration and on the type of salt. Sodium chloride enhances the sweetness of all the sweeteners to some degree. Potassium chloride has little effect on any sweetener other than sorbitol, which shows sweetness enhancement at low sorbitol concentrations and suppression at high sorbitol concentrations. Magnesium chloride additions tend to enhance sweetness, particularly of sucrose and glucose. The effects observed can not be ascribed to any inherent sweetness of the salts themselves, suggesting that the observed effects are a result of interactions between the salts and sweeteners in the aqueous medium.

1. Introduction

It is well established that water structure is one of the prime factors in sweetness chemoreception. A widely accepted model of the sweetness response postulates accession of the sweetener molecule to a receptor site, followed by a triggering phenomenon that depends on stereochemical fitting (Eggers, Acree & Shallenberger, 2000). Excitation of the membrane is accompanied by an opening of ion channels and Na^+/K^+ exchange across the membrane. Factors thought to influence the stimulus-receptor interaction include the hydrophilic-lipophilic balance of the sweet molecule (Daniel, 1989) and hydrogen bonding through water molecules involved in the molecular recognition of sweet taste (Jeffrey, 1993). The more mobile the water molecules, the more active the Na^+/K^+ flux across the receptor membrane and the more intense the sweet response.

Hydration of electrolytes is well-documented (Robinson & Stokes, 1959), and depends on the polarizing effect of the cation, which is in turn a function of the ionic radius and the electrical charge. Both Na^+ and Mg^{2+} tend to orient water molecules in their vicinity and are relatively highly hydrated, whereas K^+ is surrounded with water molecules, which are more mobile than bulk water. All these ions are present in saliva, and their importance in a biological medium is well known (Hutteau & Mathlouthi, 1998).

As part of the work carried out in the first stage of this project, Mathlouthi, Hutteau and Angiboust (1996) carried out an investigation of interactions in water–sugar–salt solutions, using a macroscopic approach based on physicochemical properties of solutions and a microscopic approach using Raman spectroscopy. Comparison of the physicochemical results and Raman data in water, on the one hand, and in salt solution, on the other, permitted determination of the influence of the biologically important cations (Na^+, K^+ and Mg^{2+}) on the effect of sugars and polyols on water structure. Na^+ and Mg^{2+} were identified as water structure enhancers, whereas K^+ had the opposite effect and can be classified as a structure breaker. This study concluded that sensory studies were needed to improve the interpretation of the observed effects.

2. Materials and methods

2.1. Materials

Sodium chloride, potassium chloride and magnesium chloride were Fisons analytical grade reagent quality. The sweeteners tested were sucrose (Tate & Lyle), D-fructose

* Corresponding author. Tel.: +44-1372-376-761; fax: +44-1372-386-228.

[1] Current address: SmithKline Beecham, Consumer Healthcare, St George's Avenue, Weybridge, Surrey, KT13 0DE, UK.

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(Fluka), D-glucose (Sigma), sorbitol (Roquette) and xylitol (Xyrofin), and were used without further purification. All solutions were prepared in still mineral water (Ballygowan, total dissolved solids <0.004%) no more than 24 h before the sensory tests. The sweetener concentrations used were 3, 4, 5 and 6% w/v.

Preliminary screening was carried out to establish taste threshold levels for the salts. The purpose of this was to determine the highest salt concentration that could be used without the characteristic tastes of the salts becoming apparent. In particular, it was important that any characteristic tastes should not be strong enough to suppress the sweetness of the lower sweetener concentrations. Concentrations of 0.01, 0.1, 0.2, 0.5 and 1% were tested in a 2% sucrose solution, and a level of 0.2% was selected.

2.2. Experimental procedures

A panel of 10–12 female panellists was used with extensive experience in previous sweetener evaluations. Retraining on intensity scaling was carried out using procedures described previously (Portmann & Kilcast, 1996). In order to maximise the sensitivity of the test procedure, an experimental design was used in which the panellists rated the sweetness of the samples relative to a reference. For this purpose, the TASTE computerised data acquisition system was set up to show a line scale, anchored at the left by the words *less sweet*, and at the right by the words *more sweet*. The central point was anchored by the word *reference*.

Panellists were presented, in each session, with an identified reference together with 4 coded samples, each set comprising a single concentration of a given sweetener. The identified reference was the sweetener solution without any added salt; the coded set consisted of the same sample as a blind control, together with the test samples containing the salts, presented in random order. Panellists were asked to taste the identified reference sample first, and to note the position of this sample in the centre of the scale. They were then asked to taste the coded samples in the order presented, and to score the sweetness intensity of each test sample on the scale relative to the sweetness intensity of the reference sample. Each set was replicated once, and each replicated test was repeated for each sweetener type at each sweetener concentration. Other tastes were not quantified in order to minimise the risk of halo effects.

Samples were presented as 12 ml aliquots in 30 ml odour-free plastic pots coded with three-digit random numbers, at a temperature of approximately 22°C. Testing was carried out in individual tasting booths under red light to minimise any appearance differences. Panellists were given a brief outline of the objectives of the work, but with no information on the type of sweeteners. A sip-and-spit procedure was employed, with mineral water and crackers available as palate cleansers. Panellists were asked to wait for at least 1 min between samples, and there was a break of 10–15 min between sessions.

2.3. Data analysis

Univariate statistical analysis was carried out on the raw data using analysis of variance and Fisher's LSD test to compare the mean sweetness intensities of the samples containing salt and the appropriate blind reference sample. Separate analyses were carried out for each sweetener type.

3. Results and discussion

Mean sweetness intensity scores are shown in Table 1. The theoretical value for the sweetness intensity of the sweetener solution without salt is 50 in each case, and deviations from this value reflect any inconsistencies in the scoring of this blind sample. Inspection of Table 1

Table 1
Sweetness intensity of sucrose, glucose, fructose, xylitol and sorbitol in salt solutions[a]

Conc. (%)	No salt		+NaCl		+KCl		+$MgCl_2$	
	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.
Sucrose								
3	50.4	3.5	54.2	4.8	48.1	4.5	58.8	3.9
4	52.9	2.1	55.3	5.2	49.1	4.7	62.9	3.9
5	49.0	1.3	59.1	3.5	50.6	4.0	57.0	3.8
6	49.8	1.5	55.8	4.0	54.6	4.3	59.1	3.2
Glucose								
3	49.4	1.8	50.5	3.8	47.8	4.0	59.8**	2.2
4	50.7	1.1	58.2*	2.9	52.5	1.5	57.1	2.2
5	50.3	1.8	55.9	3.3	58.9*	2.3	61.5**	2.9
6	52.3	2.1	60.5*	3.5	55.3	2.4	57.8	2.7
Fructose								
3	50.8	0.9	67.1***	3.1	53.6	2.6	52.2	3.0
4	53.8	1.6	61.3*	3.4	60.0	3.2	52.6	3.0
5	50.4	1.4	64.0***	3.1	56.9	3.5	53.3	3.1
6	50.6	0.3	60.2*	3.8	56.4	2.7	46.9	2.9
Sorbitol								
3	48.4	2.3	56.5	3.8	61.3**	6.1	52.9	3.6
4	48.1	1.9	54.1	5.3	50.6	4.5	54.4	3.5
5	47.1	1.7	57.5*	4.7	48.9	4.1	53.7	2.5
6	50.3	1.2	63.6**	3.1	36.7**	4.5	49.7	3.0
Xylitol								
3	50.4	1.2	61.2***	3.0	47.7	3.1	49.2	3.2
4	47.2	1.1	65.0***	3.1	49.2	3.0	46.6	3.3
5	50.4	0.5	67.8***	3.0	55.8	2.4	52.4	2.5
6	51.2	1.5	64.4***	3.0	51.2	3.0	49.5	2.4

[a] Key: star rating indicates level of significance for the given mean tested against the respective 100% sweetener solution (no salt addition); * $P<0.05$; ** $P<0.01$; *** $P<0.001$.

shows that the panellists were highly consistent in scoring this sample; a histogram of the data for all the sweeteners is shown in Fig 1.

In Table 1, statistically significant differences are identified for the mean intensity scores of the sweetener–salt combinations that are significantly different from the respective sweetener intensity at the same sweetener concentration. These data are also shown graphically in Figs 2–6.

No statistically significant differences were found ($P<0.5$) between the sweetness intensity of sucrose samples with a salt addition against the respective reference samples, although numerical increases in sweetness were found at all sucrose concentrations.

For glucose, statistically significant differences were found for the following samples:

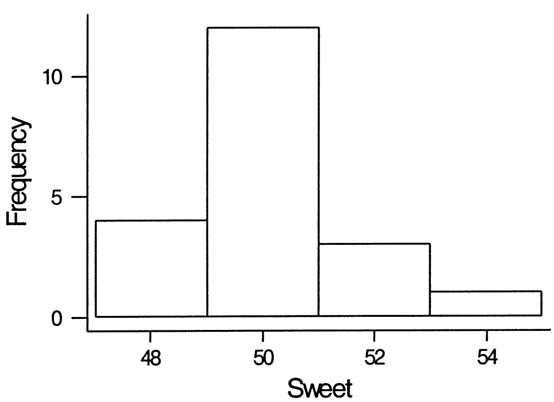

Fig. 1. Histogram showing the distribution of sweetness intensity scores for the sweeteners in the absence of added salts (i.e. blind references).

NaCl at 4% glucose ($P<0.05$)
NaCl at 6% glucose ($P<0.05$)
KCl at 5% glucose ($P<0.05$)
$MgCl_2$ at 3% glucose ($P<0.01$)
$MgCl_2$ at 5% glucose ($P<0.01$)

Statistically significant differences were found on addition of NaCl to fructose solutions at all fructose concentrations, but not for the other salts:

3% fructose ($P<0.001$)
4% fructose ($P<0.05$)
5% fructose ($P<0.001$)
6% fructose ($P<0.05$)

For sorbitol, statistically significant differences in sweetness were found for the following samples:

NaCl at 5% sorbitol ($P<0.05$)
NaCl at 6% sorbitol ($P<0.01$)
KCl at 3% sorbitol ($P<0.01$)
KCl at 6% sorbitol ($P<0.01$)

The effect of KCl at 6% sorbitol was the only significant suppression effect found.

Xylitol showed highly statistically significant sweetness increases on addition of NaCl at all xylitol concentrations, but no effects for the other salts:

3% xylitol ($P<0.001$)
4% xylitol ($P<0.001$)
5% xylitol ($P<0.001$)
6% xylitol ($P<0.001$)

The overall patterns of the effects of salt additions are shown in Table 2 and in Figs. 7–9.

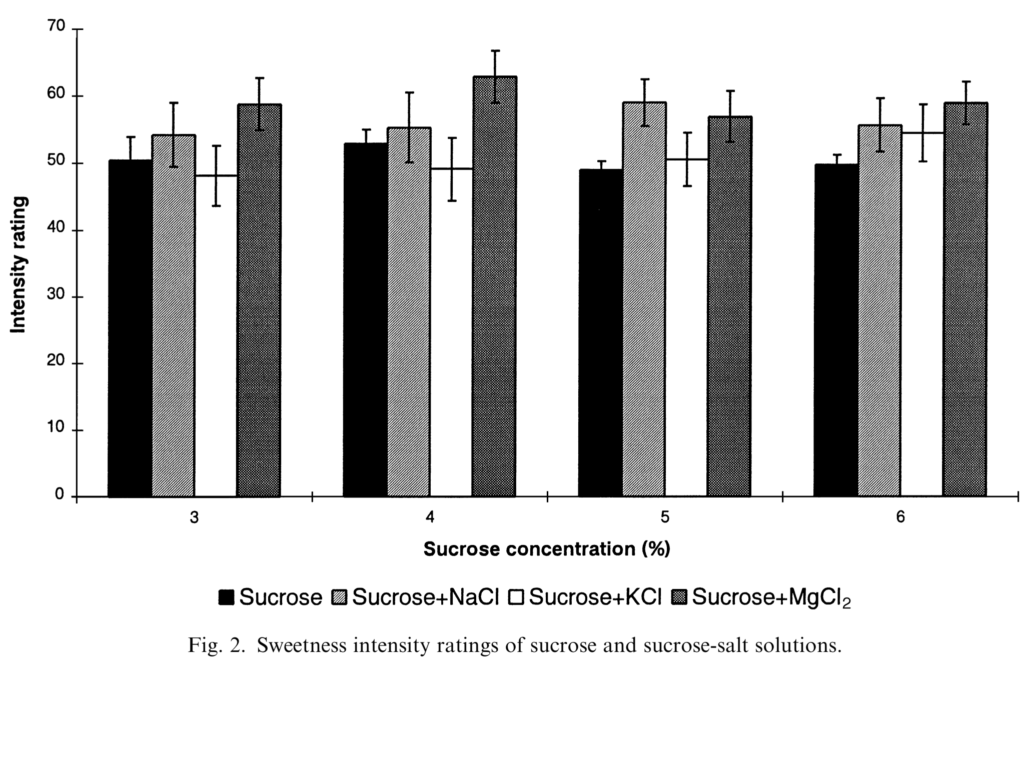

Fig. 2. Sweetness intensity ratings of sucrose and sucrose-salt solutions.

3.1. Effect of added sodium chloride

Addition of sodium chloride to xylitol solutions gives a sweetness intensity increase at all xylitol concentrations. There was no clear pattern of dependence on the concentration, but the highest increases, of between 35 and 40%, occurred at the 4 and 5% xylitol concentrations. Increases also occurred on addition to the sorbitol solutions, but these were only significant at the highest sorbitol concentrations (5 and 6%). Significant increases were also found on addition to fructose solutions. The increases were greatest for the 3 and 5% sorbitol solutions. Significant increases were found on addition to 4 and 6% glucose solutions, but no increase on addition to the 3 glucose solution. No significant increases ($P<0.05$) were found on addition to sucrose solutions, but the increase on addition to the 4% sucrose solution was almost significant ($P=0.06$). Informal assessment of the taste of 0.2% sodium chloride showed no detectable sweetness and a just detectable saltiness.

The data show that addition of sodium chloride to the sugars had substantial effects on increasing sweetness, and that the main factor determining this effect was the type of sugar. Some concentration effects were evident,

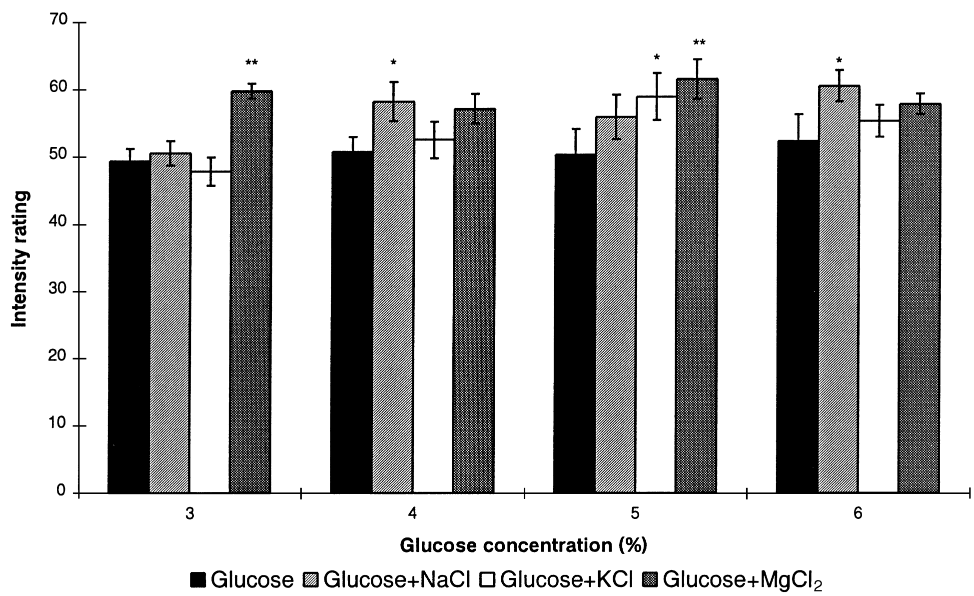

Fig. 3. Sweetness intensity ratings of glucose and glucose-salt solutions.

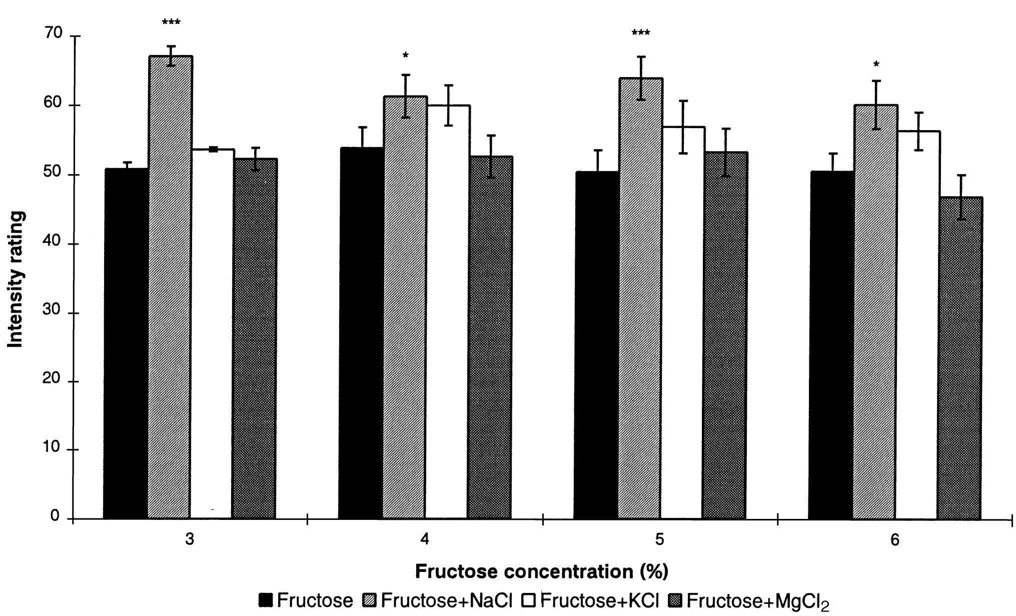

Fig. 4. Sweetness intensity ratings of frctose and fructose-salt solutions.

but these were not consistent over the concentration range, and were different between sugars.

3.2. Effect of added potassium chloride

In contrast to the effects on addition of sodium chloride, potassium chloride additions had much less effect on perceived sweetness. The magnitude of the changes found on addition to sucrose, glucose, fructose and xylitol were very small, and non-significant. The exception was in the behaviour of sorbitol, with significant increases in sweetness when added to 3% sorbitol solution, but significant suppression of sweetness when added to 6% xylitol solution. No changes were found at the intermediate xylitol concentrations. Informal assessment of a 0.2% potassium chloride solution showed a strong bitterness but no detectable sweetness or saltiness.

3.3. Effect of added magnesium chloride

Increases in sweetness on addition of magnesium chloride were seen for sucrose and for glucose, but not

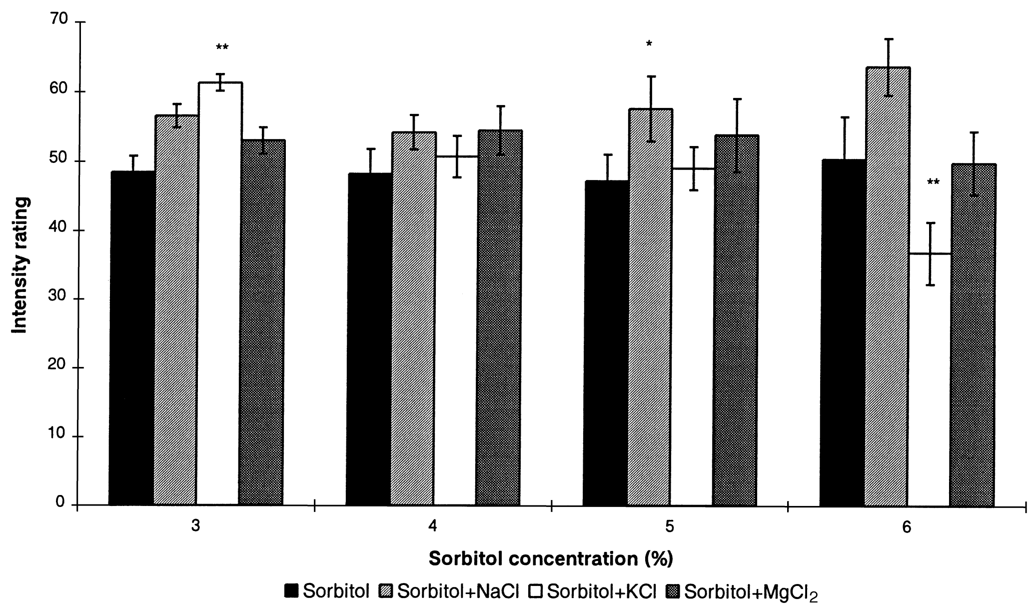

Fig. 5. Sweetness intensity ratings of sorbitol and sorbitol-salt solutions.

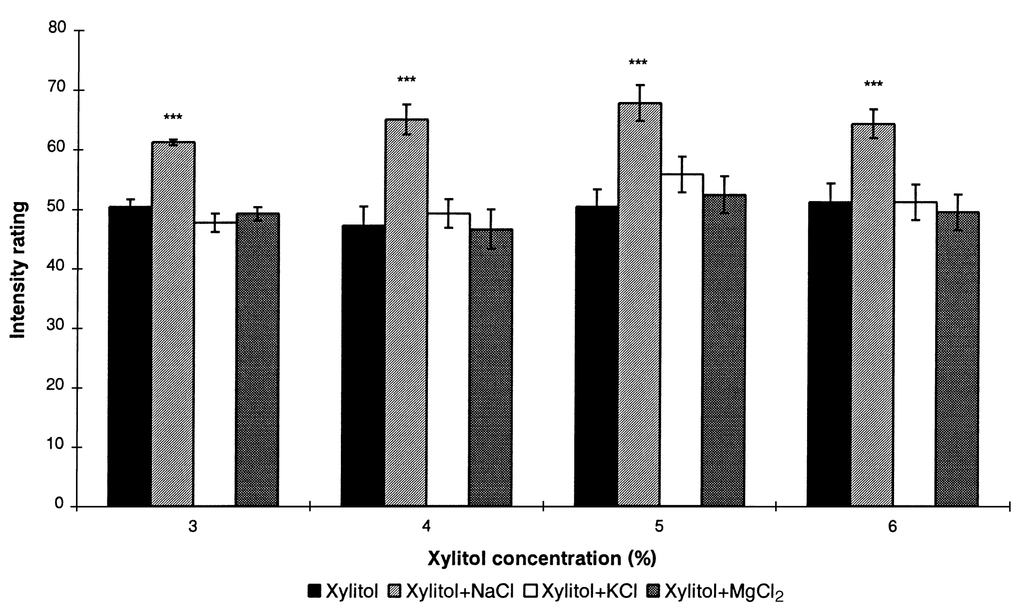

Fig. 6. Sweetness intensity ratings of xylitol and xylitol-salt solutions.

Table 2
Change of sweetness on addition of salts[a]

Concentration (%)	3	4	5	6
NaCl				
Sucrose	3.8	2.4	9.9	6.0
Glucose	1.1	7.5*	5.6	8.2*
Fructose	16.3***	7.5*	13.6***	9.6*
Sorbitol	8.1	6.0	10.4*	13.3**
Xylitol	10.8***	17.8***	17.4***	13.2***
KCl				
Sucrose	−1.7	−3.7	1.6	4.8
Glucose	−1.6	1.8	8.6	3.0
Fructose	2.8	6.2	6.5	5.8
Sorbitol	12.9**	2.5	1.7	−13.6**
Xylitol	−2.7	2.0	5.1	0.0
$MgCl_2$				
Sucrose	8.4	10.0	8.0	9.3
Glucose	10.4**	6.4	11.2**	5.5
Fructose	1.4	−0.8	2.9	−3.7
Sorbitol	4.5	6.3	6.6	−0.6
Xylitol	−1.2	−0.6	2.0	−1.7

[a] Key: star rating indicates level of significance for the given mean tested against the respective 100% sweetener solution (no salt addition);* $P<0.05$; ** $P<0.01$; *** $P<0.001$.

for fructose or xylitol. There was some possible evidence for sweetness increases in the 3, 4 and 5% sorbitol solutions. The increases for sucrose were of comparable magnitude across all sucrose solutions, and although not significant at the 5% level, were close to significant at the 10% level. The increases on addition to 3 and 5% glucose solutions were significant at the 0.1% level, but the increases on addition to the 4 and 6% solutions were not significant at the 5% level. Informal assessment of a 0.2% magnesium chloride solution did not give any evidence for sweetness or saltiness, but there was a strong taste described as similar to bitterness, but not the bitterness character of potassium chloride.

3.4. General discussion

Sweetness response in these experiments depended strongly on the type of sugar and the type of salt, and also, to a lesser extent, on the sugar concentration. The most general trend found was an increase in sweetness of all the concentrations of sugars on addition of sodium chloride. This effect was particularly strong on addition to fructose and to xylitol, and to a lesser extent on addition to glucose and to sorbitol. The increases on addition to sucrose were relatively low, and tests on the effect of a range of salts on the sweetness of 6% sucrose solution by van der Heijden, Brussel, Kosmeijer and Peer (1983) showed that an addition of 0.03% sodium chloride had no effect. An increase in sweetness of sucrose on addition of sub-threshold concentrations of sodium chloride has been extensively reported in the literature. For example, Pangborn (1962) reported increases in sweetness of 0.75 and 2.25% sucrose solutions on addition of 0.36% sodium chloride. The saltiness of higher concentrations of sodium chloride is known to mask the sweetness of sucrose. As it is known that low concentrations of sodium chloride can also have a slight sweet taste, it has been suggested that enhanced sweetness of sucrose solutions might be partly a consequence of this side taste (Bartoshuk, 1975). However, the informal tasting of the 0.2% sodium chloride solution in this experiment did not reveal any sweet character. If the sweet taste of sodium chloride were contributing significantly to the sweetness of the

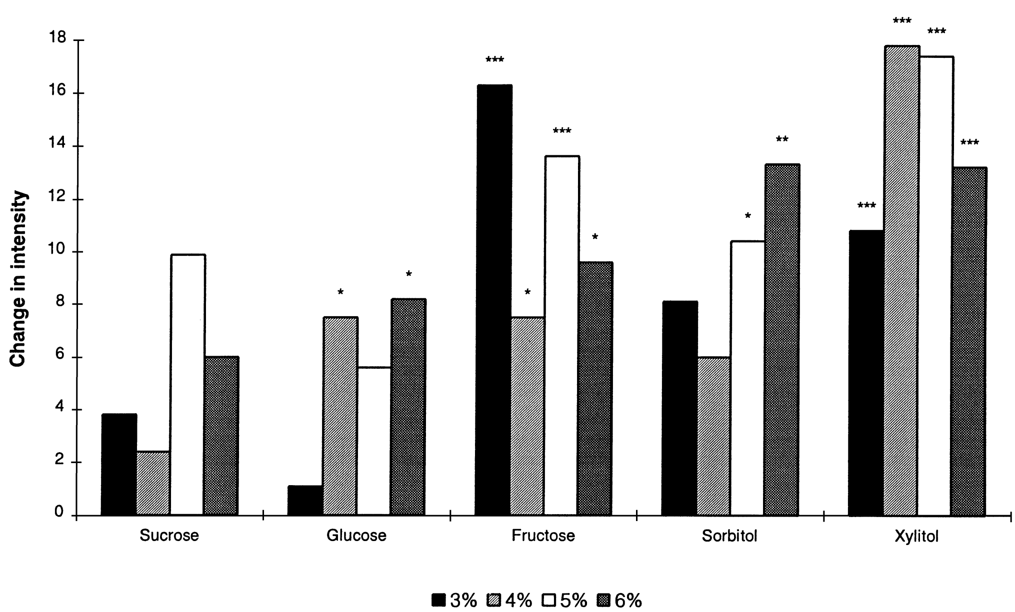

Fig. 7. Change in sweetness intensity on addition of solution chloride.

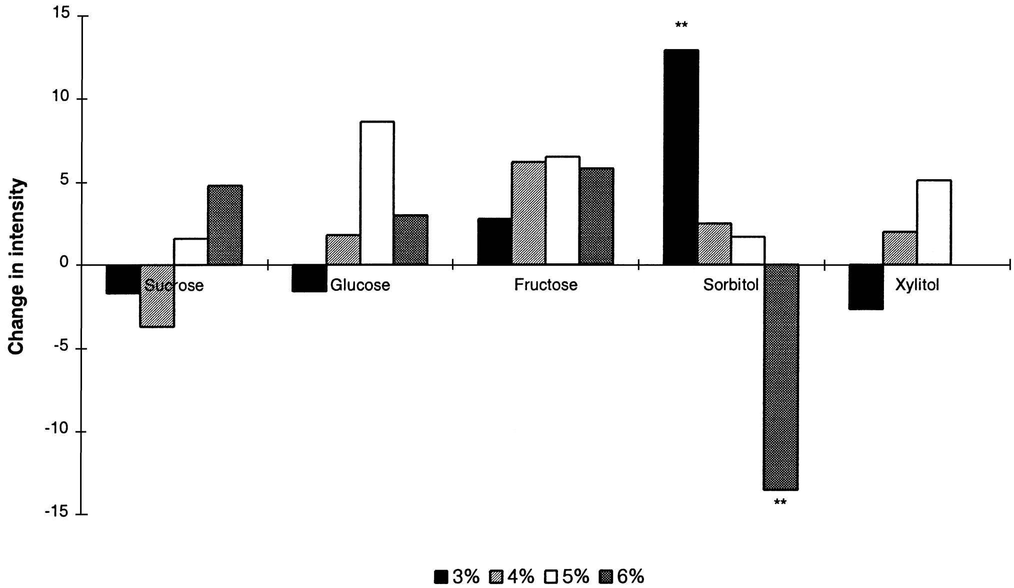

Fig. 8. Change in sweetness intensity on addition of potassium chloride.

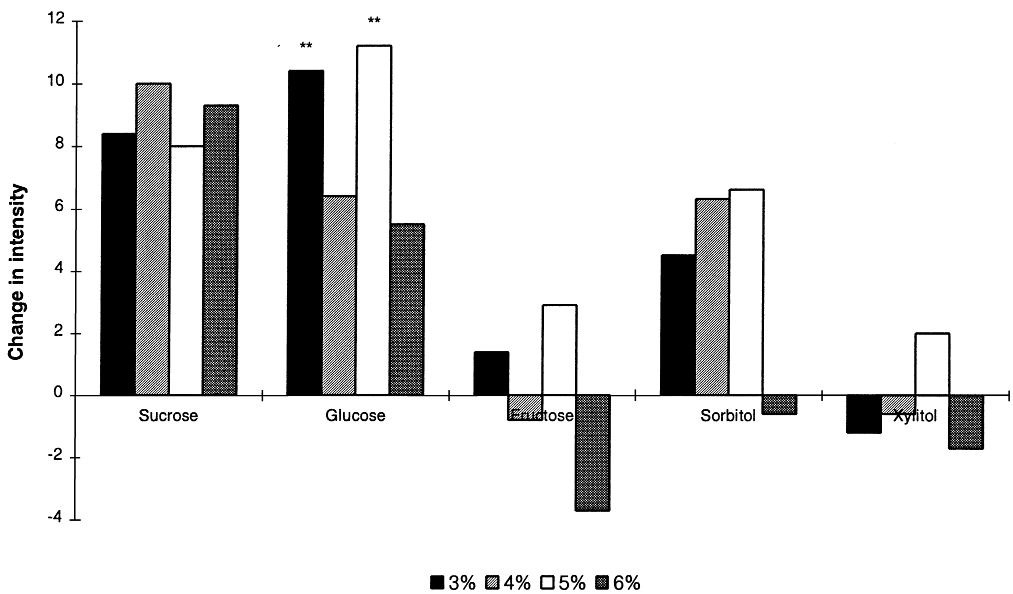

Fig. 9. Change in sweetness intensity on addition of magnesium chloride.

sugar solutions, it would be expected that this effect would be more pronounced at the low sugar concentrations, and minimal at higher sugar concentrations. Examination of Fig. 7 does not show any evidence that this is the case, and, with the possible exception of fructose, there are indications that the sweetness increase is lower at the low sugar concentrations.

There is less information in the literature concerning the effects of potassium chloride and magnesium chloride. According to the data of Dzendolet and Meiselman (1967), at the concentration of potassium chloride used in these experiments, there should be little sweetness contribution, but bitter and salty notes may be present. In direct contrast to the effects of sodium chloride, no effects on sweetness were found, with the notable exception of sorbitol. In sorbitol, an unexpected concentration dependence was seen, with significant sweetness increased at the lowest sorbitol concentration (3%) and significant sweetness suppression at the highest level (6%). If the taste of the potassium chloride itself were to influence the perception of sweetness, it would be expected that the dominant effect would be suppression of sweetness by the strong bitter character identified on informal tasting. An earlier study by van der Heijden et al. found that a lower potassium chloride addition of 0.05% enhanced the sweetness of 6% sucrose.

Additions of magnesium chloride showed different effects again from either sodium chloride or potassium chloride. Statistically significant increases were found on addition to glucose, and substantial numerical increases on addition to sucrose, whereas no clear effects were found with the other sugars. Magnesium sulfate has been reported as being predominantly bitter, but with some salty character (Shallenberger, 1993). The taste of magnesium chloride, reported here, indicated a strong bitter-type response, but there was substantial variation in the responses between tasters. In the work by van der Heijden et al. (1983), addition of 0.034% magnesium chloride to 6% sucrose showed evidence for enhancement, consistent with the results found here.

The results discussed above strongly indicate that any effects of the added salts can not be directly ascribed to the taste characteristics of the salts themselves. As the panel responses have been shown to be highly consistent, it must be concluded that the observed effects are a consequence of interactions between the sugars and the salts in the aqueous medium.

4. Conclusions

The perceived effect of adding salts on the sweetness on bulk sweeteners (sucrose, glucose, fructose, sorbitol and xylitol) depends on the sweetener type and concentration and on the type of salt. Sodium chloride enhances the sweetness of all the sweeteners to some degree. Potassium chloride has little effect on any sweetener other than sorbitol, which shows sweetness enhancement at low sorbitol concentrations and suppression at high sorbitol concentrations. Magnesium chloride additions tend to enhance sweetness, particularly of sucrose and glucose. The effects observed can not be ascribed to any inherent sweetness of the salts themselves, suggesting that the observed effects are a result of interactions between the salts and sweeteners in the aqueous medium.

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