Perception of saltiness in thickened solutions as a function of rheology

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ABSTRACT

In-mouth processing of non-Newtonian based foods is accompanied by changes in rheological behaviour which impacts on transport of tastants to taste buds. We report on salt perception in guar-thickened solutions, viscosity matched at zero, medium or high shear. Preliminary taste assessments indicate that salt perception is related to low shear viscosity.

INTRODUCTION

It is now clearly established that over-consumption of salt is, after obesity, the second risk factor for hypertension. Therefore, most of the European Food Standards Agencies have set targets to reduce the salt consumption of adults. 75% of salt intake originates from processed foods and is therefore not under the direct control of the consumer. Hence, the food industry has been put under pressure to reduce the salt content in their products to enable the government agencies to achieve their targets. This is particularly challenging since sodium chloride does not only impart saltiness to a food product but often also enhances the flavour. Taste, that is non-volatile flavour sensed by the taste buds, in particular is also affected by product viscosity which in turn can be exploited to control taste perception.

The relationship between taste and viscosity has now been studied for more than 50 years[1-3] whereby in the majority of the publications sugar is the tastant under investigation. Still, no overall model for the effect of product rheology on taste perception has been presented to-date. Even though this study is concerned with salt perception and the cellular mechanisms of sugar and salt perception are different[4], learning from sugar perception studies is relevant since in both cases the tastant molecules have to reach the gustatory cells to be perceived. It is this stage of tastant transport to the taste receptors that is affected by the solution properties, in particular the viscosity. One of the earliest studies in the field reports that an increase in solution viscosity is accompanied by an increase in the threshold values for salt perception[5] and for sucrose perception[3, 5]. At suprathreshold levels (>0.08% for NaCl), it has been shown that salt and sugar perception from viscous solutions compared to simply aqueous solutions is decreased[6-10]. Subsequent research by Baines and Morris[7], Cook et al.[8] and Koliandris et al.[11] on taste perception from polysaccharide based systems showed the importance of the coil overlap concentration, c*. For random coil polymers, above c*, polymer chains start to overlap and entangle with one another. As a result the viscosity increases rapidly with concentration and taste perception was found to decrease[7, 8].

Polymer charge is another important factor to be considered in salt perception studies. Based on NMR measurements,

there is evidence that anionic polymers such as carboxymethyl cellulose (CMC) bind sodium ions present in the solution[12]. It has been hypothesised that this binding of Na^+ was the origin of the reduction in salt perception observed by Rosette et al[12]. The sodium salt form of CMC was used in several previous salt perception studies[6, 9, 10] the results of which may be questionable in light of Rosette's findings.

Relating taste perception to viscosity also requires careful attention to the rheological profile of the tastant-containing solutions since thickened solutions tend to show non-Newtonian flow behaviour. It is generally considered that the shear rate experienced in the mouth is approximately $50s^{-1}$ [13], however, recent work suggests that transient shear rates in the mouth can be as high as $10^5 s^{-1}$ [14]. Acquisition of viscosity data at such high shear rates requires application of thin film rheology for which experimental protocols and procedures for data analysis have been reported[15].

In this paper we report from an ongoing study designed to close some of the gaps in literature on salt perception. To circumvent issues with polymer charge, we chose the non-ionic thickener guar gum. In aqueous solution, guar gum exists as a 'random coil'[16] with a c* value between 0.2 and 0.5% depending on source and molecular weight. Guar gum is neutral in taste which is an advantage for sensory testing. Salt perception was studied in guar gum solutions of different molecular weight and concentration (above c*) but of equal viscosity at low, intermediate and high shear rate in order to answer the following question: Which viscosity, at low shear or at high shear, is determining the salt perception?

MATERIAL AND METHODS

Material

Three different molecular weight guar gum samples L, M and H (Meyprodor® 30, 100 and 400 ex Danisco) with the nominal molecular weight of 420kDa (L), 1640kDa (M) and 2660kDa (H) respectively were used in this study. Stock solutions were prepared by dispersing the dry powders in commercially available still mineral water (Evian, Danone, France) using a magnetic stirrer. Evian was chosen due to its low ion content. The dispersions were stirred at 80°C for 1h followed by continued mixing overnight on a roller mixer at 4°C before storing the samples at 4°C. Preliminary experiments showed that the solutions contained a small amount of insoluble impurities that were removed by centrifugation for 1h at 2600g and 4°C. Sodium chloride in the form of commercially available table salt (purchased from a local supermarket) was added to the stock solutions to adjust the final concentration of NaCl to 0.7% (0.12M). To obtain desired rheological profiles, or viscosity values at specific shear rates, and salt concentrations in the final solution, the samples were diluted with Evian water containing the appropriate amount of salt. The maximum amount of 0.7% salt was chosen based on preliminary work with a small untrained sensory panel.

Silicon oil (100cSt; ex Dow Corning purchased from Sigma-Aldrich) was used as a Newtonian reference fluid to evaluate the gap error in the thin film viscosity measurements.

Rheology

All rheological measurements were conducted at 20°C using a shear stress controlled rotational rheometer (MCR301 ex Anton Paar, Austria). The coil overlap concentration of the guar gum samples was determined following a well established method[17]. Flow curves were acquired using a cone and plate geometry or a double concentric cylinder geometry for the less viscous samples. Viscosity data were fitted to the Cross model to obtain the zero shear viscosity. Values for c* were then estimated from a log-log plot of the concentration versus the specific viscosity from the

intersection of the two linear regressions fitting the data for $c<c^*$ and $c>c^*$.

Solutions of guar L, M and H were matched to a viscosity of 30mPa.s at zero shear, at $50s^{-1}$ and at $3000s^{-1}$. The high shear value used in this work, $3000s^{-1}$, is below the value of $10^5 – 10^6 s^{-1}$ quoted since it was limited by the extent of shear-thinning and the c* value of the guar gum samples. Viscosity data were acquired using a smooth parallel plate geometry (50mm diameter) at gaps of 500µm, 50µm and 30µm and analysed following a published protocol[15] with the exception that we used the single point correction proposed by Shaw[18].

Preliminary taste assessment

Full approval from the Ethics Committee at the University of Nottingham was obtained before the study commenced. Taste assessment was conducted using a panel of seven untrained volunteers (non-smokers, 2 male). In a first session, the ability of the panellists to rank a series of 0.5% guar gum M solutions containing levels of salt up to 1% was tested. At the same session, they were introduced to the three types of guar solutions to familiarise themselves with their slight 'off-taste'. Tests were conducted in individual booths, lit with northern hemisphere lighting, in a quiet, air-conditioned room (20°C). Water (Evian, Danone, France) and low-salt crackers (99% Fat Free, Rakusen's, UK) were provided to allow the panellists to cleanse their palates between tastings. The order of presentation was randomised for each test for each assessor. Data from preliminary experiments showed that 0.7% NaCl was the maximum level to avoid the sample becoming too unpalatable for accurate analysis.

Three different experiments were conducted. Experiment 1 involved several paired comparison tests (ISO 5495:2005). Samples (15ml) were presented to the panel in 45ml plastic pots coded with a three-digit randomised number. Plastic teaspoons were provided to administer the sample to the mouth and the panellists were advised to take a level spoonful each time (roughly 1.5ml). This mode of presentation allowed the panellists to re-test individual samples as required and ensured that, for all samples, equal volumes were tested independent of their viscosity. The samples compared were: L0 versus H0, L0 versus L3000 and L3000 versus H3000 whereby '0' and '3000' denote samples matched as zero shear conditions and high shear conditions ($3000s^{-1}$) respectively. All the samples contained 0.7% NaCl. 'No difference' verdicts were accepted. Each panellist performed the comparisons twice.

In experiment 2, five panellists were presented with a sample coded X (L0 at 0.7% NaCl) and a series of 5 coded samples of H0 with varied salt content (0.6%, 0.7%, 0.75%, 0.8% and 0.9% NaCl) in a randomised order. They were first asked to rank the series of guar H0 samples in order of saltiness and, secondly, to match X in saltiness to one of the samples in the series. The mode of presentation was identical to the paired comparison tests.

In experiment 3, the panel was asked to rate samples for saltiness. 1.5ml of each sample was presented on a spoon. This amount had been determined by the panellists as sufficient to estimate the saltiness, but the panellists were allowed to request a second sample if required. Each scale was a continuous line anchored from 'not' to 'very' salty. NaCl (0.7%) in water was provided as a reference for the top end of the scale. Two replicates were performed. Data was collected using the computerised data acquisition system, Fizz (Biosystemes, France).

Data analysis

Panel responses for experiment 1 and 2 were tallied, but no statistical analysis was performed due to the low number of assessors.

Panel responses for experiment 3 were subjected to two factor analysis of variance

(judge and product) with interaction. Where appropriate, Tukey's HSD[19] test was used to identify which samples were significantly different to the others (α=0.05).

RESULTS AND DISCUSSION

Rheology

The coil overlap concentration for the three guar gum samples L, M and H were 0.522%, 0.24% and 0.155% respectively. Viscosity was successfully matched to 30mPa.s ± 2mPa.s using concentrations ranging from ~ 0.18% to 1.5% between the samples. In the following, each sample will be denoted with a letter to indicate the molecular weight of the guar and a figure for the shear rate of matching. The viscosity curves for all 9 solutions studied are provided in Fig. 1. As expected, the higher the molecular weight, the greater the shear-thinning of the solution. This has an effect on the difference in viscosity behaviour between the samples at shear rates other than the shear rates at which the viscosity of these particular samples was matched. The effect is more pronounced in the zero shear region of samples matched at high shear, see Fig. 1c, than in the high shear domain for samples matched at zero shear, see Fig. 1a. To quantify this effect, the viscosity of H0 at 3000s^{-1} is roughly half the viscosity of L0 at 3000^{-1} whereas the zero shear viscosity of H3000 is 20 times the zero shear viscosity of L3000.

Salt perception

Despite the fact that guar is typically said to be taste neutral, the panel did report an off-taste. Solutions of guar gum M and H were described as tasting like flour, whereas guar L had a much stronger off-taste and descriptors such as pollen, honey and chalk where used.

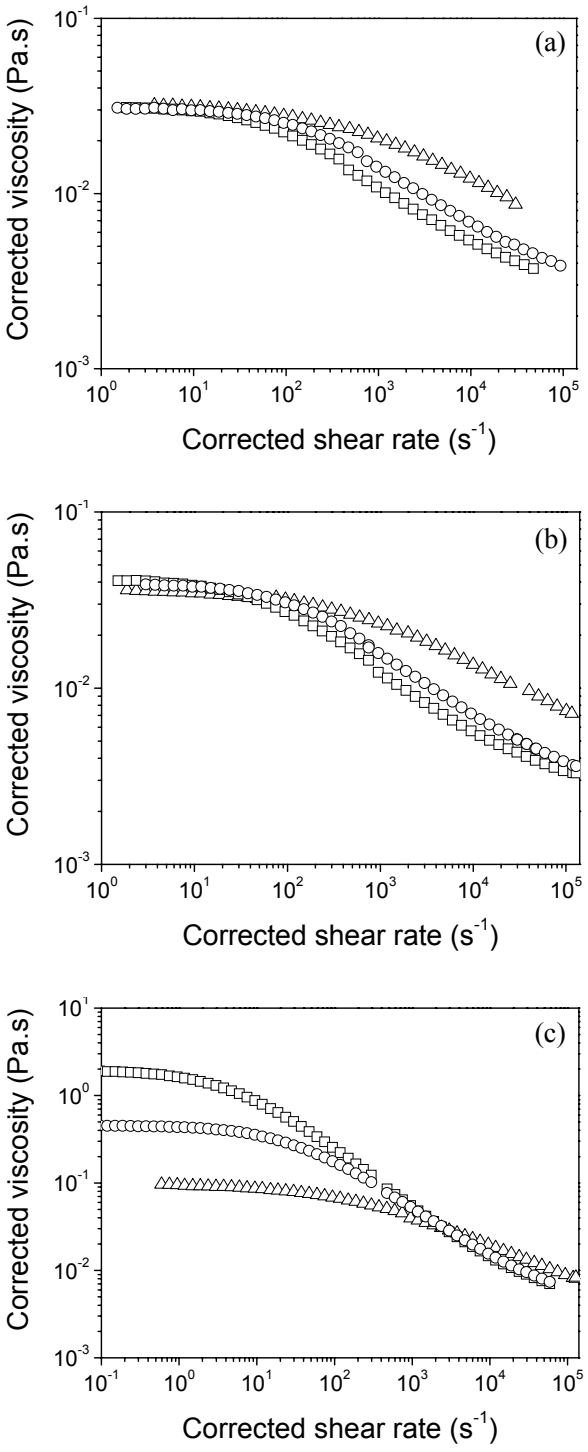

Figure. 1: Viscosity curves of the guar gum solutions (□:H ; ○:M ; △: L) matched at zero shear (a), 50s^{-1} (b) and 3000s^{-1} (c)

Overall effect of the addition of thickeners

Though all samples contained 0.7% NaCl, panellists scored them for saltiness between 47 and 77, which was below the 100 reference of 0.7% NaCl in water, as shown in Fig. 2. This was expected as it is commonly found that hydrocolloids dissolved at concentration above c* reduce taste perception[8, 9]. The effect of decreased taste perception with increased hydrocolloid concentration was clearly seen in the preliminary data when comparing the salt perception data for the three solutions prepared for each type of guar gum. With increased magnitude of the shear conditions for viscosity matching, the concentration of guar gum increased and salt perception decreased (see Fig. 2). The differences in saltiness, however, were not significant with one exception: H3000 was significantly less salty than H0. In the paired comparison test, L0 and L3000 were found to not be different: L3000 was found saltier on 5 occasions, L0 was found saltier on 4 occasions and on 5 occasions the panellists found them equally salty. We hypothesise that this finding is due to the large difference in zero shear viscosity between the samples of guar type H which is 2 orders of magnitude whereas the same difference is less than one order of magnitude for samples of guar type L. It appears that the zero shear viscosity of a solution (of guar gum at concentrations above c*) plays a crucial role in salt perception. A larger number of panellists are now required to confirm this hypothesis.

Differences in salt perception for samples based on guar type M were not significant. The difference in zero shear viscosity between M0 and M3000 was one order of magnitude which appeared to be too low to affect salt perception as measured in this study.

Further data analysis supported our hypothesis of the importance of the zero shear viscosity with regard to salt perception.

Viscosity matched at zero shear

Solutions of H0, L0 and M0 did not give significantly different salt perception in experiment 3. This result therefore confirms the results of experiment 1 and 2 of taste assessment. In the paired comparison, L0 has been found saltier than H0 on 6 occasions H0 was found saltier than L0 on 4 occasions and the two samples were found equally salty on 4 occasions. In experiment 2, the panellists successfully ranked solutions of H0 at different salt levels from the least salty to the most salty. L0 at 0.7% NaCl was found in saltiness equivalent to H0 at 0.7% NaCl by two panellists, equivalent to H0 at 0.6% NaCl by one panellist, and equivalent to H0 at 0.75% NaCl by two panellists. This result seems to indicate that a higher or lower viscosity at high shear rate does not affect salt perception.

Viscosity matched at $3000s^{-1}$

L3000 appeared significantly more salty than H3000 with an average score of 66 compared to 47. This finding was confirmed in the paired comparison test: L3000 was found saltier than H3000 12 times, and twice the two samples were found equally salty. Again, we attribute this finding to the much lower zero shear viscosity of L3000.

Viscosity matched at $50s^{-1}$

The saltiness was not significantly different for samples H50, M50 and L50 which is hypothesised to be due to the minimal differences in zero shear viscosity between these samples (see Fig. 1b).

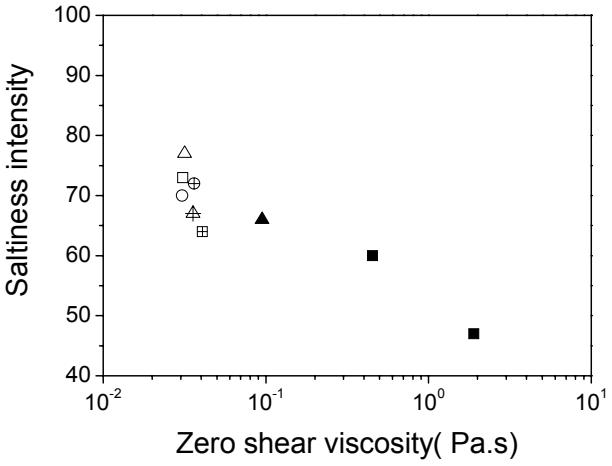

Figure 2: Perceived saltiness as a function of the zero shear viscosity for guar samples H (□), M (○) and L (△) with viscosity matched at zero shear (open symbols), at 50s^{-1} (crossed symbols) and at 3000s^{-1} (solid symbols)

CONCLUSIONS

The present results indicate that salt perception from a thickened solution based on a random coil neutral polysaccharide (with Cross type viscosity behaviour) is related to the viscosity at low shear rate. The degree of shear thinning and the viscosity at shear rates where the shear thinning domain levels off, do not appear to have a significant impact on salt perception. Further experiments need to be carried out to gain a better understanding of the mechanism of salt perception: What are the relationships between zero shear rate viscosity, Kokini oral shear stress[20] and salt perception? What is the role/mechanism of diffusion in the saliva?

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