

# Perception of sugar–acid mixtures in lemon juice drink

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## Summary

Acid was removed from lemon juice by selective adsorption on to a weak-base resin. Four levels each of sucrose and citric acid were combined factorially and dissolved in the low-acid juice, providing sixteen stimulus combinations. Using graphic-rating scales, assessors evaluated the stimuli for intensities of overall flavour, sweetness, and acidity; the relation of each of these intensities to ideal; and general acceptability. The various acceptability responses proved to be internally consistent, and the experiment suggested an optimum sugar–acid blend from the sixteen combinations. Ratings of overall flavour strength followed a compressed pattern in a factorial plot, with increasing concentrations of sugar and acid exerting a diminishingly small effect. In the perception of individual components, sucrose clearly suppressed the perceived intensity of citric acid, but only the highest concentration of acid unequivocally suppressed sweetness. There was a striking similarity between each set of intensity responses and the corresponding ideal-relative responses, suggesting a link between intensity and hedonics.

## Keywords

Product optimization, psychophysics, sensory analysis, taste, taste mixtures.

## Introduction

Lemon juice is unpalatable as a beverage because it contains a high level of acid and low level of sugar. However, a recently devised process extracts the acid from lemon juice, while leaving most other components virtually unchanged. Essentially, this involves passing the juice over a weak-base resin, which selectively adsorbs the acid molecules (Johnson & Chandler, 1986). The resulting low-acid lemon juice has potential as a beverage after additional sweetening.

The sugar–acid balance is known to be important in the acceptability of fruit juice drinks (e.g. Board & Woods, 1983). In the process noted above, the extent of de-acidification can be varied and the level of sugar addition is easily manipulated. Thus, the first aim of the study was to estimate the optimal sugar–acid balance in a base of low-acid lemon drink.

The second, more general, aim was to explore the taste perception of sugar–acid mixtures in a food base, using the protocol of integration psychophysics (McBride, 1986). Despite the prevalence of these mixtures in food and drink, there is still little understanding of their sensory processing. For instance, it is generally agreed that

taste mixtures exhibit the phenomenon of taste suppression (e.g. Bartoshuk, 1975)—one component in a taste mixture acts to depress the intensity of another—but is this suppression truly mutual? It appears that addition of sugar to an acid solution suppresses the intensity of the acid taste (Fabian & Blum, 1943; Pangborn, 1960, 1961; Kamen *et al.*, 1961; Curtis & Stevens, 1985; Frank & Archambo, 1986) but the converse may not necessarily hold: the addition of acid to a sugar solution has been variously reported to suppress (Pangborn, 1960, 1961; Gordon, 1965), have no effect on (Curtis & Stevens, 1985), or enhance (Fabian & Blum, 1943; Kamen, *et al.*, 1961) the sweetness.

## Materials and methods

### Materials

Freshly squeezed lemon juice (total soluble solids = 7.8 °Brix, titratable acid content = 4.8% w/v expressed as anhydrous citric acid) was passed through a column of weak-base resin (Amberlite IRA-93, Rohm and Haas, Philadelphia, U.S.A.; Johnson & Chandler, 1986) to give a product with a total soluble solids contents of 3.4 °Brix (total sugar = 1.9% w/v) and titratable acid content of 0.45% w/v expressed as anhydrous citric acid. The product was concentrated in a Centritherm evaporator and stored frozen until required. Before sensory testing, the concentrate was diluted to obtain a low-acid lemon juice, as close as possible to single-strength (i.e. 3.4 °Brix).

### Stimuli

All stimuli were mixtures of sucrose and citric acid (both reagent grade), dissolved in the base of low-acid lemon juice. Four levels of sucrose were combined in a factorial design with four levels of citric acid, giving sixteen stimuli in all.

The concentrations of added sucrose were 2.0, 4.0, 8.0 and 16.0% w/v, i.e. these were added on top of the residual sugars in the drink base. The concentrations of citric acid in the drink were adjusted to give final levels of 0.45 (no addition), 0.75, 1.11 and 1.82% w/v. These concentration ranges were considered sufficiently wide to span the optimum combination and also to provide general information on mixture perception.

Stimuli were made up 24 hr before tasting and held at 5°C. At tasting, each sample consisted of 50 ml served at 15°C in a small glass tumbler.

Table 1. Descriptive anchors attached to graphic rating scales

Scale	Position from left (mm)		
	0	75	150
1 Overall flavour strength	No flavour at all	Moderately strong	Extremely strong
2 Overall flavour strength relative to ideal	Not nearly strong enough	Just right	Much too strong
3 Sweetness intensity	No sweetness at all	Moderately sweet	Extremely sweet
4 Sweetness relative to ideal	Not nearly sweet enough	Just right	Much too sweet
5 Acid intensity	No acid at all	Moderately acid	Extremely acid
6 Acidity relative to ideal	Not nearly acid enough	Just right	Much too acid
7 General acceptability	Extremely poor	Satisfactory	Extremely good

### Assessors

Sixteen employees (eleven men, five women) of the CSIRO Food Research Laboratory served as assessors; all had had some experience in sensory testing but no specific training.

### Response scales

Assessors made their judgments on a sheet that contained a set of 150-mm graphic-rating scales (Table 1). Each scale included descriptions positioned at 0, 75 and 150 mm. Three of the scales related to the intensity of sensation; three to how these intensity levels compared to the assessors' ideal levels ('ideal-relative' or 'just right' scales; cf. Frijters & Rasmussen-Conrad, 1982; McBride, 1982, 1985); and the last was a variant of the bipolar hedonic scale (Peryam & Girardot, 1952).

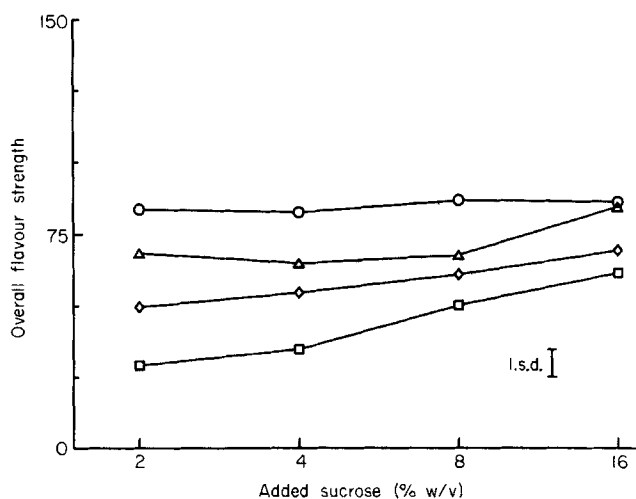
### Procedure

Assessors were presented with four stimuli per session at a total of eight sessions—one session per day, four sessions per week for 2 consecutive weeks. Thus, each stimulus was tasted twice. The stimulus sets were randomly selected, with the proviso that all sixteen stimuli were tasted before replication began.

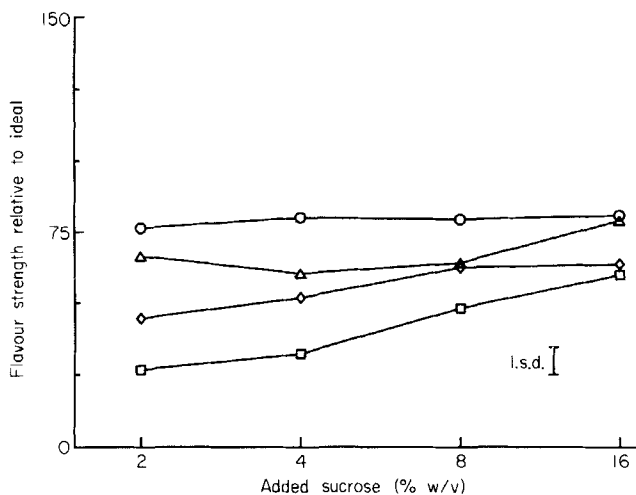
The four stimuli were presented simultaneously; assessors were instructed to taste the stimuli in the (individually randomized) order specified on the response sheet and, after tasting, to rate each on the seven graphic-rating scales. Rinsing with distilled water was mandatory between stimuli.

### Results

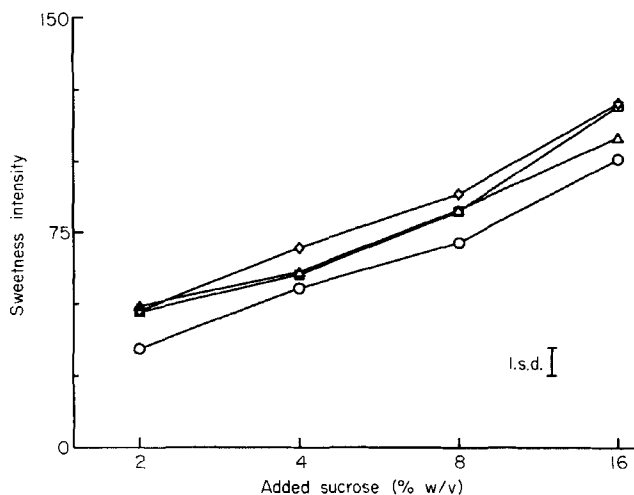
Mean ratings for the sixteen stimuli on each of the seven variates are given as factorial plots in Figs 1–7. Response is plotted on the ordinate in all cases. Except for Figs 5 and 6, sucrose concentration is given on the abscissa (log scale) and each curve



**Figure 1.** Overall flavour strength: mean responses to the sixteen sugar/acid combinations are given on the ordinate, sucrose concentration on the abscissa (log scale) and each curve represents a different concentration of citric acid (○) 1.82%, (△) 1.11%, (◇) 0.75% and (□) 0.45%. Scores separated by more than 1 l.s.d. are significantly different ( $P < 0.05$ ).



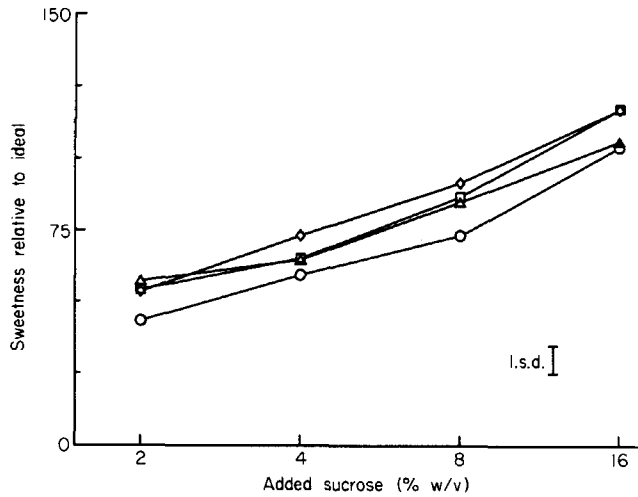
**Figure 2.** Overall flavour strength relative to ideal: details as per legend in Fig. 1. (○) 1.82%, (△) 1.11%, (◇) 0.75% and (□) 0.45% citric acid.



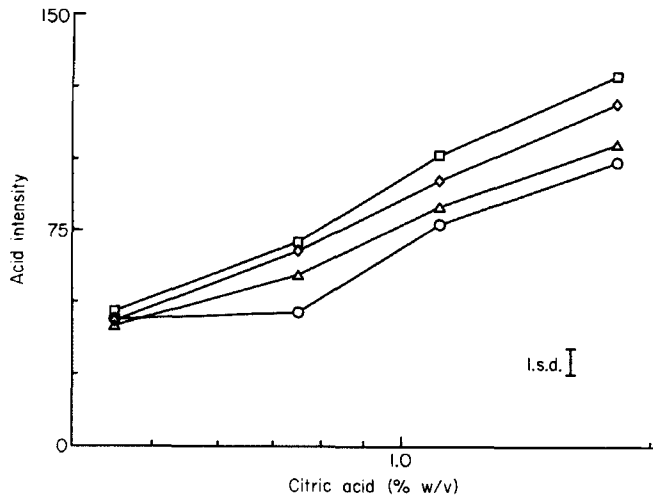
**Figure 3.** Sweetness intensity: details as per legend in Fig. 1 (○) 1.82%, (△) 1.11%, (◇) 0.75% and (□) 0.45% citric acid.

corresponds to a different level of citric acid. In Figs 5 and 6, (log) citric acid concentration is given on the abscissa and each curve corresponds to a different level of sucrose.

Each of the seven variates was subjected to a separate analysis of variance (Genstat ANOVA program), with the appropriate least significant difference (l.s.d.) values given on each plot. (Any two mean responses that differ by more than 1 l.s.d. are significantly different,  $P < 0.05$ .) Of the total 3584 responses, there were thirty-four missing values; these were estimated by the Genstat program.



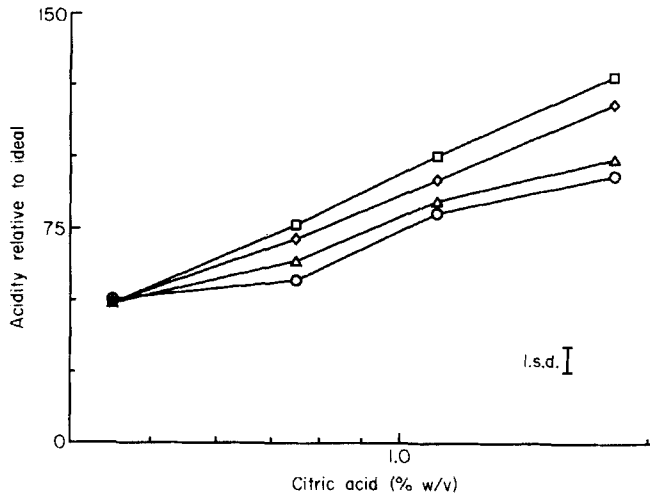
**Figure 4.** Sweetness relative to ideal: details as per legend in Fig. 1. (○) 1.82%, (△) 1.11%, (◇) 0.75% and (□) 0.45% citric acid.



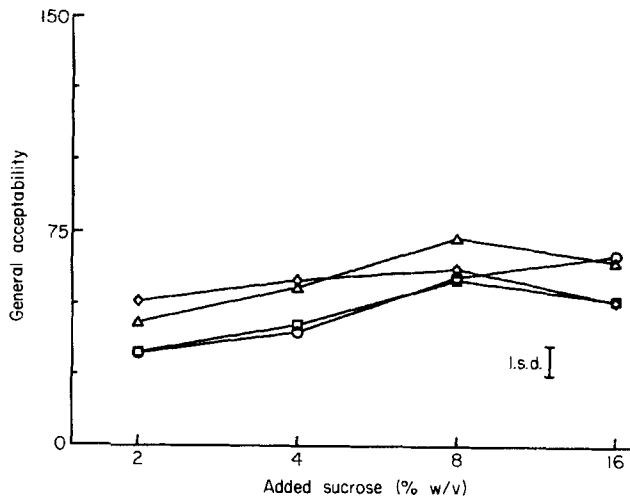
**Figure 5.** Acid intensity: details as per legend in Fig. 1, except that (log) citric acid concentration is given on the abscissa and each curve corresponds to a different level of sucrose. (○) 16.0%, (△) 8.0%, (◇) 4.0% and (□) 2.0% sucrose.

In every case there were significant main effects of sucrose [ $F(3, 255) \geq 19.81$ ,  $P < 0.001$ ], citric acid [ $F(3, 255) \geq 9.47$ ,  $P < 0.001$ ], and assessors [ $F(15, 255) \geq 9.38$ ,  $P < 0.001$ ]. There were no significant differences between replicates [ $F(1, 255) \leq 2.83$ ,  $P > 0.09$ ].

The sucrose-citric acid interaction was statistically significant for overall flavour intensity (Fig. 1), overall flavour intensity relative to ideal (Fig. 2), acid intensity (Fig. 5), acid intensity relative to ideal (Fig. 6), and general acceptability (Fig. 7)



**Figure 6.** Acidity relative to ideal: details as per legend in Fig. 5. (○) 16.0%, (△) 8.0%, (◇) 4.0% and (□) 2.0% sucrose.



**Figure 7.** General acceptability: details as per legend in Fig. 1. (○) 1.82%, (△) 1.11%, (◇) 0.75% and (□) 0.45% citric acid.

[ $F(9, 255) \geq 3.07$ ,  $P < 0.002$ ]. However, the interactions in Figs 5 and 6 dropped out when the data were re-analysed without the bottom (0.45%) level of citric acid [ $F(6, 191) = 0.71$  and  $1.95$ , respectively].

## Discussion

### *Optimal sugar-acid blend*

In terms of main effects, analysis of variance of the general acceptability data (Fig. 7) revealed 8% added sucrose (9.9% total sugars) to produce the highest overall rating

of the four sugar levels, and the rating for 1.11% citric acid to be the highest of the four acid levels. Indeed, Fig. 7 shows that the most acceptable individual blend was 8% added sucrose:1.11% citric acid. At 12.1 °Brix, this blend has a brix:acid ratio of approximately 10.9:1—comparable to a USDA Grade A sweetened grapefruit juice (United States Code of Federal Regulations, 1985).

Taken altogether, the acceptability data (Figs 2, 4, 6 and 7) are internally consistent. The 8% added sucrose:1.11% acid blend is reasonably close to the 'just right' mark for flavour strength (Fig. 2), sweetness (Fig. 4) and acid (Fig. 6). In fact, for this particular blend the sum of the deviations from the three respective 'ideal-points' is the lowest of all sixteen stimuli. Conversely, the greatest sum of deviations is for the blend 2.0% added sucrose:0.45% acid, which received the lowest score for general acceptability (Fig. 7).

It is not known how these factors are weighted in the acceptability judgment, but it appears that overall flavour strength may be just as important as the sugar-acid balance. The blends considered to be second and third most acceptable were, respectively, 16% added sucrose:1.82% acid and 16% added sucrose:1.11% acid (Fig. 7). Figs 4 and 6 suggest these blends were too sweet and too acid; however, their overall flavour strengths were close to just right (Fig. 2), which presumably enhanced their general acceptability rating. Other recent work has demonstrated the importance of optimizing overall flavour strength (McBride, 1985; McBride & Booth, 1986).

The general acceptability scores in Fig. 7 are not high and only approach the 'satisfactory' mark. Possibly this may be due to a loss of flavour volatiles during the de-acidification and concentration steps (the lack of lemon flavour is corroborated by the generally low scores in Fig. 2). A less severe de-acidification treatment (e.g. to around 1% w/v) might improve acceptability.

#### *Perception of overall flavour strength*

The factorial design provides basic information on the perception of taste mixtures. In Fig. 1, the upward trend of the curves toward the right-hand side implies that flavour strength increased with sucrose concentration. Likewise, the substantial vertical increments between curves indicate that flavour strength increased with citric acid concentration. At the concentrations used in this study, citric acid contributed more than sucrose to overall flavour strength: the slope of the curves is shallow (contribution of sucrose) whereas their vertical spacing is pronounced (contribution of acid; see Fig. 1).

If the curves in Fig. 1 were parallel this would imply that the perceived intensities of sucrose and citric acid add together in a simple, algebraic manner (Anderson, 1981; McBride, 1986). But, as noted earlier, there was in fact a statistically significant interaction, manifest as compression in the upper right-hand side of the plot. At the highest acid level the mean response barely changes, despite the large increase in sucrose concentration (top curve, Fig. 1). This occurs well below the top of the response scale, which rules out an end-effect scaling artifact. A similar compressive pattern for total intensity may be observed in another recent study of sucrose-citric acid mixtures (Frank & Archambo, 1986).

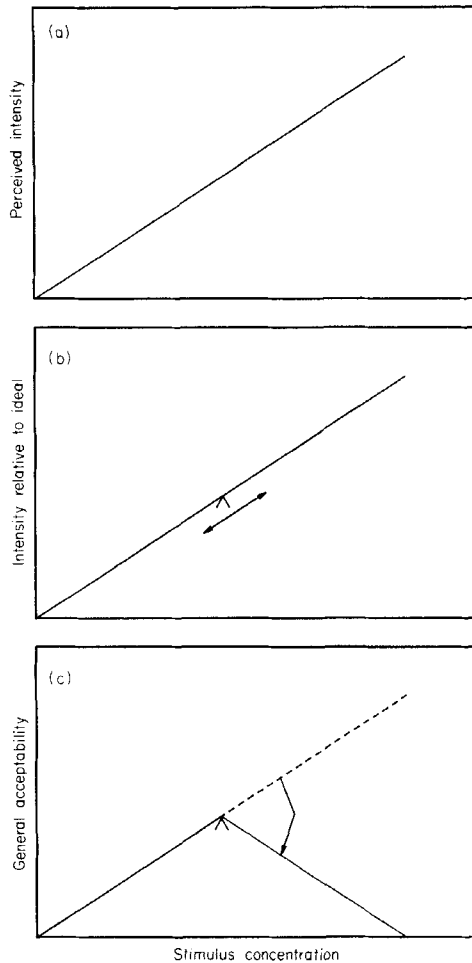
#### *Perception of individual components*

The perception of individual components follows a distinctly different pattern from that of overall flavour strength. For acid intensity (Fig. 5) the interaction dropped out when the bottom level of acid was omitted from the analysis. So, this level aside,

each sucrose concentration exerted a simple, subtractive effect on acid intensity, with the degree of suppression proportional to sucrose concentration. At a given sucrose level, the degree of suppression is independent of acid concentration.

This pattern could be said to follow a 'threshold model': it is as if the presence of one taste component (sucrose) raises the threshold concentration of the other (citric acid). Thus, in Fig. 5, increasing concentrations of sucrose displace downward the psychophysical function for citric acid, raising its threshold concentration but leaving its slope unchanged. This linear, subtractive effect is reminiscent of many other studies in integration theory (Anderson, 1981) and suggests that taste suppression may be a central (rather than peripheral) mechanism.

Statistical analysis of the sweetness intensity data (Fig. 3) revealed no interaction: within the bounds of experimental error, the curves can be taken as parallel. The top (1.82%) level of acid systematically suppressed sweetness in the same manner as



**Figure 8.** Schematic of possible link between intensity and hedonics. The psychophysical (intensity) function of a stimulus has primacy (a); the ideal-level of this stimulus acts as a sliding cursor on the psychophysical function (b); and the general acceptability (bipolar hedonic) response is folded about the ideal point (c).



sucrose suppressed acid (Fig. 5) so, to this extent, there is evidence for suppression being mutual. However, there is no clear graduated, suppressive effect evident among the lower three levels of acid as there was for the different sucrose levels in Fig. 5. This mixed result is consistent with the idiosyncratic findings cited earlier and needs further work for resolution.

#### *Link between intensity and hedonics*

A striking feature of Figs 1-6 is the near duplication of intensity data by the corresponding ideal-relative data: Fig. 2 duplicates Fig. 1, Fig. 4 duplicates Fig. 3, and Fig. 6 duplicates Fig. 5. In all cases, the level found moderately intense (Figs 1, 3 and 5) is also the most liked. This correspondence has been observed previously (Riskey, Parducci & Beauchamp, 1979; McBride, 1985; McBride & Booth, 1986; Conner, Land & Booth, 1987) and may offer a mechanism for hedonic integration.

In this schema, the psychophysical (intensity) function has primacy; it is governed by the rules of sensory transduction and is virtually immutable (Fig. 8a). The ideal-point for a stimulus would act as a 'cursor' on the psychophysical function, able to slide up or down, its position varying both between and within individuals (Fig. 8b). (Strictly speaking, the entire scale on the ordinate, of which the ideal-point is the centre, slides up and down.) When a bipolar hedonic scale is used to measure acceptability (Fig. 8c), the ideal-point would become the fulcrum about which the response function is folded (Booth, Conner & Marie, 1987). The processing of a complex stimulus, which could well be preconscious, might proceed as follows: the intensity of each component would be evaluated relative to its ideal-point; deviations from the respective ideal-points would then be weighted and integrated, resulting in the general hedonic response.

#### *Integration psychophysics*

This study has shown that the paradigm of integration psychophysics can simultaneously accomplish two goals: provide specific, applied information on product optimization, and provide general, basic information on taste perception. It also indicates that, over the concentration ranges of sugar and acid used in beverages, taste suppression is not truly mutual. Perceived acidity is strongly suppressed by sweetness, but sweetness is only weakly suppressed by acidity.

### **Acknowledgment**

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