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The Effect of Viscosity on the Perception of Flavour

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Abstract

A trained sensory panel assessed flavour and sweetness intensity in solutions containing varying concentrations of hydroxy propyl methylcellulose (HPMC), sugar and flavour volatile. The flavour and sweetness of the viscous solutions were rated using magnitude estimation with a controlled modulus. In addition, the concentration of volatile released on the breath was measured using MS Nose™. For low concentrations of HPMC (<0.5 g/100 g), perceived flavour intensity remained the same; however, a steady decrease was noted at higher concentrations (>0.6 g/100 g). The change in perceived intensity occurred at the point of random coil overlap (c^*) for this hydrocolloid. The perceived sweetness of the solution showed a similar pattern with increasing HPMC concentration, although the inflection at c^* was not so obvious. Despite the change in perceived flavour intensity, the actual concentration of volatile measured on the breath was not affected by the change in HPMC concentration. Low-order polynomial models were produced to describe perceived flavour intensity and sweetness in viscous solutions containing HPMC and potential explanations for the changes in perception are discussed.

Introduction

Flavour is defined as the combined perception of mouth-feel, texture, taste and aroma (British Standards Institute, 1975). In application, it is important to understand how varying these flavour components affects flavour quality so that foods can be formulated to maximize consumer acceptability.

Hydrocolloid thickeners are common ingredients in many food products. Utilized for their thickening properties at low concentration, they have a profound effect on both food texture and flavour. Reformulation of food flavour using empirical, trial-and-error methodology can be commercially inefficient. A fundamental understanding of how changes in matrix influence flavour release would be of great benefit to the food industry. Furthermore, understanding the relative contribution of hydrocolloid, non-volatile and volatile components to flavour perception could allow changes in perception to be predicted for a modified recipe.

It is generally understood that increasing viscosity through the addition of thickeners results in a decrease in perceived intensity of volatile and non-volatile components (Vaisey *et al.*, 1969; Moskowitz and Arabie, 1970; Pangborn *et al.*, 1973; Christensen, 1980; Baines and Morris, 1987; Malkki *et al.*, 1993). Furthermore, the decrease can be dependent on thickener type (Pangborn *et al.*, 1973, Paulus and Haas, 1980)

Previous studies showed that the perception of sweetness and strawberry flavour was greatly affected by the addition of guar gum at concentrations above the point of random coil overlap (c^*) (Baines and Morris, 1987, 1988). For any given hydrocolloid, c^* is the concentration at which individual polymer chains interpenetrate and start to form an entangled network (Morris *et al.*, 1981). It is dependent on the number and space occupancy of the polymer molecules and is associated with a sharp increase in viscosity. Below this concentration, the individual polymer chains are free to move independently. Baines and Morris discovered that guar gum had no significant effect on perception of sweetness or flavour below c^*, but above this concentration the perceived intensity of both attributes decreased steadily with increasing polymer concentration. They concluded that the decrease in flavour perception was due to inefficient mixing, as the polymer chains became obstacles to diffusion, rather than direct binding of flavour molecules to the polymer (Morris, 1987).

Contrary to the view that no binding occurs, an investigation into the effect of polymer composition [oat gum, carboxy-methyl cellulose (CMC), guar gum] on sensory perception revealed that the nature of the hydrocolloid had more effect on perceived sweetness than viscosity (Malkki *et al.*, 1993). Guar had the greatest effect on sweetness and oat gum the least. The reduction in sweetness due to the addition of thickeners was dependent on the sweetener used

(aspartame, fructose, sucrose). The same study looked at the effect of thickener type on the perception of flavour intensity. The physicochemical properties of the compounds used were more important than the type of polymer. Any differences in perception from equiviscous solutions of oat, guar and CMC were determined to be evidence of binding or interaction between the polymer and the flavour compounds.

To study potential binding effects, static equilibrium headspace was used to study the behaviour of seven volatile compounds in water and in 1% CMC solution (De Roos, 1997). At equilibrium, viscosity effects are nullified and, therefore, any differences in static equilibrium headspace between water and 1% CMC would be due to binding. No differences were found, indicating that no binding occurred with the biopolymer. However, CMC concentration did affect the release rate of the volatile compounds during dynamic headspace studies. It was concluded that, although flavour molecules do not bind to the polymer, the increase in viscosity has a physical effect on the movement of flavour molecules.

In a comprehensive study investigating the effect of thickener composition and viscosity on dynamic flavour release (Roberts *et al.*, 1996), a decrease in the release of highly volatile compounds was reported as viscosity increased. Less volatile compounds showed little or no effect with increasing viscosity. The extent of the decrease was dependent on both thickener type and viscosity, which the author suggested was because of some sort of binding mechanism and the physical inhibition of volatile mobility.

Much of the previous work investigating the effect of viscosity on flavour release and perception focuses on either the dynamics of the release mechanism or, alternatively, the sensory properties of the viscous solutions. Rarely have the two effects been studied together. Furthermore, the flavour release studies tend to simulate dynamic in-mouth conditions with the use of heated vessels, stirrers and a gas flow to represent breathing. They do not always recreate the dilution with saliva, swallowing, continuously changing volume and surface area or different chewing patterns typical of real eating or drinking. In the following study, the volatile release was measured using the MS Nose™ (Micromass, Manchester, UK). This non-invasive method allows the in-nose volatile signal to be measured, close to the nasal receptors, in human subjects rather than in model systems.

This paper investigates the effect of hydroxy propyl methylcellulose (HPMC) concentration on volatile release from viscous solutions and the perceived intensity of flavour and taste. In addition, it attempts to use low-order polynomial models to explain the perceptual responses in terms of HPMC, flavour and sugar composition of the samples.

Materials and methods

Experiment 1—effect of viscosity on release and perception of strawberry flavour

Sample preparation

Liquid samples were prepared containing HPMC (Methocel; DOW Germany) at concentrations of 0.0625, 0.125, 0.25, 0.5, 0.75, 1.0, 1.5 and 2.0 g/100 g. Each sample contained 2 g/100 g sugar (Tate & Lyle) and 200 p.p.m. of a strawberry flavour (Firmenich SA, Geneva, Switzerland).

Samples were prepared by weighing appropriate quantities of distilled water and sucrose into a beaker and heating to 55–60°C. The hot sugar solution was stirred, without turbulence, using a motorized paddle and the HPMC powder carefully added to the side of the vortex. The solution was then cooled, with continual stirring, to 4°C. A flavour concentrate was prepared by mixing 800 µl strawberry flavour with 200 µl of carmoisine food colour in a 10 ml volumetric flask and making up to volume with 100% absolute ethanol. The flavour concentrate was added to a pre-weighed quantity of the cooled viscous solution such that the final concentration was 200 p.p.m. This was mixed using a roller bed (SRT2; Stuart Scientific, Redhill, UK) for 6–10 h prior to ingestion by the panel. The carmoisine acted as a marker for complete mixing.

Experimental design

Samples were presented in a randomized complete block design. Each assessor consumed all eight samples in duplicate. The presentation order was randomized using simple random number generation in order to reduce sample order effects. Samples were presented as groups of three to minimize sensory fatigue.

Sensory panel training

A group of 13 trained assessors was selected on the basis of their sensory acuity, in particular their ability to distinguish between concentrations of the same stimulus and their ability to perform magnitude estimation (Stevens, 1957; Moskowitz, 1977).

Sensory evaluation

A trained sensory panel used magnitude estimation with a controlled modulus to rate the intensity of sweetness and strawberry flavour for each of the prepared samples. The modulus, or reference, which contained 0.25 g/100 g HPMC, 2 g/100 g sugar and 200 p.p.m. strawberry flavour, was assigned an arbitrary score of 100. The sweetness and strawberry flavour intensities of each sample were rated relative to the perceived intensity of the modulus. Assessments were carried out in individual booths designed to international standards (ISO 8589—Design of Sensory Test Facilities) with northern hemisphere daylight lighting at 750–1070 lux.

Samples were presented at room temperature (18–23°C) in sealed containers. Assessors were instructed to place a level dessert spoonful (10 ml) into the mouth, to allow the liquid

to pass over the tongue and to swallow. They were advised not to hold the sample in the mouth for longer than a few seconds, as it would become diluted with saliva and make rating difficult. A break of 15 min was given between each set of three samples to prevent fatigue. Plain crackers and still mineral water were used as palate cleansers between each sample.

Instrumental analysis—volatile release during consumption.

The release of ethyl butyrate onto the breath was measured using the MS Nose™ interface fitted to a platform LCZ mass spectrometer (Micromass, Manchester, UK). Ethyl butyrate was selected as a marker for the strawberry flavour, which contained several fruit esters with similar release profiles. Each assessor consumed all eight samples in a single session, with a break of at least 15 min between each sample. Plain crackers and water were used as palate cleansers. The method of consumption was standardized; assessors were asked to take a normal breath in, place 10 ml of sample in their mouth and close, place their nose over the sampling tube, swallow the liquid and exhale normally, thereafter continuing to breath regularly into the tube. The sampling tube, which was attached to the MS Nose transfer line, allowed exhaled air to be sampled in real time at a rate of 30 ml/min. Volatile molecules were ionized (4 kV corona discharge, sample cone voltage 18 V) and the volatile release followed by monitoring the appropriate MH^+ ion (ethyl butyrate: m/z 117, dwell time 0.05 s). The concentration of ethyl butyrate on the first and second breaths was determined against the signal from an ethyl butyrate standard in hexane (Taylor *et al.*, 2000).

Rheological studies

Seventeen samples were prepared at HPMC concentrations of 0.025, 0.05, 0.075, 0.1, 1.15, 1.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.6, 0.8, 1.0, 1.5 and 2.0 g/100 g. They were prepared using the method detailed for experiment 1, without addition of sugar and flavour. The flow characteristics of each solution were determined using a CS10 Controlled Stress Rheometer (Bohlin Instruments, Lund, Sweden) at 25°C, for a range of shear rates (5–100 s^{-1}). Double gap geometry was used for low concentrations of HPMC, whereas cone and plate geometry was used for the higher concentrations. For each sample, the viscosity at zero shear [η0], was extrapolated from the data and used to produce a Huggins–Kraemer plot from which the intrinsic viscosity [η] could be calculated. The value of c^* was then estimated from a plot of log(specific viscosity) versus log(c^*[η]) (Figure 2).

Experiment 2—effect of viscosity on release and perception of almond flavour

Sample preparation

In a further experiment, samples were prepared containing HPMC at concentrations of 0, 0.3, 0.6, 0.9 and 1.2 g/100 g. At each concentration of HPMC, samples were prepared containing 2, 5 and 8 g/100 g sucrose. For each combination of HPMC and sucrose, samples were prepared containing 10, 55 and 100 p.p.m. benzaldehyde (Firmenich SA, Geneva, Switzerland). This produced a total of 45 samples (Figure 1).

Low, medium and high intensity flavour concentrates were prepared by mixing 40, 220 and 400 µl of benzaldehyde with 200 µl of carmoisine in a 10 ml volumetric flask and making up to volume with 100% absolute ethanol. The appropriate flavour concentrate was added to a pre-weighed quantity of the cooled viscous solution such that the final concentration was 10, 55 or 100 p.p.m. This was mixed for 6–10 h prior to ingestion by the panel.

Experimental design

A three factorial response surface design was used to investigate the effect of HPMC, sugar and volatile concentration on the perception of sweetness and almond flavour, and the release of benzaldehyde on the breath. The experiment was designed with the aid of Design Expert 5.0 (Statease, Minneapolis, MN; Figure 1).

Within the experimental design, samples containing 0, 0.3, 0.9 and 1.2 g/100 g HPMC were duplicated, samples containing 0.6 g/100 g were replicated four times and the centre point (0.6 g/100 g HPMC, 5 g/100 g sugar, 55 p.p.m. benzaldehyde) was replicated an additional 24 times. This resulted in a grand total of 132 samples presented overall. The design was split into 12 blocks, each containing 11 samples. Of these 11 samples, nine were of different composition and two were replicate samples of the centre point. The samples selected for any single block were orthogonal, thus creating a design in which the variables were not correlated with each other or with the blocks. This is important as it allows the results to be modelled using independently

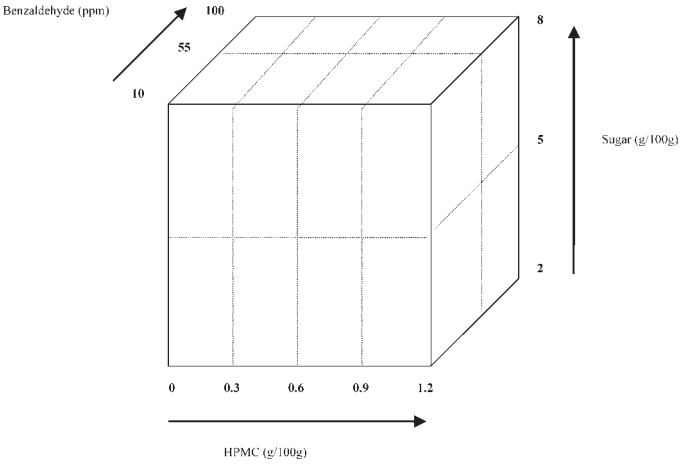

Figure 1 Diagrammatic representation of the full factorial response surface design to study the effect of varying sugar, thickener and volatile concentration on volatile release and the perception of flavour and sweetness.

assessed design variables. Each block represented the set of samples presented to any one assessor. The orthogonality and blocking structure allowed any variation in results due to assessors to be separated from the main effects and residual error when analysing the data. All 11 samples in a block were prepared separately, including the two centre point replicates. Any variation in these results provided a measure of pure error for the experiment.

Sensory panel training

Due to the complexity of this experiment, the panel was given additional training in magnitude estimation of sweet and almond flavour solutions. This involved familiarizing the panel with sugar solutions of differing concentrations (1, 2, 3, 4.5, 5, 6.5 and 8 g/100 ml) and then, in a further exercise, asking individuals to score their perceived intensity of sweetness against a modulus, given an arbitrary score of 100. The samples were presented randomly, in triplicate and included internal references. This exercise was repeated using solutions containing a fixed concentration of sugar (2 g/100 ml) but differing concentrations of benzaldehyde (10, 55, 75, 100 and 200 p.p.m.), with assessors asked to score sweetness and almond flavour (results not shown).

Sensory evaluation

The panel used magnitude estimation with a controlled modulus to rate the intensity of sweetness and almond flavour for each sample within their block. The modulus, or reference, which contained 0.6 g/100 g HPMC, 5 g/100 g sugar and 55 p.p.m. benzaldehyde, was assigned an arbitrary score of 100. The sweetness and almond flavour intensities of each sample were rated relative to the perceived intensity of the modulus. The tasting protocol was as described for experiment 1.

Static equilibrium headspace

The concentration of benzaldehyde in the headspace at static equilibrium was determined for the 45 almond flavour samples. Approximately 100 ml of each sample were placed in a 250 ml bottle (Schott bottle; Fisher Scientific, Loughborough, UK). Samples were allowed to equilibrate for 60 min at room temperature (22°C), after which the headspace was sampled using the MS Nose™ fitted to a platform LCZ mass spectrometer (Micromass, Manchester, UK). The headspace was sampled at a rate of 10 ml/min. Compounds present in the gas phase were ionized (4 kV corona discharge, sample cone voltage 18 V) and the resulting MH^+ ion was monitored (benzaldehyde: *m/z* 107, dwell time 0.05 s). Headspace concentrations were calibrated against a signal from a benzaldehyde standard in hexane at 100 p.p.b.v. (Taylor *et al.*, 2000).

Instrumental analysis—volatile release during consumption

The release of benzaldehyde onto the breath was measured using the MS Nose™ interface fitted to a platform LCZ mass spectrometer (Micromass, Manchester, UK), as detailed in experiment 1. Each assessor consumed all 11 samples in a single session with a break of at least 15 min between each sample. Volatile molecules released on the breath were ionized (4 kV corona discharge, sample cone voltage 18 V) and the volatile release followed by monitoring the appropriate MH^+ ion (benzaldehyde: *m/z* 107, dwell time 0.05 s). The concentration of benzaldehyde on the first breath was determined against the signal from a benzaldehyde standard in hexane (Taylor *et al.*, 2000).

Results and discussion

Determination of c^* for HPMC

Rheological studies of the HPMC solution confirmed that c^* (the point of random coil overlap), occurred at a concentration 0.57 g/100 g (Figure 2).

The effect of viscosity on volatile release and perception of strawberry flavour and sweetness intensity

Analysis of variance (two factor, repeated measures, with interaction) showed a significant difference in perceived strawberry flavour intensity and perceived sweetness intensity between samples containing increasing concentrations of HPMC ($P < 0.001$). Fisher's LSD ($P = 0.05$) showed that, for strawberry intensity, samples containing >0.5 g/100 g HPMC were significantly different to all others, whereas lower concentrations were not significantly different (Table 1). Similarly, for sweetness intensity, many significant differences were evident between samples containing increasing concentrations of HPMC. Generally, the higher the thickener concentration, the more differences were observed (Table 2).

Results also showed a significant difference between assessors ($P < 0.001$) and a significant interaction between samples and assessors ($P < 0.001$) for flavour and sweetness. Despite the use of a controlled modulus, individuals used a varying range of scale values to score the flavour properties. These differences show a lack of consistency across the panel and may be due to a poor understanding of 'strawberry flavour' and 'sweetness', or confusion associated with experiencing different viscosities in mouth.

The results for strawberry flavour and sweetness intensity (arbitrary units) were averaged for the panel and plotted against HPMC concentration (g/100 g). Whilst averaging sensory data is never recommended, in this context it was used to illustrate the general trend in the data. Initially, perception of strawberry flavour is constant below a HPMC concentration of ~0.5 g/100 g, after which point the perception of flavour intensity decreases steadily with increasing HPMC concentration (Figure 3). The minimum concentration of HPMC at which flavour perception is reduced is consistent with the value of c^*, determined to be 0.57 g/100 g.

The results for sweetness intensity (Figure 4) showed a similar reduction with increased HPMC concentration; however, the intensity tended to decrease steadily rather than

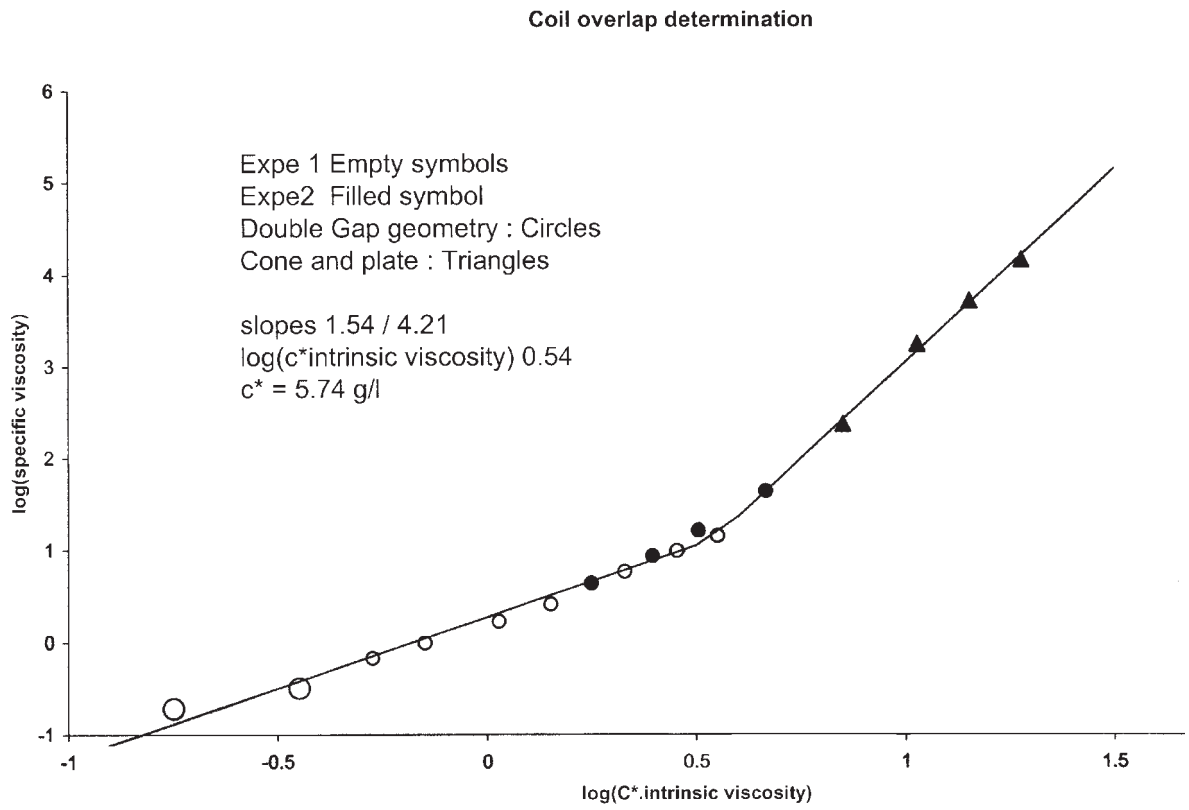

Figure 2 The calculation of c^* from determination of intrinsic viscosity in HPMC solutions of varying concentration.

Table 1 Significant differences in perceived strawberry flavour

HPMC (g/100 g)	Flavour intensity (panel average)	Significance ($P = 0.05$)
2	54.17	A
1.5	68.75	B
1	82.71	C
0.75	95.00	D
0.5	108.33	E
0.25	107.29	E
0.125	108.75	E
0.0625	108.33	E

Table 2 Significant differences in perceived sweetness

HPMC (g/100 g)	Sweetness intensity (panel average)	Significance ($P = 0.05$)
2	53.08	A
1.5	59.23	AB
1	78.85	B
0.5	95.58	C
0.75	98.85	C
0.25	104.23	CD
0.0625	111.15	DE
0.125	118.65	E

show a sharp decline at the concentration corresponding to c^*.

This pattern of results is similar to those obtained in previous studies (Morris *et al.*, 1981). To explain the decrease in perception, Morris hypothesized that, at c^*, the hydrocolloid molecules begin to overlap and, as a result, there is a decrease in volatile mobility through the matrix. As discussed previously, the decreased mobility would affect the dynamics of volatile flavour release and, since eating and swallowing are dynamic processes, we would expect to see a reduction in concentration of volatile on the breath.

Analysis of variance (two factor, repeated measures, without interaction) showed no significant effect of HPMC concentration on the release of ethyl butyrate onto the breath. Large differences were seen between assessors, reflected in a significant difference in their results ($P < 0.001$; Figure 5). These are a consequence of differing physiology (e.g. size and shape of buccal cavity, size and movement of tongue, diameter of airway, size of nasal cavity) and are a common feature of flavour release studies involving human subjects.

Furthermore, neither the concentration of ethyl butyrate released on the second breath after swallowing nor the persistence of ethyl butyrate (ratio of first to second breaths)

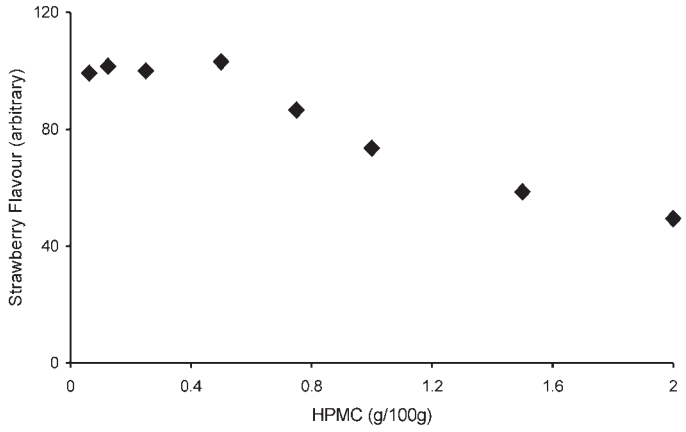

Figure 3 The effect of HPMC concentration on perceived intensity of strawberry flavour (solutions contained 2 g/100 g sugar and 200 p.p.m. strawberry flavour).

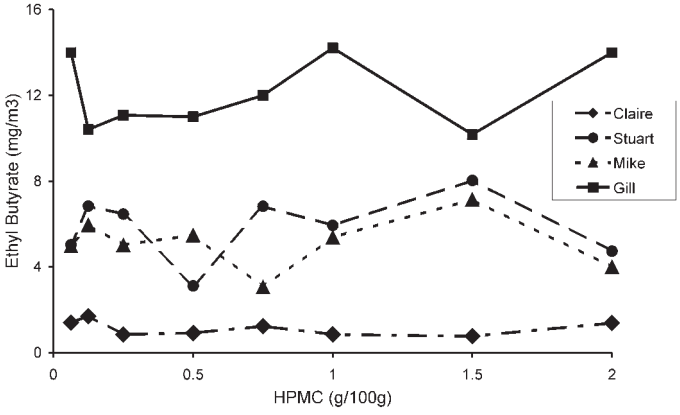

Figure 5 The effect of HPMC concentration on the release of ethyl butyrate on the breath—results for four separate assessors (solutions contained 200 p.p.m. strawberry flavour and 2 g/100 g sugar).

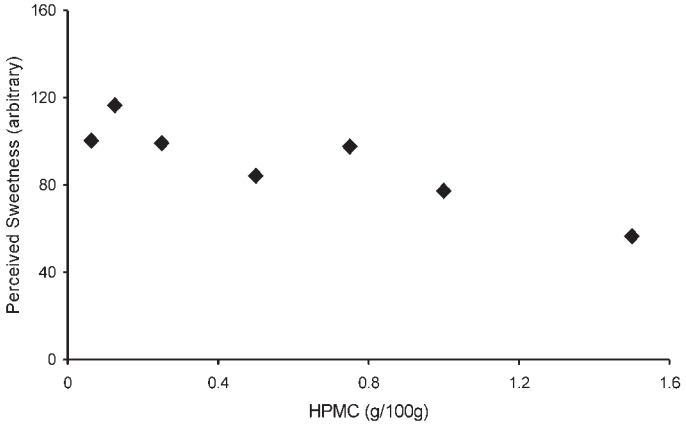

Figure 4 The effect of HPMC concentration on perceived sweetness intensity (solutions contained 2 g/100 g sugar and 200 p.p.m. strawberry flavour).

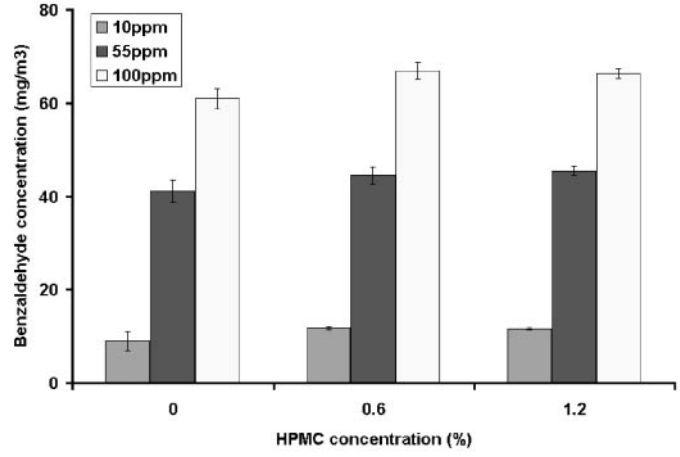

Figure 6 The effect of HPMC concentration on the static equilibrium headspace concentration of benzaldehyde at 10, 55 and 100 p.p.m. of volatile.

were affected by the concentration of HPMC. This is consistent with previous studies, which have shown no effect of HPMC on the persistence of several volatile compounds, regardless of physicochemical properties (Linforth and Taylor, 2000).

The effect of viscosity on release and perception of almond flavour

Static equilibrium headspace

Static equilibrium headspace concentrations of benzaldehyde were calculated for each sample. There was no significant effect of HPMC or sugar concentration on the headspace concentration of benzaldehyde. As expected, there was a significant effect of volatile concentration on the headspace values ($P < 0.001$). For illustration (Figure 6), headspace concentrations (mg/m^3) were averaged across the different sugar concentrations to give a mean result for each volatile level in 0, 0.6 and 1.2 g/100 g HPMC. The lack of an effect due to HPMC concentration suggested that no binding or chemical interaction occur between the hydrocolloid and volatile molecule.

Sensory Perception and In-nose Volatile Release

The data for perceived almond intensity, sweetness intensity and benzaldehyde release were analysed using multiple linear regression (Design Expert 6.0). Low-order polynomial models were derived to explain the variation in the data and to predict volatile release (equation 1), sweetness intensity (equation 2) and almond flavour intensity (equation 3) in terms of sample composition.

$$\sqrt{(\text{benzaldehyde in-nose})} = +0.23 + 0.02[\text{benzaldehyde}] - 7.33\text{E}{-}005[\text{benzaldehyde}]^2 \quad (1)$$

The model describing the release of benzaldehyde on the

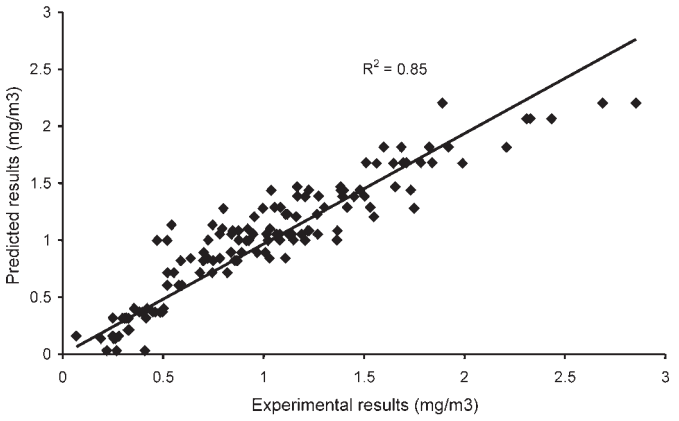

Figure 7 Release of benzaldehyde from viscous solutions: a comparison of predicted values from the model (equation 1) and experimental results.

breath only included terms relating to the volatile concentration used in the sample. This was in agreement with static equilibrium headspace results, which showed no evidence of molecular binding or interaction. As determined in experiment 1, there was a significant variation in the data due to assessors ($P < 0.01$). The model was highly significant ($P < 0.0001$) with adjusted R^2 and predicted R^2 values of 0.78 and 0.73, respectively and an 'adequate precision' (signal-to-noise ratio) of 30.22. These statistics indicate a robust model that well describes variation across the design space. This was further illustrated when the experimental values were plotted against values predicted from the model ($R^2 = 0.85$; Figure 7)

$$\sqrt{(\text{sweetness})} = +0.87 - 1.21[\text{HPMC}] + 2.43[\text{sugar}] - 2.01[\text{HPMC}]^2 - 0.09[\text{sugar}]^2 + 0.19([\text{sucrose}][\text{HPMC}]) \quad (2)$$

The model for perceived sweetness included linear and quadratic terms for sugar and HPMC concentration and an interaction term for thickener and sugar. It was highly significant ($P \leq 0.0001$), with adjusted R^2 and predicted R^2 values of 0.97 and an 'adequate precision' of 57.42. The interaction term indicates that the relationship between sweetness and sugar concentration is dependent on HPMC and, conversely, that the relationship between sweetness and HPMC concentration is also dependent on sugar level.

A further illustration of the model for perceived sweetness intensity is shown in Figure 8. This graph represents a slice through a three-dimensional model at benzaldehyde = 55 p.p.m. Each contour represents a sweetness value (60, 80, 100, 120, etc.). As would be expected, the contour 'sweetness = 100' passes through the point 0.6% HPMC, 5% sugar and 55 p.p.m. benzaldehyde. The ability of the assessors to rate a blind coded sample (identical to the modulus) as '100', gives a good indication of their consistency. The shapes of the contours indicate that, for any given sweetness intensity, the concentration of sugar must be increased to compensate for

Figure 8 Two-dimensional contour plot derived from the model for perceived sweetness. Each contour represents a perceived sweetness intensity, whilst its shape illustrates how sweetness is affected by relative concentrations (g/100 g) of sucrose and HPMC.

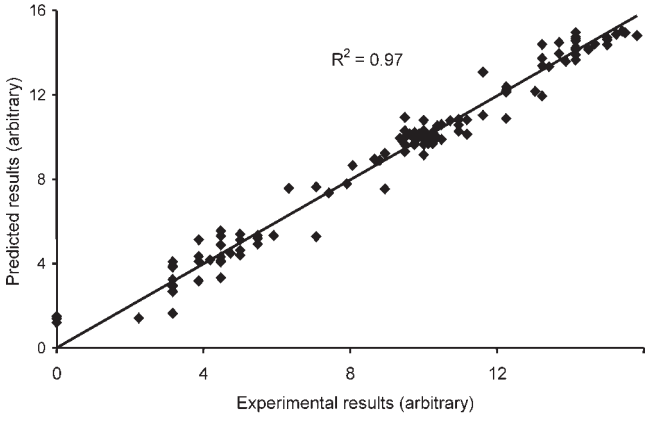

Figure 9 Perceived sweetness in viscous solutions: a comparison of predicted values from the model (equation 2) and experimental results.

an increase in thickener. The model for predicting sweetness was robust and well described the variation in the results. Predicted values from the model plotted against the experimental values gave an $R^2 = 0.97$ (Figure 9)

$$\sqrt{(\text{almond flavour})} = -1.63 + 1.01[\text{HPMC}] + 1.72[\text{sugar}] + 0.14[\text{benzaldehyde}] - 2.30[\text{HPMC}]^2 - 0.15[\text{sugar}]^2 - 7.68\text{E}{-}004[\text{benzaldehyde}]^2 + 6.25\text{E}{-}003([\text{sucrose}][\text{benzaldehyde}]) \quad (3)$$

The model describing perceived flavour intensity was, once again, highly significant ($P \leq 0.0001$). It included terms for HPMC, sugar and benzaldehyde concentration with quadratic terms for each variable and an interaction

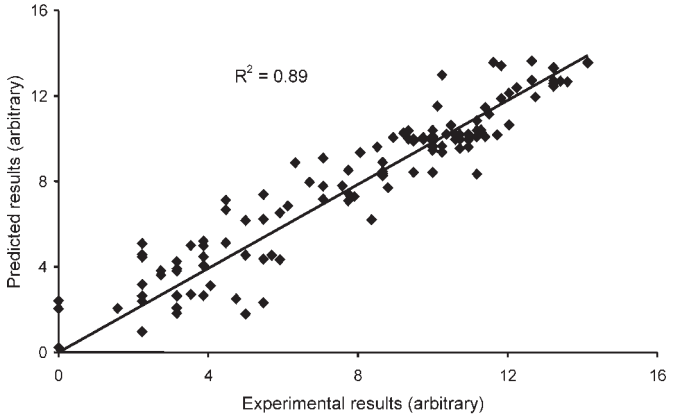

Figure 10 Perceived almond flavour in viscous solutions: a comparison of predicted values from the model (equation 3) and experimental results.

between sugar and benzaldehyde. All terms included had a significant effect on the model. The adjusted and predicted R^2 values for the model were 0.89 and 0.85, respectively and the 'adequate precision' was 27.85. The model for predicting almond flavour was robust and well described the variation in the results. Predicted values from the model plotted against the experimental values gave an $R^2 = 0.97$ (Figure 10).

The inclusion of the interaction term suggests that, for any given level of HPMC, the relationship between perceived almond intensity and volatile concentration is dependent on sugar level. A further illustration of the model is shown in Figure 11. Each contour represents almond flavour intensity; the contour shape illustrates the effect of HPMC and sugar concentration at 55 p.p.m. benzaldehyde. For HPMC values >0.5% and for any given almond flavour intensity, the sugar level can be increased to maintain perceived flavour. This holds true until a level of 6–6.5% sugar, after which point an increase in sugar results in a decrease in flavour perception. This effect is most dramatic at low levels of HPMC and may, in part, be due to the intense sweetness masking the almond flavour.

Interactions between volatile and non-volatile stimuli are well documented (Noble, 1996). Davidson *et al.* (Davidson *et al.*, 1999) reported that a decrease in perception of mint flavour correlated closely with decrease in sugar release from chewing gum, despite constant delivery of mint volatiles to the nasal receptors. It follows, therefore, that the decrease in flavour perception observed from these results may be due to the effect of HPMC on stimulation of taste receptors by sugar molecules, rather than volatile stimulation of nasal receptors.

One possible explanation may be the effect of HPMC on the mobility of free water in solution (particularly at concentrations $>c^*$). Studies (Mathlouthi, 1984; Mathlouthi *et al.*, 1986; Mathlouthi and Seuvre, 1988) have shown that sweetness increases as water mobility increases. Conformational changes in sucrose molecules in solution enhance sweetness

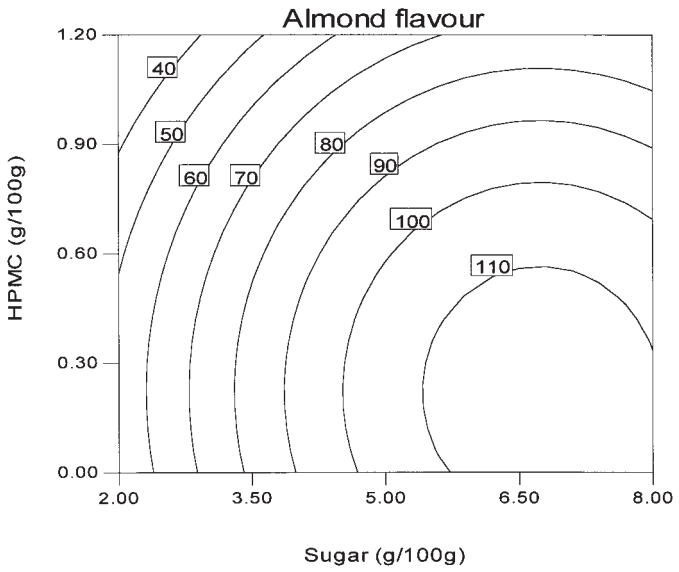

Figure 11 Two-dimensional contour plot derived from the model for perceived flavour intensity. Each contour represents a perceived almond flavour intensity, whilst its shape illustrates how flavour is affected by relative concentrations (g/100 g) of sucrose and HPMC.

intensity. Furthermore, dissociation of free water molecules arranged around the periphery of the sugar molecule produces a high membrane potential across the taste cell, thereby enhancing sweetness perception.

A possible alternative hypothesis is that the perception of viscosity itself affects overall flavour perception. Interactions may occur at a neurological level where gustatory and trigeminal inputs converge, or even at a perceptual level where previous dietary experiences could influence taste judgements in thick and thin solutions (Christensen, 1980).

Conclusion

The perception of flavour and sweetness is greatly reduced when HPMC is added to sugar/flavour solutions at concentrations $>c^*$. However, the concentration of volatile released onto the breath is not affected by the increase in viscosity. Significant, robust statistical models were derived to describe the results and to predict the intensity of perceived flavour, sweetness and the release of volatile from the thickened liquids.

A possible explanation for the decrease in perception may be the effect of increasing HPMC on the free water available in solution, resulting in a decrease in sweetness intensity and, therefore, a decrease in flavour intensity. Investigation of this would require nuclear magnetic resonance studies of the mobility of water and conformation of sweeteners in thickened solutions.

Alternatively, the perception of a thickened solution in the mouth may have an impact on the perception of tastants and, consequently, overall flavour.

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