The effects of high shear rheology on flavour perception

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ABSTRACT

Samples containing dextran, xanthan, sucrose and IAA were designed to have the same viscosity at a shear rate of $50s^{-1}$ but significantly different viscosities at high shear rates (> $1000s^{-1}$). The relationship between high shear rate rheology and flavour perception will be investigated using sensory QDA method.

INTRODUCTION

Flavour is considered as one of the most important quality attributes that contribute to the acceptance of food. As different people have different definitions about flavour, the one proposed by the British Standards Institute "The combination of taste and odour, influenced by sensations of pain, heat and cold and by tactile sensation." is widely agreed (1). Flavour perception is one of the most complex of human behaviours because it involves almost all the senses. The perceived flavour characteristics are a combination of taste, aroma, mouthfeel, texture and irritation/pain (2, 3). The flavour perception we experience from eating a food product is not only dependent on the nature and quality of the flavour components, but also the availability of these components to the sensory systems and the physiological mechanism of perception. Stimulation occurs when the compounds from the food come into contact with the receptors, which are taste buds for the taste and mucous membranes of the nose for the aroma. Besides taste and smell, physical food properties can affect mastication and therefore texture perception or there may be interaction with saliva which can change mouthfeel (4). These stimulations produce a complex set of signals, which are processed locally and centrally to produce the sensation of flavour (5). The flavour perception is based upon the integration of multiple, concurrent sensations and the judgment in one sensory stimulus is strongly and frequently affected by the other stimuli, even though they are not physically or chemically related (3). Understanding the relationship between physical properties and flavour perception is essential to manufacture healthy food products with maximum acceptability and the food industry would benefit from an improved understanding of the mechanisms behind such changes.

In food products, hydrocolloid thickeners are common ingredients which have a profound effect on viscosity and flavour perception. It is generally accepted that increasing viscosity could lead to a decrease in the perceived intensity of volatile (aroma) and non-volatile (taste) components (6, 7). However, the mechanism behind the phenomena by which viscosity affects the flavour perception is not fully understood. One hypothesis is that the viscous or texture properties of a food system can affect the rate of tastant release and therefore modify flavour perception

through a change in aroma-taste interaction (6,8,9). Another hypothesis is that viscosity or texture are distinct sensory attributes and can therefore cause cross modal effects at the cognitive level (8).

Most hydrocolloid solutions exhibit non-Newtonian behaviour, whereby the viscosity is dependent on the applied shear stress or shear rate. However, the relationship between perceived mouthfeel and the rheological properties of fluid and semi-solid food products are not fully established. If texture attributes could be related to a single physical attribute or a combination, then these parameters could be used to design healthy food products or monitor quality during processing. Several measures derived from instrumental measurements have been descried to correlate closely with perceived thickness. The viscosity at a shear rate of 50 s^{-1} (10), oral shear rate from the Shama and Sherman curve and Kokini oral shear stress (the apparent shear stress when the tongue compresses food samples against the palate (11, 12)) have been investigated and some correlations have been established. Among these, steady-state viscosity at $50s^{-1}$ is generally used to estimate the perceived thickness and creaminess. However, Dickinson's' work on oil-in-water emulsions proved that the apparent viscosity at $50 s^{-1}$ is insufficient to describe fully the perceived thickness or creaminess of some samples (13) and he suggested that the hydrodynamic conditions in the mouth correspond to substantially higher shear rates than 50 s^{-1} . Furthermore, the instrumental measurement in previous studies was limited from shear rate 1 s^{-1} to 1000 s^{-1} and some important information, which are provided by the viscosity at shear rates over 1000 s^{-1} were ignored. Malone *et al* (13) proposed that the shear rate on the oral surface could be estimated as being 1000 s^{-1} and could be correlated to taste intensity.

The novel technique of using narrow-gap parallel-plate rheometry to explore the high shear properties of multiphase fluids (14) offers opportunities for studying the effects of both bulk and high shear rheology on flavour perception. The aim of the present work was to evaluate the effects of high shear rheology of the samples on flavour perception and to determine the key rheological parameters for determining mouthfeel perception in vivo. To achieve that aim, samples were designed to have the same viscosity at a shear rate of $50s^{-1}$ but have different viscosities at high shear rate. This particular shear rate of 50 s^{-1} was chosen as it has been considered by several previous studies as the sensing shear rate in the mouth for semi-solid and fluid samples (13). The measurable viscosity has been increased from shear rate 1 s^{-1} to 100,000 s^{-1} and hence the effect of the high shear viscosity on flavour perception can be estimated.

MATERIALS AND METHODS

Materials:

Dextran and xanthan were selected as the thickening polymers in this test. . Dextran is a novel food ingredient produced from sucrose by a strain of the lactic acid bacterium *Leuconostoc mesenteroides.* The reason why we use dextran in our study is that it has a unique rheological behaviour that is Newtonian flow even at high shear rates of several thousand reciprocal seconds. Dextran is tasteless and does not interfere with flavour perception. Dextran was supplied by Meito Sangyo Co., Ltd (Japan) and xanthan was supplied by CP Kelco, (USA).

Sucrose and IAA (isoamyl acetate) were chosen as the taste and aroma components. Sucrose was purchased in a local supermarket and IAA was purchased from Aldrich (Germany). All ingredients are food grade and the water was from Evian (France).

During the process of choosing the material, pullulan and maltodextrin were selected as other candidate biopolymers and their flow curves are shown in the result section.

Methods:

Sample preparation:

Dextran was stirred with distilled water for at least 6 hours at room temperature until the dextran was fully dissolved. For preparing xanthan, water was heated up to 85°C and xanthan powder was added and thoroughly mixed with an over-head paddle stirrer for 40 minutes. IAA and sucrose were prepared separately and all the ingredients were mixed on a roller bed for 8 hours at room temperature prior to ingestion by the panel. All the samples contained 3% sucrose and 100 p.p.m IAA.

Rheology measurements

The flow characteristics of each sample were measured at 25°C on MCR applied-stress rheometer (Anton Paar, 301, Germany). A 50mm diameter parallel plate geometry was used and the technique of using narrow-gap (5 -100 μm) in a parallel-plate geometry in a rotational rheometer was applied to extend the flow curve to shear rate above $10^5 s^{-1}$. However, Davies and Stokes (15, 16) showed that misalignment of plates and the squeeze flow of air during gap zeroing procedures can cause a significant gap error. Hence, the gap error was checked in all measurements in order to achieve the accurate and repeatable measurements.

The procedures used here closely follow the work of Davies and Stokes (15). In summary, the gap error is determined by measuring Newtonian fluids (silicone oil) at several gaps using Eqs. (1). This assumes that the sum of the error (ε) and the required set gap (δ) gives the true gap ($h = \delta + \varepsilon$) according to (15,17):

$$\frac{\dot{\gamma} M \delta}{\sigma} = (\frac{1}{\eta})\delta + \frac{\varepsilon}{\eta} \Rightarrow \frac{\delta}{\eta M} = (\frac{1}{\eta})\delta + \frac{\varepsilon}{\eta} \quad (1)$$

η_M is considered to be the uncorrected or measured viscosity. Therefore, plotting $\delta\eta_M$ against the commanded gap δ, gives a gradient of $1/\eta$ and an intercept of ε/η. This graphical method allows the actual viscosity and true gap to be determined from the measured rheological data for Newtonian fluids. The relatively shear stress and shear rate was calculated with the measured gap error according to:

$$\eta = \frac{3Mh}{2\pi R^4 \Omega_1}\left(1 + \frac{d \ln M}{3d \ln \Omega_1}\right) \quad (2)$$

M is the torque, Ω is the rotation rate, R is the plate radius and h is the true gap. The typical gap error was around 15-30 μm. All measurements were performed with two replicates on the same batch of solutions prepared for sensory analysis.

Experimental design:

A two factorial response surface was used to investigate the relationship between xanthan, dextran concentration on the viscosties at shear rate of 50 s^{-1} and 100,000 s^{-1}. The experiment was designed with the aid of Design Expert 6.0 (Statease, Minnepolis MN). Then five samples were designed based on the establishment to have the desired rheology characteristics. The details are shown in the Results section.

Sensory evaluation:

The QDA (quantitative descriptive analysis) method for sensory assessment was chosen for this experiment. The QDA methodology (18) provides a complete word description for all of a product's sensory properties. Panellists are allowed to use any words to describe a product based on the samples' mouthfeel attributes, taste and flavour perception in the first four training

sessions. After that, the subjects will be encouraged to group the words by modality and in the process, they will indentify the definition of the sensory experience and give an agreed definitions of these words. The exercises and the final evaluation of the samples with the agreed attributes were performed in subseqent sessions. The advantages of using QDA in this test are: responsive to all the sensory properties of a product, able to evaluate multiple products and have a useful data analysis system. (19). 10 panellists were be selected from the University of Nottingham external panel on the basis of their ability to discriminate between samples based on different levels of sucrose and IAA (banana) flavour. These 10 experienced panellists received training in assessment of sweetness, banana flavour intensity and mouthfeel perception in 12 sessions. Each session was no longer than 3 hours.

APcI-MS analysis of volatile release from samples:

The breath volatile composition during consumption was monitored using a mass spectrometer (Platform II, Micromass, Manchester, UK) fitted with Atmospheric pressure ionization-Mass Spectrometer. The panellist was asked to position the nostril on the nasal sampling tube and breath normally in a period of 2 minutes for each program. As the panellist chewed and swallowed the sample, the breath was introduced (30ml/min) into the source and the aroma compound was ionized by a 4kv corona discharge. To ensure that the panelists' breath pattern was unaffected by the environment, acetone (a marker for exhalation) was monitored on the breath. The selected ion mode was *m/z* 59 and IAA, *m/z* 131 (20).

Besides, headspace of the five samples were also measured to test whether there was a binding between the thickeners and aroma.

Statistics analysis:

Data was be evaluated by analysis of variance (ANOVA) to determine if significant differences existed in terms of the sensory properties between different samples. If a significant was found, two multiple comparisons (LSD and HSD) were used to identify which samples were significantly different to the others. Besides, Correlation coefficients were also calculated between the perceived mouthfeel attributes and measured viscosities.

RESULTS AND DISCUSSIONS

At this stage of the experiment, the goal was to design samples with the desired rheological characteristics. This included developing samples with the same low-shear response but varying high-shear characteristics and vice-versa. Several steps were needed to achieve that aim:

<u>Finding a Newtonian behaviour polymer without taste</u>

Pullulan (polysaccharide polymer consisting of maltotriose units, also known as α-1,4- ;α-1,6-glucan), maltodextrin (low molecular-weigh carbohydrate produced by the hydrolysis of starch) and dextran were initially characterised to determine whether they displayed Newtonian behaviour up to high shear rates of 100,000 s^{-1}. However, while pullulan had a constant viscosity up to a shear rate of 1000 s^{-1}, it was shear-thinning behaviour at high shear rates (Figure 1). Maltodextrin displayed Newtonian behaviour up to very high shear rates (Figure 2). However, it tasted sweet at the concentration of 30% which would affect the sensory study. Dextran was chosen in this project based on its properties: Newtonian behaviour at high shear rate and no sweet taste at the concentration of 30% (Figure 3). The taste tests were performed with 10 students

from the University of Nottingham and the panellists described 30% dextran as having a "flour" taste with no sweet taste.

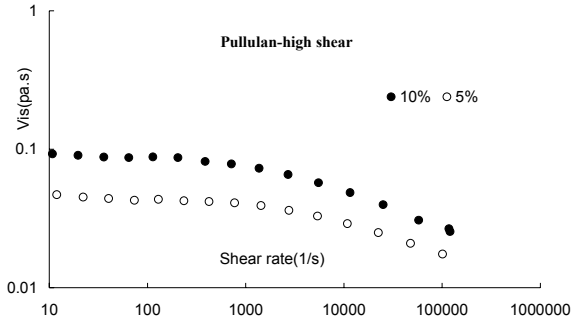

Figure 1: Steady-state shear viscosity versus shear rate profiles of pullulan. The concentrations of pullulan were 5% and 10%.

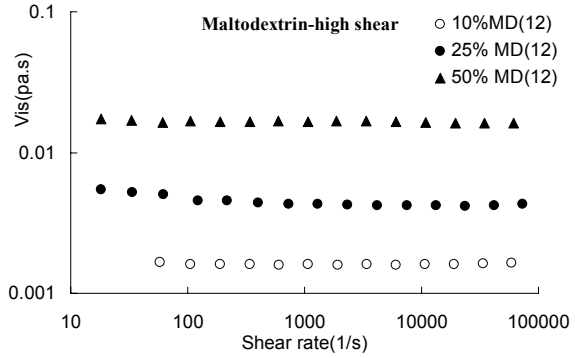

Figure2. Flow curves of maltodextrin 10, 20 and 30% (w/w). The number in the brackets is the DE (dextrose equivalent) number of the maltodextrin.

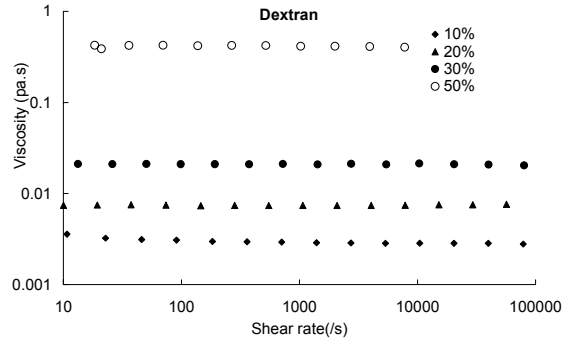

Figure3. Flow curves of dextran at 10, 20, 30 and 40% (w/w).

Designing samples:

Five samples were designed in this test. Samples 1, 2 and 3 have the same viscosity at 50 s^{-1} but significantly different viscosities at 100,000 s^{-1} and samples 3, 4 and 5 have the same viscosity at 100,000 s^{-1} but different values at 50 s^{-1}. The samples were designed with the following two equations which were established with the Design Expert and a two factorial response surface design.

Sqrt(Viscosity at 50 s^{-1}) =+0.66247
+0.097583*A-9.33262E-003*B
+0.015865 * A *B (3)

Log_{10}(high shear viscosity) =-2.70050
+0.26037*A+0.031702*B
+6.71683E-003 * A * B (4)

A indicates xantha concentration (%) and B is for dextran concentration (%)

The samples were prepared using various levels of the following ingredients: mineral water (70%-95%), xanthan (0.16%-3%), dextran (0.03%-30%), sucrose (3%) and iso-amylacetate at 100 p.p.m (banana aroma). The concentrations of the ingredients are shown in Table 1.

Table1. Sample compositions and estimated viscosities of the five samples.

Sample Number	Xanthan (%)	Dextran (%)	(Viscosity at 50s-1) (pa.s)	Log10 (high shear rate) (pa.s)
1	0.94	0	0.754	-2.455
2	0.65	28.59	0.754	-1.5
3	0.66	24.33	0.754	-1.65
4	2.71	8.9	1.16	-1.65
5	0.38	27.72	0.61	-1.6

As dextran is a novel food ingredient in EU, the maximum intake of the samples in a session was limiter to less than 45g.

Samples evaluation

Typical viscosity profiles (Fig 4) are shown for samples 1, 2 and 3 as a function of shear rate. Samples 1, 2 and 3 were

designed to have the same viscosity at 50 s^{-1} but different viscosities at high shear rates (in this case, it is 55531 s^{-1}). The reason why this shear rate was chosen was because sample 2 showed some secondary flow behaviour at a shear rate of 100,000 s^{-1}. The secondary flow led to an apparent increase in viscosity and that was a false value of the infinite-shear viscosity. To get the same shear rate through all the samples, the shear rate at 55531 s^{-1} was chosen.

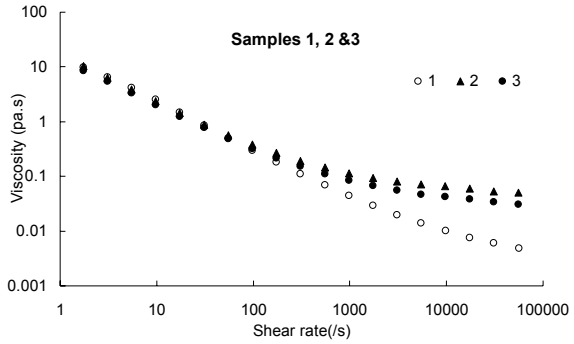

Figure4. The flow curves of samples 1, 2 and 3. They were designed to have the same viscosity at 50 s^{-1} but different viscosities at high shear rate.

Figure 5 shows the flow curves of sample 3, 4 and 5. They were designed to have the same viscosity at the high shear rate but different viscosities at 50 s^{-1}. However, some improvement has to be done for sample 4 in figure 5. The viscosity at high shear rate of sample 4 is less than that of sample 3 and 5. Experiments are underway to achieve the same viscosity in sample 3, 4 and 5 at the high shear rate.

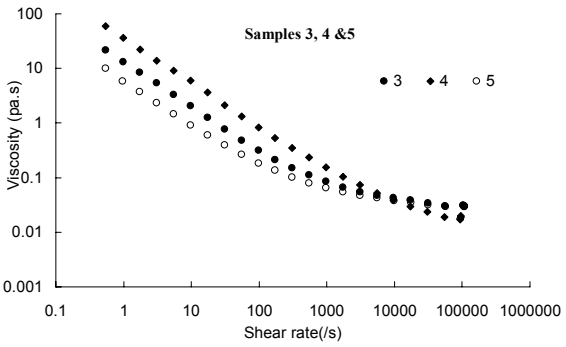

Figure5. Flow curves of samples 3, 4 and 5.

The apparent viscosities of all five samples at the shear rate of 50 $s^{-1}$and 55531 s^{-1}.are shown in Table 2. Samples 1, 2 and 3 had similar viscosities at 50s^{-1} but for the high shear viscosity, sample 2, the value was a decade higher. However, more work has to be done to match the high shear viscosity for samples 3, 4 and 5, which have different viscosities at the shear rate of 50 s^{-1}.

Table2. Viscosities of samples 1-5 at the high and low shear rates. Values are the means of the two replicates performed.

Sampe number	Viscosity at 50s-1(pa.s)	Viscosity at high shear(pa.s)
1	0.5038076	0.004853336
2	0.5629186	0.050782337
3	0.4856196	0.030433386
4	1.323177	0.019029533
5	0.2646354	0.029224408

Headspace analysis of the samples:

All five samples were measured with APcI-MS to test whether there was binding between the aroma and the samples. Sucrose and IAA in water was used as a control. No significant differences were found between these five samples and the control. It indicated that no significant binding occurred between the aroma and the polymers

CONCLUSION

Five samples were designed to have the desired physical properties to test the effect of high shear rheology on flavour perception. More tests are undertaken at this stage to design more accurate samples. Besides, sensory analysis and the in vivo analysis are in process to test the effect of high shear rheology on flavour perception. However, with the methodology mentioned, designing samples with desired physical properties is achievable. Sensory properties will be evaluated in the next two months and the results will be presented in the conference.

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