ABSTRACT

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Texture is a criterion by which quality is judged and an important factor when selecting or rejecting products. Therefore, an understanding of food texture is paramount to deliver foods that adhere to consumer expectations. Texture profile analysis, a method of quantifying textural attributes, has successfully been employed for solid foods, however the texture profile analysis procedure for solids is not easily applied to fluid foods. Characterization of fluid foods has primarily focused on viscosity as the primary textural property of interest. Unfortunately, viscosity alone can not describe the myriad of fluid food textural properties.

Processing, preparation, and swallowing subjects fluid foods to different stresses that influence flow behavior. Some fluids possess a complex set of intrinsic material properties, such as viscoelastic and time - dependent properties. These materials can respond differently depending on the type and magnitude of stress. In this research project, fluid foods were exposed to a variety of rheological methods, exerting different stresses to invoke unique flow behaviors. Rheological methods included measurements for shear viscosity, biaxial extensional viscosity, an empirical stringiness index, and yield stress. These tests were evaluated at different rates to examine properties other than viscosity as possible textural

attributes of fluid foods. Principal component and correlation analysis identified stringiness and yield stress to be separate rheological properties from viscosity; whereas biaxial extensional viscosity was interrelated with shear viscosity. Therefore, the most appropriate conditions for these instrumental methods were selected so as to determine viscosity, stringiness, and yield stress as independent rheological properties.

Reference materials as well as terminology and definitions have been established for viscosity sensory methods. However, fluid foods possess rheological properties in addition to viscosity that may contribute to texture. Therefore, a sensory protocol involving model systems was developed to investigate the contribution of stringiness and yield stress on fluid food texture. Principal component and correlation analysis specified definitions and procedures, along with model systems, to individually assess sensory responses to stringiness, yield stress, and viscosity as textural attributes of fluid foods.

Texture clearly ties together several intrinsic attributes, like structure, with a set of human interaction variables, like chewing and handling, to result in a complicated process of many stimuli working in combination. Therefore, texture lends itself to both rheological and sensory evaluation. Appropriate instrumental and sensory methods to evaluate viscosity, stringiness, and yield stress as separate attributes of fluid foods were developed, however it was not known if these techniques quantified similar textural attributes. The relationship between instrumental and sensory evaluation of fluid food texture was examined to determine if these methods were related. In addition, since stringiness, viscosity, and yield stress were separate rheological and sensory attributes, a visual representation of the textural “pattern” of these properties was developed, called a texture map. Results showed correlation between instrumental and sensory methods, suggesting these methods evaluated similar textural characteristics. Texture mapping was an adequate tool for visually evaluating the texture of fluid foods based on selected instrumental and sensory methods.

There are many benefits to the food scientist from this experiment. Due to the limited amount of research on the textural importance of stringiness and yield stress, the instrumental and sensory protocol in this experiment offers a tool to evaluate these properties as textural attributes, whereas traditionally viscosity has been the primary property of interest. Furthermore, texture mapping provides a technique to visually compare and differentiate fluid foods on a fundamental basis. Also, the mapping procedure provides a tool to assess new ingredient functionality in a food or to track ingredient performance as a function of temperature, storage conditions, and shelf life. This profiling technique provides the food industry with a protocol to rapidly quantify the textural behavior of fluid foods.

Instrumental and Sensory Characterization for a Texture Profile Analysis of Fluid Foods

by

Noel R. Pollen

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Department of Food Science

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APPROVED BY:

Christopher R. Daubert

Dr. Christopher R. Daubert
Chair of Advisory Committee

M A Drake

Dr. Mary Anne Drake

Marcia Gumpertz

Dr. Marcia L. Gumpertz

DEDICATION

I would like to dedicate this thesis to my wife, Ginnie. Your unconditional love, support, and prayers have always been with me through the peaks and valleys of life. Thank you for being my champion and counselor and for showing me what is truly important in life.

BIOGRAPHY

Noel Robert Pollen was born January 4, 1977 in Harvey, Illinois to Charles and Barbara Pollen. Noel grew up in Schererville, Indiana with his sister Dana and brother Andrew. Noel graduated from Lake Central High School in 1995 after which he attended Purdue University in West Lafayette, Indiana. After graduation in 2000 with a B.S. in Food Science, Noel joined the Food Rheology Laboratory. Under the direction of Dr. Christopher Daubert, he pursued a major in Food Science and minor in Statistics. During his graduate program, Noel married his high school sweetheart, Virginia Stallard. After graduation, Noel and Virginia will move to Minneapolis, Minnesota where Noel will work for General Mills as a product development scientist.

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I

An Instrumental Assessment of the Textural Attributes of Fluid Foods.

ABSTRACT

Shear viscosity, imperfect squeezing flow for biaxial extensional viscosity, and an empirical stringiness index were compared at different rates to determine which methods quantified viscosity and stringiness as separate rheological attributes for selected pourable foods. In addition, these foods were evaluated with a vane attachment on a controlled stress rheometer to assess yield stress. These rheological methods were chosen because they were hypothesized to independently contribute to fluid food texture. Results indicated the rate of evaluation significantly affected all rheological measurements. Principal component and correlation analyses identified shear viscosity and imperfect squeezing flow to be highly correlated at each rate of evaluation, therefore imperfect squeezing flow and shear viscosity were interrelated. Shear viscosity at 25 s^{-1}, the empirical stringiness index at 100mm/min, and yield stress were determined to be the most appropriate rheological methods for differentiating viscosity, stringiness, and yield stress as separate, rheological attributes of fluid foods. These rheological methods offer a protocol for the rheological analysis of fluid foods that may be contributors to fluid food texture. These procedures are useful for product comparisons and ingredient performance evaluation.

INTRODUCTION

Texture is included with flavor, appearance, and nutrition as a principal quality factor of foods (Bourne, 1982). Because texture is a criterion by which quality is judged, it is an important factor when selecting or rejecting foods (Rosenthal, 1999). Due to the importance of texture on quality and choice, understanding factors that influence texture perception, is essential to the food scientist.

In the classification of textural phenomena, Bourne (1982) separated foods into two simple classes: solid and liquid. Bourne (1982) hypothesized that texture pertained to solid foods whereas viscosity, or the tendency of a fluid to resist flow, pertained to liquid foods. For many years, viscosity has been the primary property of interest to researchers investigating stimuli influencing fluid food perception (Shama *et al.* 1973; Shama and Sherman, 1973; Houska *et al.* 1997; and Christensen, 1979). However, Bourne (1982) stated it was virtually impossible to draw a line of distinction between solid and liquid foods because depending on the type of stress applied to the fluid, some fluids exhibit solid-like behavior.

Handling for processing, preparation, and swallowing subjects fluid foods to different stresses that influence flow behavior. The response to stress is a function of material structure. Some fluids possess a complex set of intrinsic material properties, such as viscoelastic and time dependent behaviors, suggesting complex fluids can become "texturized" depending on the stress associated with evaluation. For example the same sample can exhibit drastically different behaviors depending on the handling. Viscosity is a fluid response to shear flow, where shear flow may be visualized as rubbing two hands past each other with a sample between them. The spacing between the hands stays the same, and the fluid flows in the gap between them (Clark, 1997). The speed of rubbing is related to the rate of shear. However, a different kind of stress applied to a fluid can drastically alter the rheological behavior. For example, if the two hands are moved apart in a direction perpendicular to that used to create shear flow, a different type of flow is created (Clark, 1997). This type of stress is called a normal stress, resulting in extensional flow. Fluids with large extensional viscosities are said to be “stringy.” Therefore, depending on the type of force applied to a fluid, the same fluid can be independently viscous and stringy.

Another phenomena complicating fluid food behavior is yield stress. A yield stress results from time dependent chemical changes or from intrinsic material properties causing the formation of a network. Because of this network, the fluid will not flow until the minimum energy required to overcome the yield stress has been placed on the system. Therefore, yield stress, and extensional viscosity (stringiness), in addition to viscosity, may serve as components to the “texturization” of fluid foods. Although viscosity, stringiness, and yield stress may be important to fluid food texture, other rheological properties may contribute to the overall texture of fluid foods.

Viscosity

As part of the original texture profile analysis technique, Szczesniak (1963) developed one, panelist - defined term to evaluate fluid food texture. The term was called viscosity, defined as the rate of flow per unit force and perceived as the force required to draw liquid from a spoon over the tongue. Szczesniak *et al.* (1963) also developed a standard viscosity reference scale. Rotational coaxial viscometry was used to examine the correlation between physical viscosity and sensory responses to viscosity. Physical viscosity measurements were taken for each fluid reference on the reference scale at an unspecified shear rate. Szczesniak *et al.* (1963) found good correlation between fundamental viscosity measurements and sensory responses suggesting coaxial viscometry was an appropriate method for assessing physical viscosity as a textural attribute.

Several other researchers explored the relationship between rotational coaxial viscometry and sensory responses (Christensen, 1979; Smith *et al.* 1997; Houska *et al.* 1998; and Dickie and Kokini, 1983). A rotational viscometer was used to study the viscosity of samples over a broad shear rate range. Shama *et al.* (1973), and Shama and Sherman (1973) identified stimuli controlling sensory evaluation of viscosity using oral and non-oral sensory methods by measuring physical viscosity with a rotational viscometer. The researchers concluded that one non-oral method of viscosity determination, stirring a sample with a rod, was analogous to the situation encountered with rotational coaxial viscometry. "Practically all test participants indicated that they judged viscosity as the resistance offered by the sample to stirring. Thus, in effect, we had a situation roughly similar to that in a rotational coaxial cylinder viscometer where viscosity is measured by the viscous drag exerted on the inner cylinder when it rotates" (Shama *et al.*, 1973). During oral evaluation of viscosity for more viscous foods, Shama and Sherman (1973) concluded viscosity stimulus to be a function of shear stress developed in the mouth at a relatively low shear rate of approximately 10 s^{-1}. The researchers suggested that this type of evaluation paralleled the non-oral stirring method, and therefore was analogous with rotational coaxial viscometry.

However, a thorough rheological characterization of fluid foods should provide a complete explanation of properties in addition to viscosity. In an effort to classify the mouthfeel characteristics of beverages, Szczesniak (1979) remarked ***"The classification of textural characteristics published earlier by this laboratory dealt with solid foods and only one parameter, viscosity, was specifically applicable to liquid foods. A deeper analysis reveals that this one parameter is totally inadequate to describe the mouthfeel nuances of the various beverages."*** This study clearly established that texture could not be described as a single overlying rheological attribute. Rather, texture is a human experience that incorporates many attributes (rheological, geometric, and surface) of food, suggesting that the experience of texture is a result of many stimuli working in combination (Rosenthal, 1998). Therefore, rheological properties such as viscosity, yield stress, and extensional viscosity (or stringiness) may contribute to the texture of fluids.

The majority of research performed on fluid food texture has been focused on viscosity perception and correlations between instrumental and sensory results. However, fluids have complex material properties in addition to viscosity that can be measured instrumentally, such as yield stress and extensional viscosity.

Yield Stress

During investigation of stimuli controlling sensory evaluation of viscosity, Shama *et al.* (1973) and Shama and Sherman (1973) noted additional situations where sensory viscosity evaluation was affected by yield stress. Yield stress is defined as the minimum shear stress required to initiate flow (Steffe, 1996). The yield stress of foods has been linked with quality and consumer acceptance (Daubert *et al.* 1998) and has been used to predict the spreadability of elastoplastic foods (Kokini and Dickie, 1982) as well as the scoopability of ice cream (Briggs *et al.* 1996).

There are several rheological methods available for yield stress measurement. A common technique for evaluation of food is the vane method (Daubert *et al.* 1998; Tung *et al.* 1990; and Missaire *et al.* 1990), used to measure the yield stress of cheese, butter, fruit pulp suspensions, mayonnaise, and salad dressings. Despite the ease of measurement, limited research has been conducted relating yield stress properties of fluid foods to sensory perception.

Extensional Viscosity

Water soluble polymers such as carboxymethyl cellulose (CMC) or xanthan gum are added to fluids to increase viscosity (Collins and Dincer, 1973). "Too stringy" is a frequent consumer complaint about these products: The product does not break cleanly when the container is maneuvered to stop flow, i.e. a stringy filament strand forms from the lip of the container (Clark, 1997). This property - extensional viscosity - is a measurable rheological parameter of fluid foods, contributing to texture.

Although extensional viscosity measurement is among one of the most difficult challenges in rheometry, especially for low-viscosity fluids (Fuller *et al.*, 1987), there are several fundamental and empirical methods available for measurement. Fundamental techniques to evaluate extensional viscosity of foodstuff include the opposing jet, fiber spinning, and imperfect squeezing flow (Steffe, 1996).

Imperfect squeezing flow, a relatively simple and inexpensive compression test, has been applied to foods by several researchers (Hoffner *et al*., 1997; Suwonsichon and Peleg, 1999; and Lorenzo *et al*., 1997) to determine extensional viscosity in an ideal frictionless lubricated flow. It is perhaps counterintuitive to think extensional viscosity, or stretching of molecules, can occur under compression. Molecular stretching results from extensional flow, and biaxial flow is a type of extensional flow. During biaxial flow, the material is stretched under compression in two directions with a size reduction in the third (Steffe, 1996). Compression creates velocity in the axial and radial directions, and biaxial extension is called "shear free" flow because there is no velocity gradient to cause rotation or shear flow. This method is called "imperfect" because as the upper plate compresses, the fluid exits to the filled annulus of the shallow reservoir. This process results in confounding end effects and an "imperfect" flow pattern (Lorenzo *et al*. 1997).

The extensional viscosity of syrups containing CMC and xanthan hydrocolloids was examined by Clark (1997) using an opposing jet rheometer. In another study Plucinski *et al.* (1996) used a fiber spinning technique to measure the extensional viscosity of molten chocolate. Despite the large number of studies focused on fundamental measurements of extensional viscosity, a single procedure has not been universally accepted and adopted.

Stringiness

Henry and Katz (1969) developed an empirical instrumental method to determine the stringiness of semi-solid foods. This test involved stretching a sample under tension, i.e. an upward motion. The test was coined the "S-value" for determining stringiness, and was considered by the researchers to be a new texture profile parameter (Henry *et al.* 1971). Henry and Katz (1969) uncoupled stringiness from physical viscosity by fixing the viscosity of each sample before measuring stringiness. Henry and Katz (1969) found that semi-solid foods with identical viscosities had different levels of stringiness. Therefore, the "S-value" index was independent of viscosity. In addition, the stringiness index did not correlate with traditional TPA compression parameters, except gumminess. A factor analysis of the instrumental measurements identified the basic underlying textural properties of the samples. The researchers concluded that semi-solid foods could be organized into distinct instrumental factors that related to texture; one of which was stringiness (Henry *et al.* 1971).

Objectives

The intent of this research was to assess rheological properties of foods that may be of textural importance. This experiment is especially needed for extensional viscosity and yield stress, because the majority of fluid food texture studies have focused on viscosity. The research intent was to establish that through rheological characterization, yield stress and extensional viscosity can be assessed as separate properties from viscosity.

MATIERIALS AND METHODS

Commercial Samples:

A variety of commercial food samples was chosen to represent a wide range of rheological and textural attributes of interest. Samples (table 1) were purchased at a local grocery store in bulk, and the same brands were consistently selected. All foods were stored at 25°C in an incubator (Percival Scientific model I – 36NL, Perry, IA) until evaluation.

Rheological Methods:

Viscosity

Viscosity was measured using rotational coaxial viscometry at 25°C with a Stress Tech controlled stress rheometer (ATS Rheosystems, Bordentown, NJ / Rheologica Instruments AB, Lund, Sweden), see figure 1. Three individual samples from each food container were sheared from 1 to 100 s^{-1} using a CC 25 couette assembly.

Extensional Viscosity

Extensional viscosity was determined using a compression technique called imperfect squeezing flow viscometry, described by Hoffner *et. al.* (1997), Suwonsichon and Peleg (1999), and Lorenzo *et. al.* (1997), to determine biaxial extensional viscosity (figure 2). Samples were stored in original containers at 25°C in an incubator prior to immediate transfer into a 279 x 279 x 51 mm Plexiglass container. Initial height of the sample was 6-7 mm in all tests, and the top was leveled with a spatula. The sample was compressed by an inert plastic upper plate 206 mm in diameter and 38 mm high. Samples were compressed by an Instron Universal Testing Machine (model 1122, Canton, Mass.) equipped with a 50 Kg load cell. Samples were compressed to a final height of 0.5 mm at speeds of 1, 10, and 100 mm/min. Care was extended to insure the attached upper plate was parallel with the bottom plate of the reservoir before testing. Biaxial extensional viscosity as a function of strain rate was calculated using equation 1.

$$\eta_B(t) = \frac{2F(t)H(t)}{\pi R^2 V} \qquad (1)$$

where V is the constant displacement rate, F(t) is the momentary force, H(t) is the momentary specimen height, and R is the radius of the upper plate. Three individual tests were conducted at each rate for each sample.

Stringiness "S-value"

The "S-value" empirical stringiness index was performed using methods described by Henry and Katz (1969), see figure 3. Samples were stored in a 25°C incubator in the original container prior to transfer into a cylindrical plastic reservoir 70 mm in diameter and 85 mm high. The initial height of all samples was 20 mm. Next, a Nylon® disc, 20 mm diameter and 20 mm high, was affixed to an Instron Universal Testing Machine (model 1122, Canton, Mass.). The face of the disc was roughened for better adhesion to the sample surface. The disc was lowered to the sample until the sample surface made complete contact with the disc. Then, the Instron crosshead was run in tension mode (upward direction) at a fixed rate in the range of 10 to 200 mm/min. As the plastic disc separated from the sample, the sample adhered to the disc forming a strand. The sample stretched between the plastic disc and reservoir until rupture. At this point the test was immediately terminated, and the distance traveled by the plastic disc was recorded as the "S-value" or stringiness of the sample. Three individual tests were conducted for each rate.

Yield stress

A dynamic yield stress was determined for each sample using the Stress Tech controlled stress rheometer (figure 4) (ATS Rheosystems, Bordentown, NJ / Rheologica Instruments AB, Lund, Sweden) at 25°C with a four-blade vane attachment: 37 mm high, 13.5 mm diameter. Samples were loaded into a 27.5 mm cup, and the top was leveled with a spatula. The vane was slowly immersed into the sample until the top of the vane was flush with the sample surface. After insertion, the sample was pre-sheared by the vane for 12 seconds at 2 s^{-1} to eliminate time - dependent structures; the sample equilibrated for 120 seconds after pre-shear. Next, the sample was subjected to a stress sweep between 0.1 to 5 Pa, the minimum stress required to initiate flow was recorded as the yield stress. This stress value was selected when the apparent viscosity displayed a sudden decrease. Three individual tests were conducted for each sample.

Statistical Analyses:

All statistical analyses were conducted using SAS (Version 8.1) and JMP (Version 4.0.2) statistical software (SAS Institute, Inc., Cary, NC). All analyses were conducted on the means of the three tests for each sample. Linear correlations (PROC CORR) were performed to determine individual relationships between instrumental tests. In addition, principal component analysis of the standardized responses (PROC PRINCOMP) was performed on the correlation matrix to determine how instrumental tests were differentiated. Biplots were produced from principal component data using Sigma Plot (Version 5.0, SPSS, Inc., Chicago, IL). In the biplot the first two principal components of the standardized responses were plotted against each other and labeled with the food name. Overlaid on this scatter plot were vectors for each of the method variables. The lengths of these vectors were related to the standard deviations of the original variables and the location reflected the correlations between the response variable and the two principal components. A small angle between a vector and a principal component axis corresponds to the variable being highly correlated with the principal component.

RESULTS AND DISCUSSION

The following sections present results obtained for rheological properties of proposed textural importance as well as their methods of measurement.

Viscosity

As expected, figure 5 supports the ability to differentiate samples based on shear viscosity over a range of shear rates. All samples exhibited pseudoplastic behavior: as the shear rate increased the viscosity decreased. The extent of thinning behavior frequently caused crossover at specific shear rates, i.e. chocolate syrup and caramel topping had approximately the same viscosity at lower shear rates (~ 2 s^{-1}), however at a higher shear rate chocolate syrup had a much lower viscosity than caramel topping. Therefore shear rate selection was critical to viscosity measurements.

Extensional Viscosity

Figure 6 is a typical biaxial extensional viscosity versus strain rate curve for table syrup over three decades of compression obtained by imperfect squeezing flow. Each curve was characterized as having a transient flow and a fully developed extensional flow (Lorenzo *et al.* 1997).

Figure 7 displays biaxial extensional viscosity as a function of strain rate over three decades of compression rates. The transient flow section leading up to fully developed extensional viscosity was removed in this figure to show only fully developed extensional flow. All samples in figure 7 exhibited a weakening extensional viscosity response with increasing strain rates. As with shear viscosity, there were differences in the degree of "string weakening" for each sample. For example, ketchup had the highest biaxial extensional viscosity at strain rate 0.01 s^{-1}, however at higher strain rates, ketchup had the fourth lowest biaxial extensional viscosity. Nevertheless, differentiating between samples was possible using biaxial extensional viscosity, i.e. each sample had a distinct curve. Similar results were obtained by Lorenzo *et al.* (1997) in the investigation of biaxial extensional viscosity for tomato paste and ketchup.

<u>Stringiness</u>

Figure 8 indicates the empirical "S-value" was a function of evaluation rate for all samples. The figure shows samples had approximately the same "S-value" at the lowest testing speed, 10 mm/min. As the rate increased, greater differentiation was observed between samples, because the "S-value" for most samples increased with test speed. Greater experimental error was encountered at higher rates. As the plastic disc separated from the surface of the sample, the sample was stretched and a strand resulted. Once the strand ruptured the experiment was manually stopped. As the speed increased, stopping the test at the exact moment of strand rupture became more difficult. Henry and Katz (1969) noted a similar observation, and as a result recommended the optimum evaluation rate to be 25 mm/min.

Yield Stress

Figure 9 is a typical yield stress curve for ketchup. Viscosity was relatively independent of shear stress until the sample began to flow. The yield point was marked by the shear stress required to cause a steep decrease in the viscosity. Table 2 exhibits yield stress values for all samples. Since materials in this experiment were fluids, most samples were expected have a low or no yield stress. Many samples did not exhibit a large yield stress with the exception of ketchup. A slight yield stress was detected for Catalina salad dressing, sweetened condensed milk, chocolate syrup and caramel topping.

Statistical Analysis

Principal component analysis was conducted as a function of sample means to visually assess the relationship between shear viscosity, imperfect squeezing flow for extensional viscosity, the empirical "S-value" for stringiness, and yield stress rheological techniques. Principal component analysis (PCA) is a multivariate statistical technique designed to reduce a large number of original variables into subset groupings of variables relatively independent of one another. The analysis is conducted by finding linear combinations accounting for the highest proportion of variation (Tabchnick and Fidell, 1989).

Due to the rate dependent nature of all tests, analysis was conducted at three different evaluation rates, except for yield stress. Shear viscosity was evaluated at shear rates 1, 25, and 100 s^{-1}; biaxial extensional viscosity was measured at strain rates 0.01, 0.1, and 1.0 s^{-1}; and the "S-value" for stringiness was recorded at testing speeds 25, 50, and 100 mm/min.

Figure 10 is a biplot of principal component 1 versus principal component 2 for instrumental methods as a function of food sample means. This figure revealed that a high proportion of the total variation, 93.6%, was explained by linear combinations making up principal components 1 and 2, 58.9% and 33.8% respectively. Vectors (arrows in figure 10) represent rheological methods, and the scatter plot (foods in figure 10) represents samples.

Principal component 1 primarily differentiated samples based on viscosity and stringiness. Samples with lower viscosities such as pancake syrup and chocolate syrup, had negative values of principal component 1, whereas samples with higher viscosities like sweetened condensed milk and caramel topping had positive values of principal component 1. A similar trend was observed for stringiness as well. Samples with low "S-values" had negative values of principal component 1, and samples that had positive values on principal component 1 had the highest "S-values".

Principal component 2 differentiated samples based on yield stress. Most samples had negative values of principal component 2 and the majority of these samples had low or undetectable yield stress values. Samples that had the highest values of principal component 2 were ketchup and Catalina salad dressing. Both of these foods had a significant yield stress.

All instrumental methods loaded positively on principal component 1. The "S-value" at testing speeds 25, 50, and 100 mm/min, shear viscosity at shear rate 25 and 100 s^{-1}, and biaxial extensional viscosity at strain rates 1 and 0.1 s^{-1} loaded highest at approximately the same value on principal component 1. Shear viscosity at shear rate 1 s^{-1}, biaxial extensional viscosity at strain rate 0.01 s^{-1} and yield stress all loaded highest on principal component 2 at approximately the same value.

Instrumental methods were primarily differentiated by principal component 2 in five separate groups (color-coded in figure 10). The first group was "S-value" at 100 mm/min. The second group was "S-value" at rates 25 and 50 mm/min, shear viscosity at shear rate 100 s^{-1}, and biaxial extensional viscosity at strain rate 1 s^{-1}. The third group included biaxial extensional viscosity at strain rate 0.1 s^{-1} and shear viscosity at shear rate 25 s^{-1}. The fourth group involved shear viscosity at shear rate 1 s^{-1} and biaxial extensional viscosity at strain rate 0.01 s^{-1}. Finally, the fifth group was the yield stress measurement. Methods within each group were highly correlated (table 3).

Principal component 2 also differentiated by rate. Evaluation rates for all tests increased as principal component 2 decreased from positive to negative. For example, group 4 (colored green in figure 10) represented tests at the lowest rates of evaluation, whereas groups 1 and 2 (colored red and black in figure 10) represented tests at the highest rates of evaluation.

According to evaluation rates, biaxial extensional viscosity and viscosity methods were consistently grouped as well as highly correlated. For example, according to table 3, shear viscosity at 1 s^{-1} and biaxial extensional viscosity at 0.01 s^{-1} were highly correlated ($r = 0.93$). Also significant were correlations between shear viscosity at shear rate 25 s^{-1} and biaxial extensional viscosity at 0.1 s^{-1} (r = 0.95), as well as shear viscosity at 100 s^{-1} and biaxial extensional viscosity at 1 s^{-1} (r = 0.98). This pattern suggested biaxial extensional viscosity was a duplicate measurement of shear viscosity for the specific food samples under investigation. Therefore, biaxial extensional viscosity may not be the best method for determining extensional viscosity (stringiness) as a textural attribute of fluid foods independent from viscosity.

Rotational coaxial viscometry has been used by many researchers (Shama *et al.* 1973, Christensen, 1979; Szczesniak, 1963) to investigate viscosity as a textural attribute of fluid foods. Shama *et al.* (1973) proposed that rotational coaxial viscometry was an appropriate method for determining viscosity for correlation with sensory results. More specifically, shear viscosity at 25 s^{-1} was not correlated with "S-value", or yield stress measurements. This result suggests shear viscosity at 25 s^{-1} may be the best instrumental test to measure the viscosity component of fluid foods, independent of yield stress or stringiness factors.

The empirical "S-value" for stringiness may be better than imperfect squeezing flow to determine stringiness as a rheological attribute of fluid foods. Henry and Katz (1969) showed stringiness values obtained from the "S-value" method can be used to differentiate the stringiness of food samples. The "S-value" at 100mm/min may be the most appropriate method for assessing stringiness as a rheological attribute separate from viscosity and yield stress. The "S-value" at 100 mm/min was poorly correlated with yield stress (r = -0.41) and shear viscosity at 25 s^{-1} (r = 0.59), therefore the test may have measured stringiness as an independent rheological attribute. Henry and Katz (1969) also supported the independence of shear viscosity and the "S-value" stringiness method.

Yield stress was poorly correlated with all "S-value", viscosity, and biaxial extensional viscosity measurements with the exception of shear viscosity at 1 s^{-1} (r = 0.88) and biaxial extensional viscosity at 0.01 s^{-1} (r = 0.90). Therefore, shear viscosity and biaxial extensional viscosity measurements taken at the lowest rates may be measuring a yield stress component. Due to the relative ease of yield stress determination and its ability to accurately determine the yield point of foods (Yoo *et al.* 1995), this test may be the most appropriate method for assessing yield stress as a rheological attribute of fluid foods. Yield stress correlated poorly with shear viscosity at 25 s^{-1} (r = -0.22) and "S-value" at 100mm/min (r = -0.41), therefore yield stress measured an independent rheological attribute.

CONCLUSIONS

Three rheological tests were identified to assess viscosity, extensional viscosity (stringiness), and yield stress as separate rheological that may be important to fluid food texture. Shear viscosity at 25 s^{-1}, the "S-value" for stringiness at 100 mm/min, and yield stress were determined to evaluate viscosity, stringiness, and yield stress as independent rheological attributes. The rate effect of shear viscosity, biaxial extensional viscosity, and "S-value" was determined to be significant to the differentiation of rheological attributes. Although shear viscosity at 25 s^{-1}, the "S-value" for stringiness at 100 mm/min, and yield stress were found to be independent rheological methods for texture determination, it is not known if these methods correspond with sensory perception of these parameters. Therefore, applications of these rheological methods shall be considered for correlation with sensory assessment, and ultimately applied to develop a texture profile analysis technique for fluid foods.

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Table 1: Commercial food samples

Sample	Brand	Abbreviation
Ketchup	Heinz	Ketchup
Sweetened condensed milk	Eagle®	SCM
Caramel topping	Smuckers®	caramel
Chocolate syrup	Hershey's®	choc. syrup
Catalina salad dressing	Kraft®	Catalina
Pancake syrup	Aunt Jemima®	pan. syrup

Table 2: Yield stress for all samples determined using a vane attachment

Food sample	**Mean yield stress values ± standard deviations at 25°C (Pa)**
Pancake syrup	0.12 ± 0.01
Caramel topping	0.63 ± 0.07
Catalina	2.24 ± 0.51
Choc. syrup	0.74 ± 0.22
SCM	1.47 ± 0.06
Ketchup	13.84 ± 0.83

Table 3: Instrumental correlations

	visc1	**visc25**	**visc100**	**sval25**	**sval50**	**sval100**	**biax0.01**	**biax0.1**	**biax1.0**
yield	**0.88**	0.44	-0.16	-0.22	-0.17	-0.41	**0.90**	0.41	-0.13
visc1		0.62	-0.18	0.16	0.16	-0.18	**0.93**	0.62	0.06
visc25			**0.77**	0.64	**0.75**	0.59	0.53	**0.95**	**0.80**
visc100				**0.70**	**0.84**	**0.91**	-0.06	**0.70**	**0.98**
sval25					**0.95**	**0.85**	0.11	0.68	**0.79**
sval50						**0.91**	0.11	**0.80**	**0.92**
sval100							-0.18	0.59	**0.92**
biax0.01								0.59	0.02
biax0.1									**0.80**

yield: yield stress

visc1: shear viscosity at 1 s^{-1}

visc25: shear viscosity at 25 s^{-1}

visc100: shear viscosity at 100 s^{-1}

sval25: "S-value" at 25mm/min

sval50: "S-value" at 50mm/min

sval100: "S-value" at 100mm/min

biax0.01: biaxial extensional viscosity at 0.01 s^{-1}

biax0.1: biaxial extensional viscosity at 0.1 s^{-1}

biax1.0: biaxial extensional viscosity at 1.0 s^{-1}

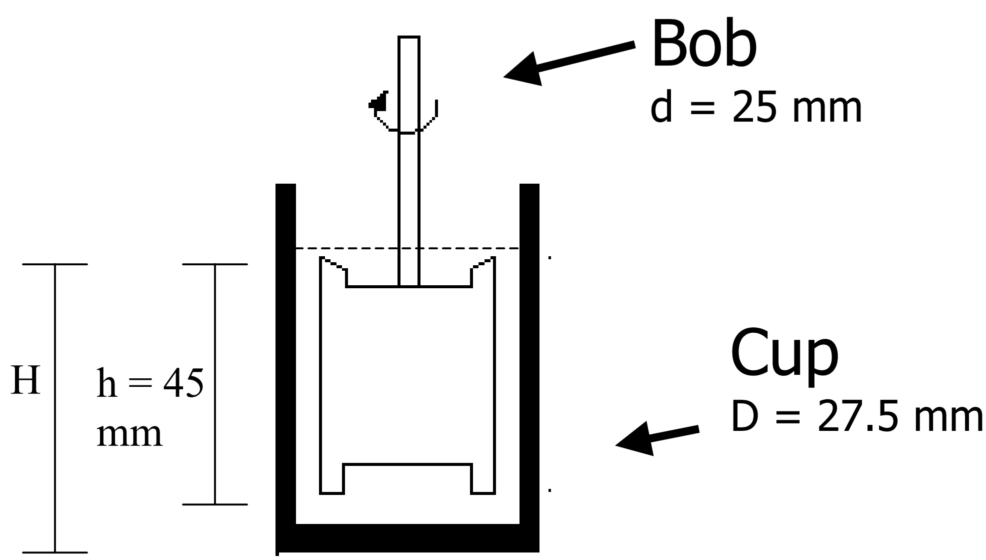

Figure 1: StressTech rheometer and schematic of coaxial attachment used to determine shear viscosity at 25°C.

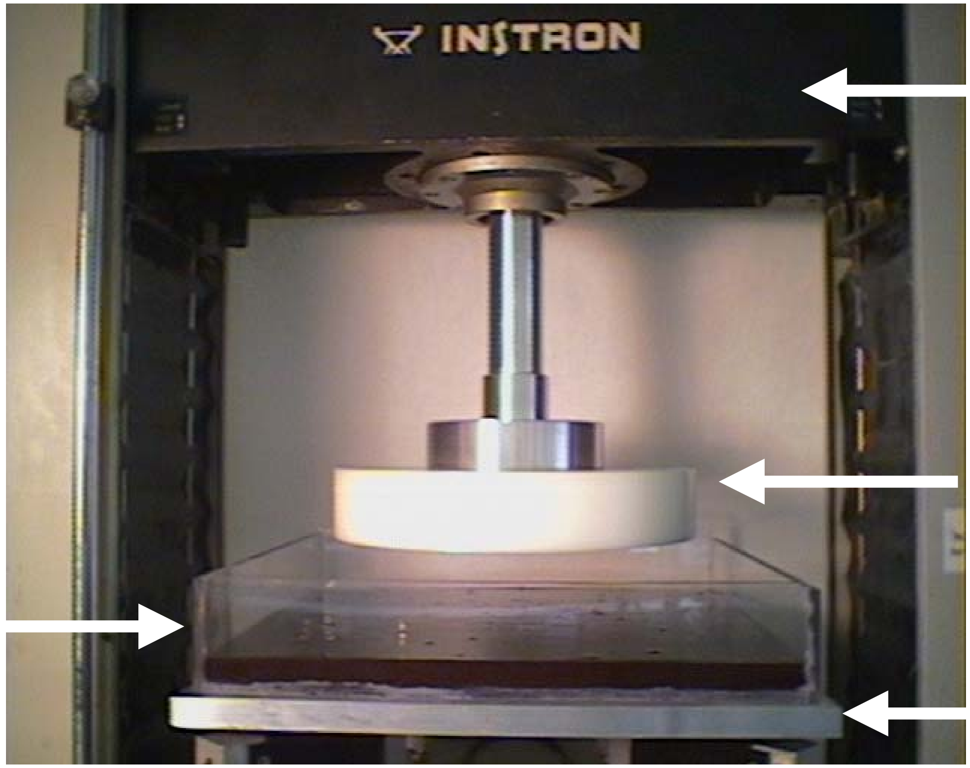

Figure 2: Imperfect squeezing flow viscometer used to determine biaxial extensional viscosity at 25°C.

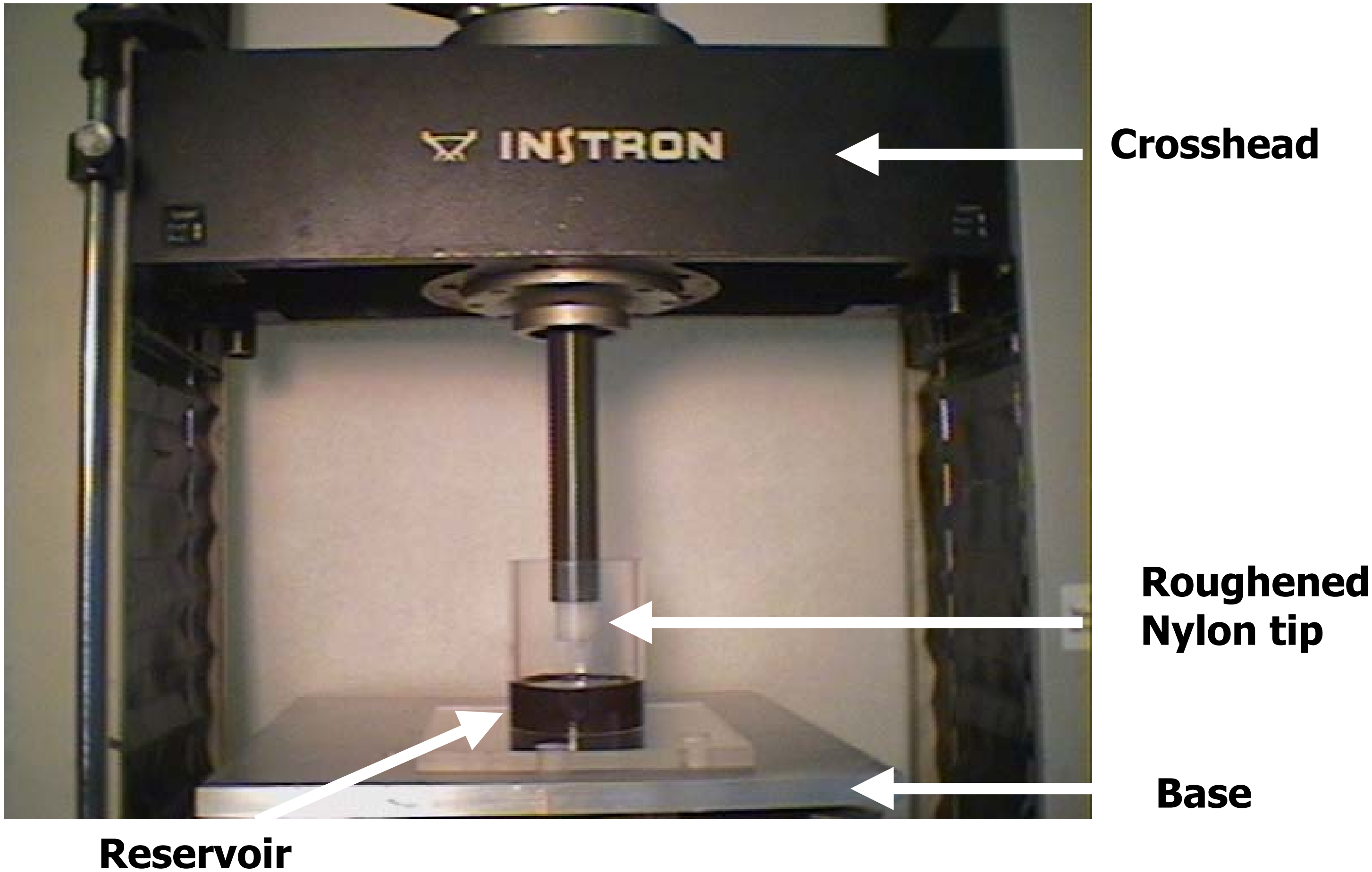

Figure 3: Apparatus used to determine the empirical "S-value" for stringiness at 25°C.

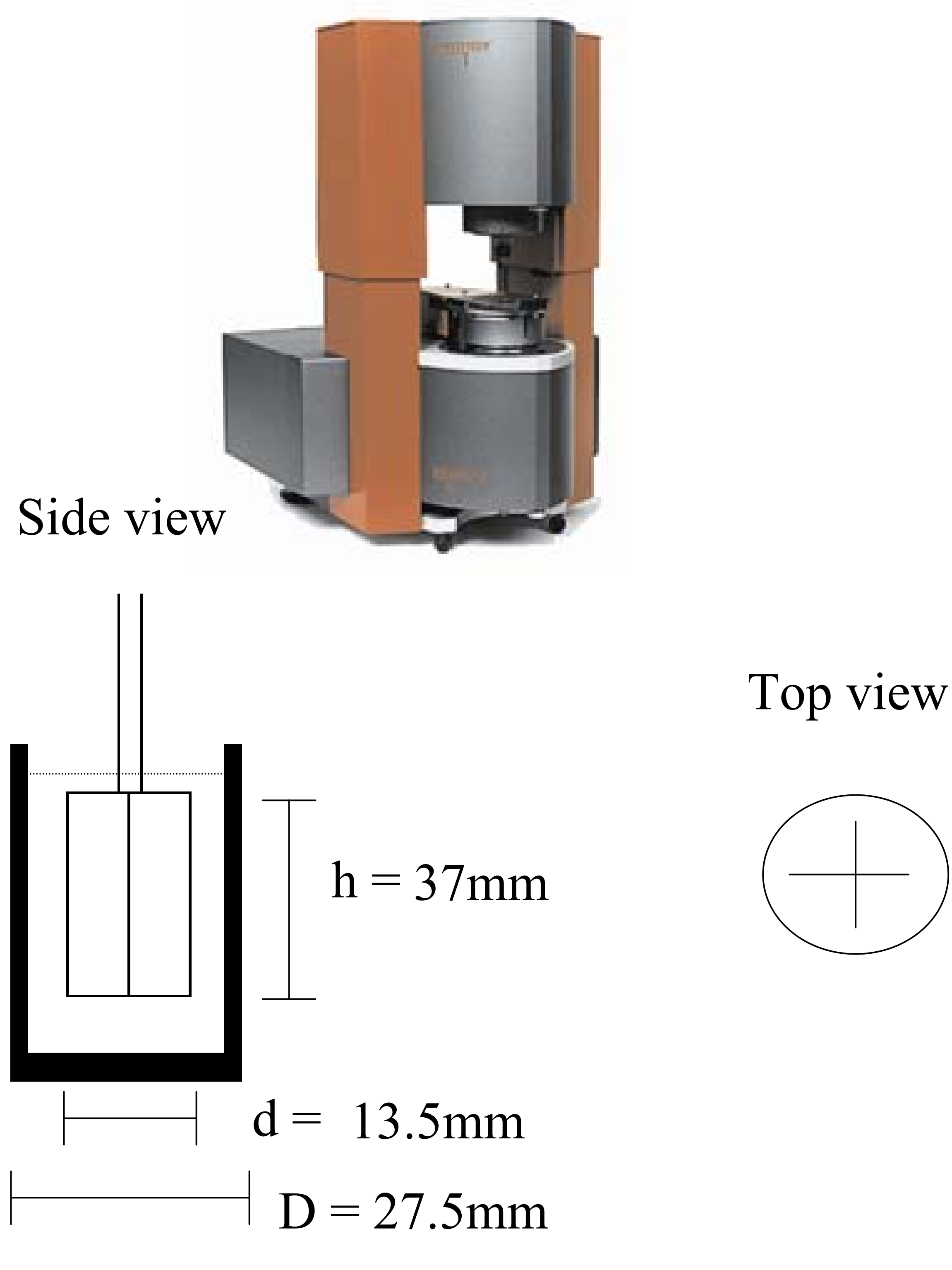

Figure 4: StressTech rheometer and schematic of 4-blade vane attachment used to determine yield stress at 25°C.

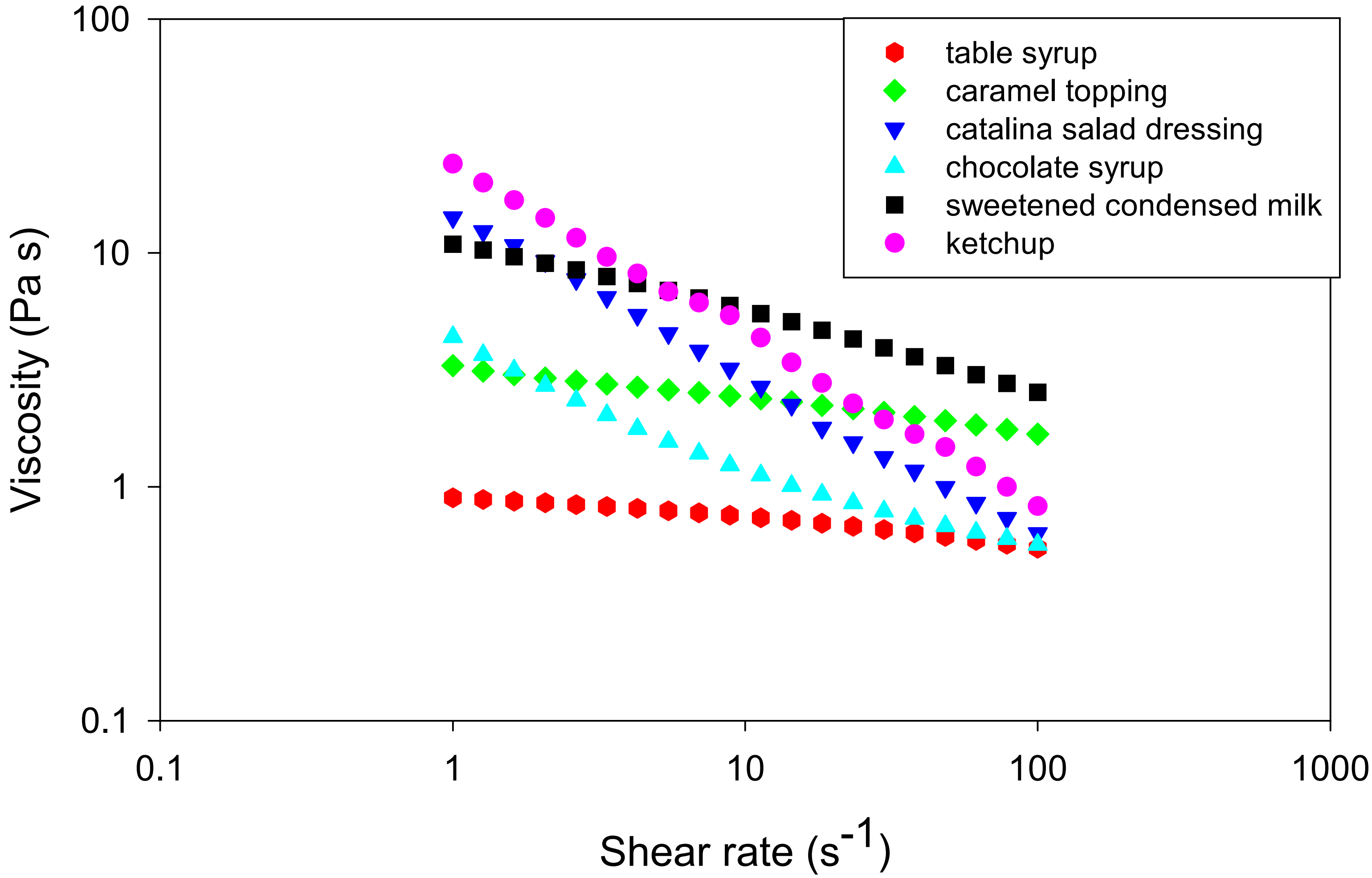

Figure 5: Viscosity versus shear rate for food systems at 25°C.

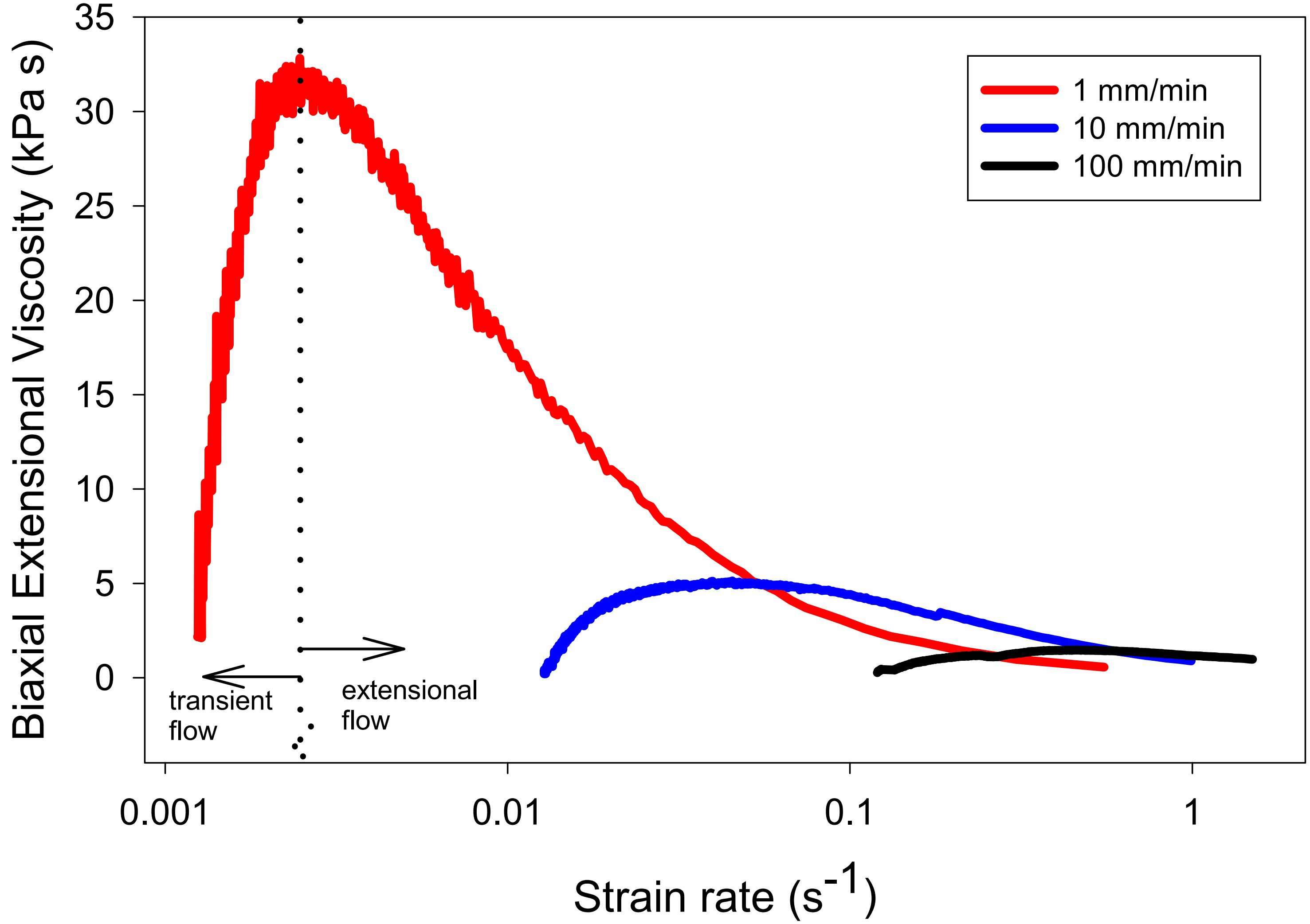

Figure 6: Typical extensional viscosity vs biaxial strain rate of pancake syrup obtained using imperfect squeezing at 25°C.

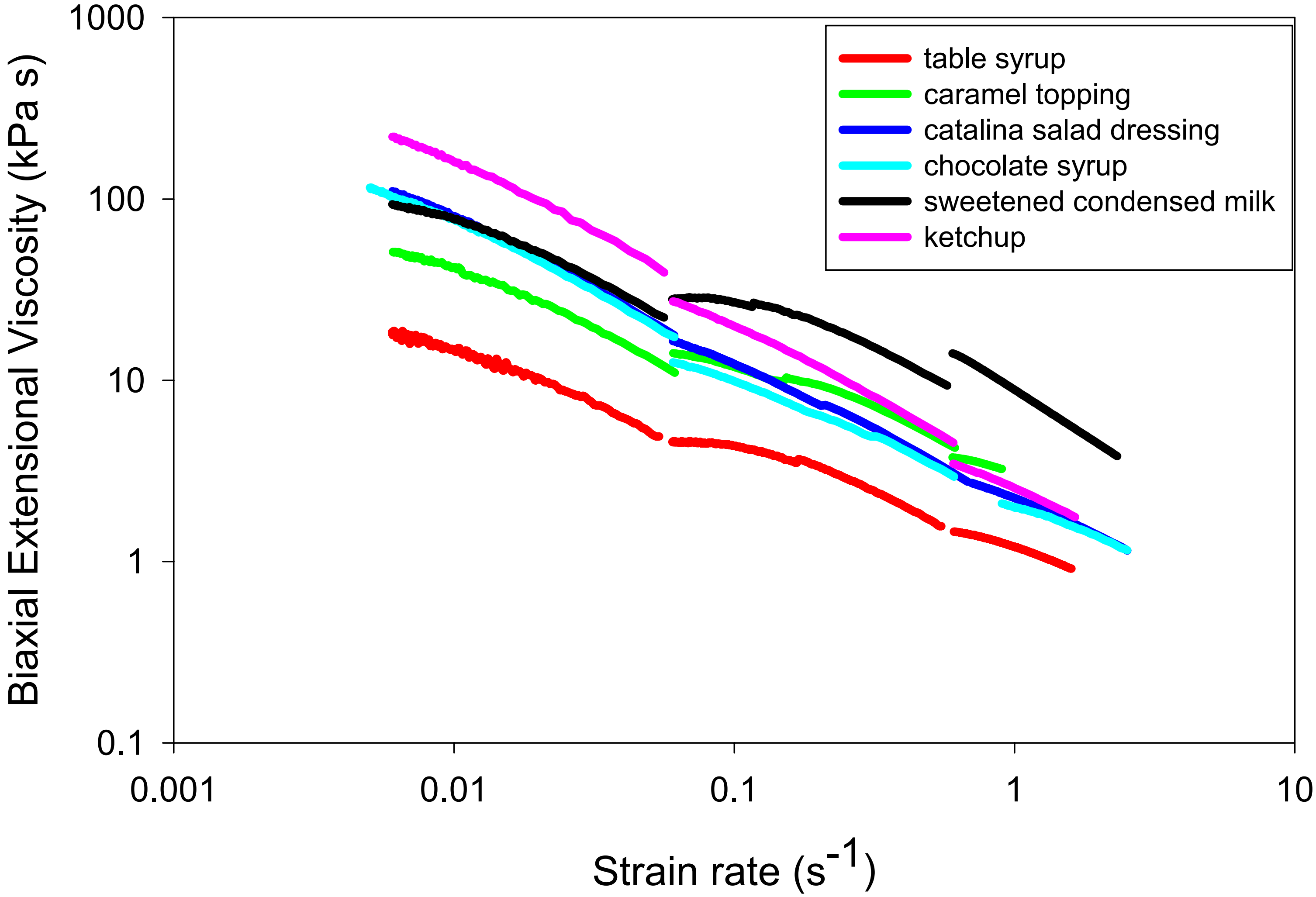

Figure 7: Imperfect squeezing flow biaxial extensional viscosity as a function of strain rate at 25°C.

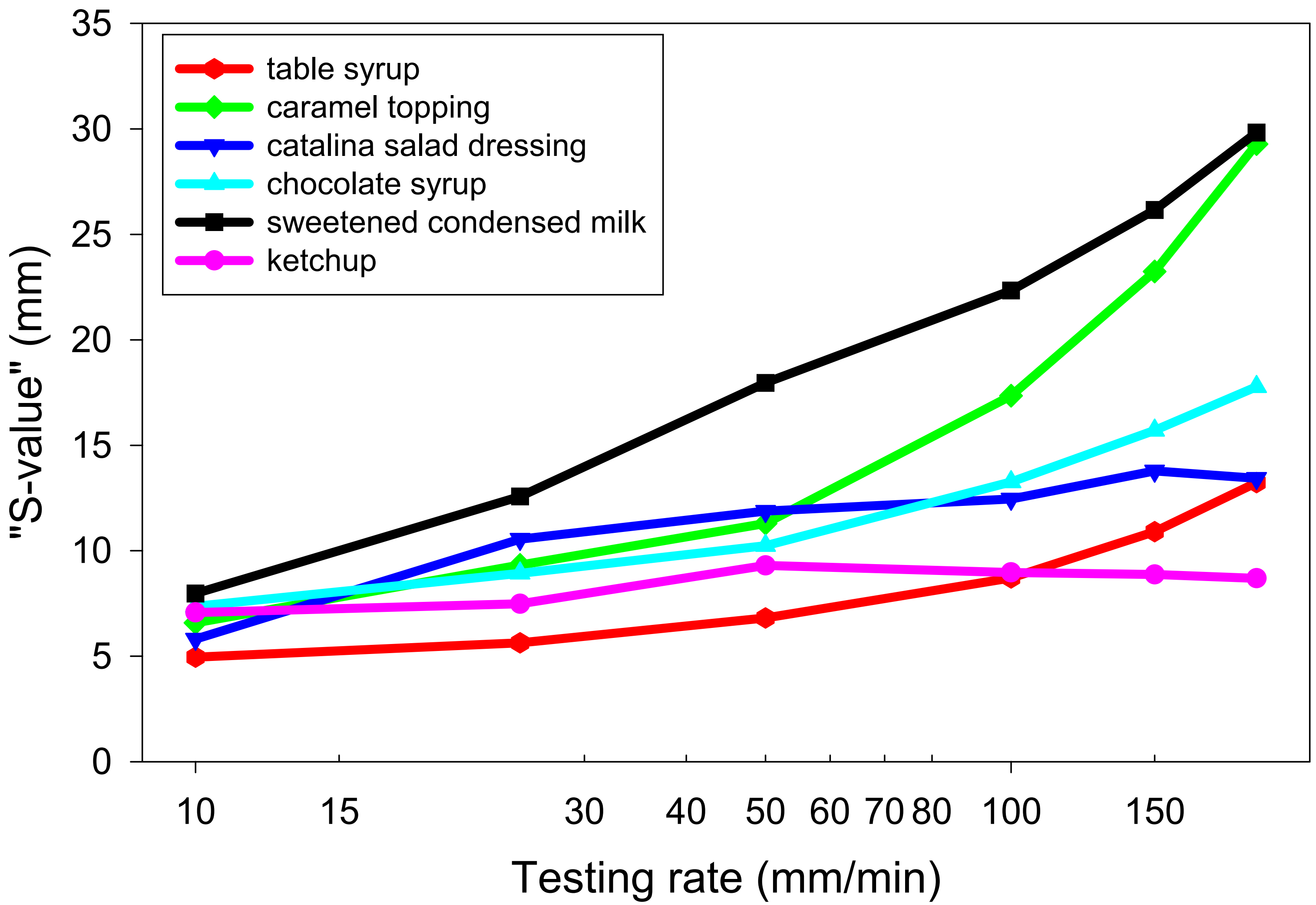

Figure 8: Empirical "S-value" as a function of rate at 25°C.

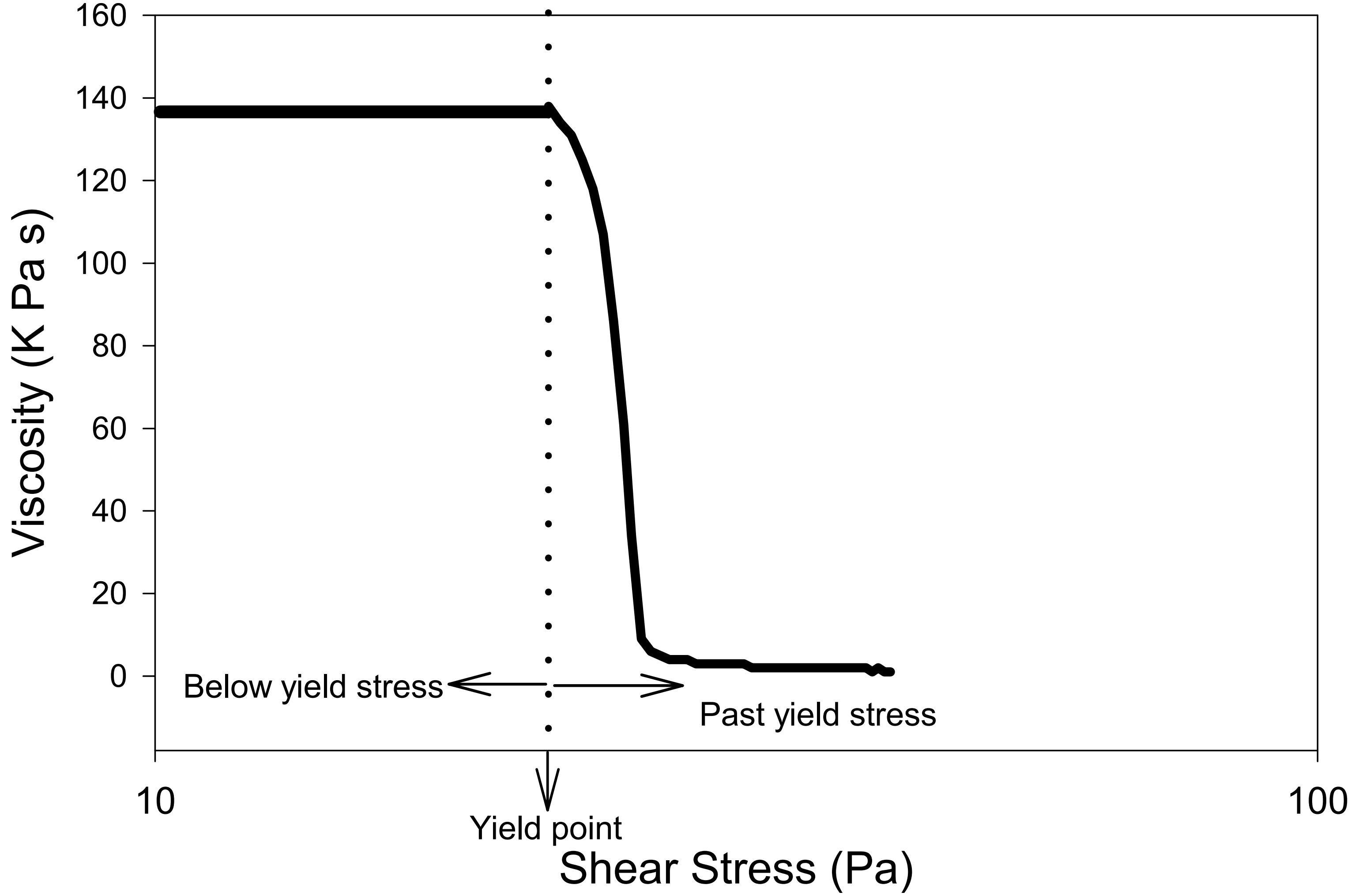

Figure 9: Typical yield stress curve for ketchup using the vane attachment on a controlled stress rheometer at 25°C.

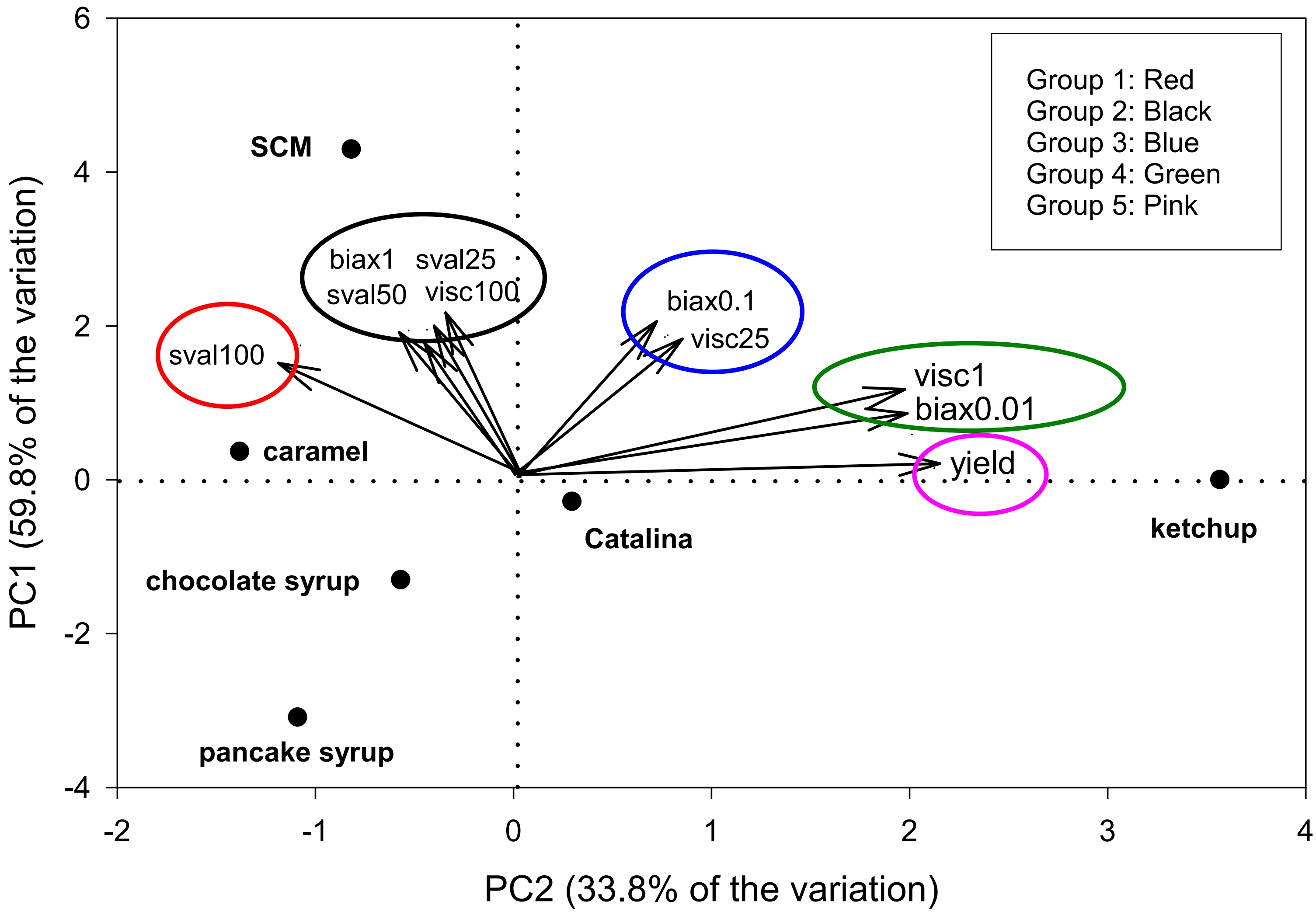

Figure 10: Biplot of instrumental methods as a function of sample means.

II

A Sensory Assessment of the Textural Attributes of Fluid Foods.

ABSTRACT

In addition to viscosity, oral and non-oral methods were developed to identify sensory attributes contributing to fluid food texture. Panelists identified six viscosity, three yield stress, and three stringiness evaluation methods as well as standard evaluation procedures during the course of training. Simple model system references were developed to aid in training and evaluation for each attribute. Methods and model systems were used to evaluate six fluid foods possessing a wide range of textural attributes. In addition to viscosity, stringiness and yield stress methods were able to distinguish fluid foods. Significant rate effects were observed for each evaluation method. Principal component and correlation analysis revealed that viscosity, stringiness, and yield stress are three measurable and separate components of fluid foods, each contributing to texture. Sensory quantification of these textural attributes will contribute to the understanding of overall fluid food texture.

INTRODUCTION

Reference materials as well as terminology and definitions have been established for sensory methods of viscosity (Wood, 1968; Szczesniak, 1963; Shama and Sherman 1973; and Shama *et al.* 1973). However, Szczesniak (1979) showed properties other than viscosity were contributing to the mouthfeel of beverages. In the previous chapter, rheological properties, such as stringiness and yield stress, were instrumentally measured to differentiate fluid foods. These properties, in addition to viscosity, may be important to fluid food texture.

One of the first studies on fluid food texture was conducted by Szczesniak (1963) as part of the Texture Profile Analysis (TPA) technique. In this study Szczesniak (1963) identified viscosity as one of the five basic mechanical textural attributes of foods. In another study, Szczesniak and co-workers (1963) developed terminology and definitions for oral viscosity evaluation. Viscosity was defined as the rate of flow per unit force and was perceived organoleptically as the force required to draw liquid from a spoon over the tongue.

Szczesniak *et al.* (1963) also developed a standard rating scale for viscosity using a range of fluids as reference materials. The purpose of the viscosity reference was to provide a standard for panel training and evaluation. This type of standardization fostered an emphasis on objective analysis rather than subjective opinion (Civille and Liska, 1975). Standard reference foods were chosen based on the criteria that foods "possess the desired intensity of the textural attribute, that the attribute is not overshadowed by other textural parameters, and that the foods were readily available, of constant quality, and generally familiar" (Szczesniak *et al.* 1963). Nine foods of specific brand requirements were chosen to represent the sensory continuum of viscosity. These foods fell at equidistant intervals on an intensity scale.

Due to availability limitations in many parts of the country as well as formula or process changes, there can be difficulties using the original rating scales described by Szczesniak (Civille and Liska, 1975). Appropriate substitutes can be used to replace the original standard reference materials if, after instrumental testing, the substitute exhibits the intensity of the desired textural property (Civille and Liska, 1975). For example, in addition to viscosity, Szczesniak (1963) developed a standard reference scale for each of the basic five mechanical textural attributes of foods. One of the original textural attributes, called gumminess, had the simplest reference scale. The gumminess scale was simply composed of different mixtures of flour and water. This scale was easy to produce and resulted in a controlled system with limited variability. In an effort to reduce problems associated with unavailable and inconsistent standard references, suggestions have been made to change all standard scales to more easily controlled model systems (Civille and Liska, 1975), however Bourne (1975) pointed out that this procedure does not always yield consistent references.

Viscosity

Following Szczesniak's (1963) classification of viscosity as an important textural property of fluids, other researchers investigated viscosity perception. Shama *et al.* (1973) and Shama and Sherman (1973) investigated rheological stimuli responsible for oral and non-oral methods of viscosity assessment. Shama *et al.* (1973) developed two sensory techniques to evaluate the viscosity of several foods using non-oral methods. Evaluation methods were adopted from previous research conducted by Wood (1968) in which viscosity was evaluated by tilting a beaker gently to assess flow and by stirring the contents of the beaker with a glass rod. Both methods were performed by panelists with no prior texture training. Shama and Sherman (1973) used an oral evaluation technique to investigate stimuli responsible for the oral evaluation of viscosity. In this study untrained panelists introduced a small volume of each sample into their mouth and evaluated viscosity through oral manipulation of the sample.

In another study, Houska *et al.* (1998) evaluated viscosity perception as a function of shear rate with very specific oral and non-oral methods of evaluation using a trained panel. The researchers proposed five methods of assessment. The first two non-oral methods were similar to procedures used by Shama *et al.* (1973). The effort necessary to mix the sample in a beaker with a spoon and the manner in which the sample poured back into a beaker from a spoon were non-oral viscosity methods. One of the three oral evaluation procedures closely followed the viscosity method proposed by Szczesniak (1963), where subjects evaluated the effort to slurp the sample from a spoon into the mouth. The other two oral evaluation methods involved compressing the sample between the tongue and upper palate and swallowing the sample. The researchers concluded sensory evaluation of viscosity should be conducted under specific evaluation protocol.

In addition to studies mentioned above, other studies involving sensory viscosity perception have been performed (Christensen, 1979; Cutler *et al.* 1983; Dickie and Kokini, 1983; Smith *et al.* 1997; and Morris *et al.* 1984). In fact, a recent standardization of texture was completed in Europe (ISO 11036), and the sensory evaluation standard included evaluation procedures for evaluating viscosity as a textural attribute. The standard procedure for viscosity evaluation was defined as the effort necessary to drag the fluid into the mouth while slurping from a teaspoon, similar to Szczesniak (1963). Therefore, viscosity as a textural property of fluid foods has been well characterized and standardized.

Szczesniak (1979) stated that previous work on texture profile analysis dealt with solid foods and only studied one fluid food property, viscosity. The researcher expressed that viscosity alone was totally inadequate to describe the textural nuances of beverages. Therefore, Szczesniak (1979) developed a word association experiment to generate a large number of mouthfeel terms for a variety of beverages. Not surprisingly, 30.7% of the total responses dealt with viscosity related terms like thin, thick, and viscous. However, Szczesniak (1979) found other textural terms used to describe mouthfeel and classified them into eleven categories, only one of which was viscosity. Therefore, it was established that viscosity was not the only sensory property responsible for fluid food texture.

Stringiness

Limited research exists in sensory methods for extensional viscosity. Extensional viscosity is a fundamental rheological property of fluids defined as the maximum stretching of molecules in non-shear flow (Steffe, 1996). This phenomenon may be perceived as stringiness. Many researchers have developed methods to assess extensional viscosity using instrumental techniques (Clark, 1997; Lorenzo, 1997; Plucinski, 1996). There are two categories of instrumental methods for extensional viscosity measurement - those designed to measure extensional viscosity as a fundamental rheological property, and those designed to measure stringiness using empirical methods.

Clark (1997) conducted a fundamental approach to measuring extensional viscosity for the purpose of discerning the extensional flow of pancake syrups with different hydrocolloids. In this study a fundamental rheological instrument called an opposing jet rheometer was used to study the extensional flow behavior of xanthan and carboxymethyl cellulose (CMC) gums. These two gums are commonly used hydrocolloids in pancake syrup. Sensory tests were not conducted in this study to evaluate extensional viscosity, however the researcher hypothesized the importance of extensional viscosity on pancake syrup texture.

Henry and Katz (1969) developed an empirical instrumental method to determine the stringiness of semi-solid foods. The method involved stretching a sample in tension (upward direction), and was called the “S-value” for stringiness. This method was considered empirical because it did not measure fundamental rheological properties, and the value was dependent on the testing protocol. Henry *et al.* (1971) used sensory methods to relate the perceived stringiness of a variety of foods to the instrumental "S-value." The researchers used untrained panelists and unspecified methods of evaluation in this experiment. Panelists recorded responses on a 7-point structured scale.

Yield Stress

Textural properties, such as the spreadability of margarine and cheese spread, have been quantified using an instrumental rheological technique called the vane method to measure yield stress (Daubert *et al.* 1998). Yield stress is defined as the minimum shear stress required to initiate flow, and below this stress the material will not flow (Steffe, 1996). The yield stress of several semi-solid foods and food spreads has been measured (Tung *et al.* 1990; Missaire *et al.* 1990; and Yoo *et al.* 1995), however limited research has been conducted to investigate the impact of yield stress as a textural attribute of foods, particularly fluid foods.

Objectives

Given the limited amount of research in fluid food texture, the objective of this research was to determine if stringiness and yield stress are separate sensory attributes from viscosity. Also, to develop appropriate sensory terminology and definitions for stringiness and yield stress evaluation. Another objective was to develop model systems from simple food ingredients for each of the above textural attributes to be used as standard rating scales for sensory evaluation of viscosity, stringiness, and yield stress. Although the overall texture of fluids is not limited to these three properties, understanding these properties will help to develop a more complete picture of fluid food texture

MATERIALS AND METHODS

<u>Sensory Evaluation:</u>

Descriptive analysis was performed by thirteen to eighteen trained panelists using the texture profile method described by Meilgaard *et al.* (1991). Three separate studies were conducted, and each study measured a different textural attribute. Separate training was completed for each individual textural property of interest. During training, panelists were presented with a variety of foods, as well as model systems, to define oral and non-oral methods of evaluation for viscosity, stringiness, and yield stress. One or two oral and non-oral methods were selected for each textural property. All samples were presented at 25°C under normal lighting conditions in two-ounce sample cups coded with random three-digit numbers. Model systems were presented at each session to serve as reference materials, and the experiments were conducted in duplicate.

Viscosity

Six methods were used for viscosity evaluation. Methods included two oral and four non-oral procedures, see table 1 definitions. A nineteen-point category scale with word anchor descriptors was used for each method, see figure 1 for a sample scale. Five one-hour training sessions were conducted, and evaluation was performed for two weeks.

Initial training revealed panelists were not independently evaluating food and method combinations. For example, after evaluating the intensity of chocolate syrup using a non-oral method, the panelists would assign chocolate syrup the same intensity using oral methods. Therefore, it was necessary for each food and test combination to be evaluated independently. In addition, the viscosity of twelve food samples was evaluated using six assessment methods, resulting in seventy-two individual tests per session. This approach could promote adaptation to the stimulus, which is decreased sensitivity from continued exposure. This effect is an important, but undesirable source of variability in sensory tests. (Meilgaard *et al.* 1991).

To avoid these complications, a statistical design was used to minimize the number of samples presented to each panelist and to minimize the food and method interactions noted in panel training. The primary intent was to make food and method combinations independent. A Latin rectangle design was chosen for this experiment, using 6-6X6 Latin squares with a separate row for each food and column for each panelist (see figure 2). Each Latin square was generated using a set of standard Latin squares while randomizing rows and columns. In this design, the row block factor was food, and the column block factor was subject. Food and subject labels were randomly assigned for each treatment. The complete 6-6X6 Latin square design was re-randomized and used again for a separate evaluation session.

Stringiness

Following the viscosity experiment, stringiness evaluation was completed on a smaller set of food samples. Three evaluation methods were chosen by the trained panelists to evaluate stringiness. Procedures included one oral and two non-oral procedures (table 2).

Samples were evaluated on a 19-point category scale with word anchors. A randomized complete block design was used in this experiment, and food-method combinations were presented in random order to eliminate interaction bias. Testing commenced after training.

Yield Stress

Yield stress was measured on the same sample subset used in the stringiness experiment. Methods included one oral and two non-oral procedures (table 3). Yield stress was evaluated on a 15-point category scale with word anchor descriptors assigned to the ballot. A randomized complete block design was used for this study. Panel training was conducted for three weeks, and evaluation was performed for one week.

Model Systems:

Experimental model systems were prepared from simple, readily available ingredients and were used as standard, controlled reference materials for panel training and evaluation. Model systems were chosen for standard anchors rather than reference foods to minimize difficulties from product unavailability and inconsistencies described by Civille and Liska (1975) and Bourne *et al.* (1975). Model systems were prepared for each rheological property of interest to provide references of a desired intensity, not overshadowed by other textural properties. Model system ingredients were of consistent quality, available, and familiar. Lastly, the controlled systems were easy to prepare, store, and handle.

Viscosity

Over the years, several modifications have been made to the original standard reference scales proposed by Szczesniak *et al.* (1963) for texture profile analysis (Munoz, 1986). The original standard viscosity scale was expanded from a 0-8 point intensity scale to a 0-15 intensity scale for the same reference foods proposed by Szczesniak *et al.* (1963) using the Sensory Spectrum™ method (Meilgaard *et al.* 1991). For this adjustment, a trained panel assessed viscosity using two oral evaluation methods. The first technique involved evaluating the force required to gently slurp 1 teaspoon of sample from a spoon into the mouth. The second technique measured flow across the tongue by moving the tongue slowly to the roof of the mouth (Meilgaard *et al.* 1991). Figure 3 indicates the relationship between the published Sensory Spectrum™ viscosity intensity for 5 foods and experimentally determined instrumental viscosity measured at 25 s^{-1} using the StressTech controlled stress rheometer at 25° C. This relationship yielded a power law function:

$$\text{Intensity} = 2.0(\eta_{25s^{-1}}\ (\text{mPa s}))^{0.25} \qquad \text{eq.1}$$

The non-linear nature of equation 1 was observed by other researchers. Christensen (1979) observed power functions, with exponents ranging from 0.34 to 0.38, adequately described the relationship between physical viscosity measurements and oral judgments of viscosity for CMC solutions. Cutler *et al.* (1983) also examined the relationship between perceived viscosity intensity and physical viscosity for Newtonian fluids. The researchers found an exponent of 0.22 as a valid index of the inner-relation between physical viscosity and sensory intensity. The exponent in the power law relationship in equation 1 validated the use of instrumental viscometry at 25 s^{-1} as a valid rheological technique for correlation with sensory results of fluid food viscosity.

The relationship in equation 1 was used to create Newtonian model systems from 42/43 DE corn syrup (ADM, Decatur, IL), with an initial viscosity of 90,000 mPa s, and distilled water mixtures to encompass the viscosity range of food samples at a shear rate of 25 s^{-1}. Specific ratios of water were added to 42/43 DE corn syrup corresponding to the desired viscosity of the model system, see table 4 for dilution ratios. Blue food coloring was added as a visual aid in sensory analysis. Approximately 500 ml of each model system was prepared with a Kitchen-Aid® mixer at a medium speed for 30 minutes. The mixture was covered and stored at room temperature for 24 hours prior to analyses.

Stringiness

Stringy model systems were prepared using deionized water, 42/43 DE corn syrup (ADM, Decatur, IL), and high molecular weight carboxymethyl cellulose (CMC) gum Ticalose® 6000 (TIC gums, Belcamp, MD). Model fluid preparation followed similar procedures described by Clark (1997) to achieve a water/hydrocolloid system with significant stringiness. A stock solution was created by mixing a 1:4 ratio of deionized water and 42/43 DE corn syrup to achieve a Newtonian viscosity of 100 mPa s. This solution was mixed with a Kitchen-Aid® mixer at medium speed for 30 minutes. To prevent clumping, CMC was wet with corn oil, then the slurry was directly added at 0.20% (wt/wt) to the water/corn syrup solution. Mixing continued for 1 hour at room temperature. Blue food coloring was added as a visual aid for sensory evaluation, and samples hydrated at 25°C for 24 hours prior to testing.

There has been limited research in the development of standard reference scales or model systems for stringiness. Therefore, development of the stringiness model system followed an instrumental approach. The stringiness "S-value" was determined for all foods at 25 mm/min, as described in the previous chapter. The "S-value" of the stock model system was also measured at 25 mm/min. The stock solution was diluted with distilled water to achieve a range of stringiness, spanning the continuum of food samples (table 5).

Yield Stress

Yield stress model systems were created from previous work on skinfeel textural attributes of lotions. Sensory Spectrum™ descriptive analysis was conducted on skinfeel properties of lotions and creams to develop terminology to describe textural attributes as well as a standard rating scale for each term (Meilgaard *et al.* 1991). One of the terms was integrity of shape. This appearance term assessed the degree which the lotion or cream maintained shape under gravity. In rheological terms, this action gives a visual assessment of yield stress, i.e. the lotion or cream does not flow until the yield stress is overcome by the sample weight.

Figure 4 describes the relationship between the published Sensory Spectrum™ integrity of shape intensity for baby oil, Keri® lotion, Vaseline® Intensive Care® lotion, and Lanacane® cream (Meilgaard *et al.* 1991) and yield stress determined experimentally using the vane attachment. The following relationship also produced a power law function where

$$\text{Integrity of shape intensity} = 2\sqrt{\text{yield stress}}\ \text{(Pa)} \qquad \text{(eq. 2)}$$

Therefore, equation 2 was used to create yield stress model systems.

Yield stress model systems were prepared using pregelatinized starch (Ultra-Sperse® 2000; National Starch, Bridgewater, NJ) and deionized water. Starch and water were mixed at different concentrations (table 6) with a Kitchen-Aid® mixer at medium speed for 10 minutes. Blue food coloring was added to aid in sensory evaluation. Prior to testing, samples were stored at 25°C for at least 12 hours to allow proper hydration.

<u>Commercial Food Samples</u>

A variety of commercial food samples were chosen to represent a wide range of rheological and textural attributes of interest (table 7). Samples were purchased at a local grocery store in bulk, and the same brands were consistently purchased. All foods were stored at 25°C in an incubator (Percival Scientific model I – 36NL, Perry, IA) until evaluation.

Statistical analyses

Statistical analyses were conducted using SAS (Version 8.1) and JMP (Version 4.0.2) statistical software (SAS Institute, Inc., Cary, NC). Univariate analysis (PROC MIXED) was conducted to determine least square means which were used in correlation, scatter plot, and principal component analysis. The mixed model was defined as:

$$y_{ijklm} = \mu + R_i + S_j + P_k + F_l + M_m + (RxS)_{ij} + (RxP)_{ik} + (RxF)_{il} + (RxM)_{im} + (FxM)_{lm} + \varepsilon_{ijklm}$$

where

i = 1, 2 replications

j= 1…n subjects

k = 1…p periods

l = 1…f foods

m = 1…m methods

y = sensory intensity response

With the assumption that $\varepsilon_{ijklm,}$ $R_{i,}$ $(RxS)_{ij}$, $(RxP)_{ik}$, $(RxF)_{il}$, and $(RxM)_{im}$ are normal with mean 0 and variance component σ_ε^2, σ_r^2, σ_{rs}^2, σ_{rp}^2, σ_{rf}^2, and σ_{rm}^2 respectively.

The same subjects were used in each replication. Subjects were defined as fixed effects because they were trained and were specifically selected by the researchers for these experiments. The same model was used for the Latin square and the randomized complete block designs.

Correlations (PROC CORR) were performed to determine linear relationships between the evaluation procedures for each textural component. In addition, principal component analysis of the standardized responses (PROC PRINCOMP) was applied to differentiate samples and sensory methods. Biplots of principal component analysis results were created using Sigma Plot (Version 5.0, SPSS, Inc., Chicago, IL). In the biplot the first two principal components of the standardized responses were plotted against each other and labeled with the food name. Overlaid on this scatter plot were vectors for each of the method variables. The lengths of these vectors were related to the standard deviations of the original variables and the location reflected the correlations between the response variable and the two principal components. A small angle between a vector and a principal component axis corresponds to the variable being highly correlated with the principal component.

RESULTS AND DISCUSSION

Several researchers have established sensory methods for viscosity assessment. Szczesniak (1979) showed fluid foods have textural attributes in addition to viscosity. Previous studies showed other rheological properties, such as stringiness and yield stress, were measurable and may influence the texture of fluid foods. Therefore, sensory viscosity procedures were speculated to be possibly influenced by stringiness and yield stress.

An analysis of variance (table 8) was conducted on the sensory viscosity experiment to identify foods with inconsistent viscosity intensities across methods of assessment. Results showed panel training with viscosity model systems permitted detection differences between samples. Also, significant differences were recorded between evaluation methods. Not surprisingly, viscosity for a specific food depended on the evaluation method.

The significance of food type in the food-method interaction was examined to determine which foods generated the most variable responses across the six methods of viscosity evaluation. This analysis was conducted because it was speculated that properties other than viscosity might affect the sensory response of viscosity. Conversely, oral and non-oral methods specifically chosen to evaluate viscosity may not solely be measuring viscosity properties. Results showed that for six out of twelve foods there were significant differences ($p \leq 0.15$) in mean intensity ratings among methods of evaluation (see table 9 for slice effects and table 10a for least squares means); this result is shown graphically for ketchup in figure 5. The figure depicts the mean viscosity intensity as dependent on the method of evaluation.

For example, the mean intensity for ketchup is almost twice as high when evaluated using the pourability method versus the adhesivness method.

The interaction between evaluation method and food sample could be attributed to at least three scenarios. The first situation could be from significant rate effects affecting the stimuli responsible for viscosity perception. The second situation could result from these foods possessing distinguishable rheological properties in addition to viscosity. These properties, such as stringiness and yield stress could be impacting viscosity perception. Finally, the third situation could arise from inadequate panel training or poor descriptive methods for viscosity evaluation.

The previous chapter showed the rate of instrumental evaluation significantly influenced physical viscosity measurements. For example, the instrumental viscosity of most foods decreased as the shear rate, or rate of stirring, increased. Therefore, sensory assessment of viscosity is most likely dependent on the rate of evaluation. While investigating methods of viscosity assessment, Shama *et al.* (1973) and Shama and Sherman (1973) showed the shear rate associated with stirring a sample with a rod was different from the shear rate associated with oral manipulation of the sample. Therefore, two tests designed to assess viscosity were conducted at different shear rates.

To further examine the likely cause of the food-method interaction in the viscosity experiment, six foods were chosen from the original twelve samples to be evaluated using stringiness and yield stress methods (table 11). These foods displayed significant interaction between method of evaluation and food during viscosity testing (tables 9 and 10a) with the exception of caramel topping. This condiment was chosen despite the lack of interaction, because it showed apparent stringiness.

Table 12 shows that the panelists were able to differentiate between foods using oral and non-oral methods of stringiness evaluation, supporting panelists ability to distinguish the stringiness of fluid foods after training with model systems. As with viscosity, the interaction between sample and sensory procedure was significant (tables 12 and 10b): stringiness intensity was dependent on the method of evaluation. The former chapter also showed that the empirical "S-value" technique was highly dependent on the rate of evaluation. For most foods, stringiness increased with the testing speed. In addition to Shama *et al.* (1973) and Shama and Sherman's (1973) conclusions that the rate of assessment for viscosity tests was a function of the test procedure, an experiment was conceived to determine if the rate of hand stringiness was consistent between panelists. The speed of evaluation for the hand stringiness method was video recorded for five panelists to determine the range of speeds for each. Results found the range of evaluation speeds ranged from 18 to 120 mm/min. This study confirmed panelists were performing the same sensory tests at different rates.

Panelists were able to differentiate samples based on yield stress, in addition there was also a significant food – method interaction (table 13). Most foods were determined to have a low yield stress with the exception of ketchup (table 10c). On average, yield stress intensity was higher for oral versus non-oral methods. In addition, there was limited differentiation between foods using non-oral methods. As with viscosity and stringiness, yield stress stimuli might be influenced by additional rheological parameters, including stress overshoot phenomena.

Texture perception is a human activity of which many stimuli are working in combination. One such stimuli is the rate of evaluation, and its been shown in this experiment and by other researchers (Shama *et al.* 1973; Shama and Sherman 1973; and Houska *et al.* 1998) that viscosity as well as stringiness and yield stress perception can be influenced by the rate of sensory assessment. This occurrence is attributed to non-Newtonian behavior of most foods. In addition, individual panelists were shown to evaluate the same sensory test at different rates. Therefore, evaluation rate can influence a sensory response. However, stimuli in addition to rate effects may also impacts the perception of specific textural attributes such as viscosity, stringiness, and yield stress.

Despite the rate effects underlying all sensory methods, principal component analysis was conducted to visually determine if panelists could separately identify the viscosity, stringiness, and yield stress components of food samples. Principal component analysis is a multivariate statistical technique designed to reduce a large number of original variables into subset groupings of variables that are relatively independent of one another. The analysis is conducted by finding linear combinations of the original variables to explain the majority of the variation (Tabachnick and Fidell, 1989). The purpose of this analysis was to determine if stringiness and yield stress would be represented in principal component subgroups, thereby making them separate from viscosity.

Figure 6 is a biplot of principal component 1 (PC1) versus principal component 2 (PC2) for all oral and non-oral methods as a function of sample means. A high percentage of the variation, 95.1%, was explained by PC1 and PC2, 61.9% and 33.2% respectively. Vectors (arrows in figure 6) represent sensory methods, and the scatter plot (foods in figure 6) represents samples.

Food samples differentiated by PC1 were separated by viscosity and yield stress, whereas foods differentiated by PC2 were separated by stringiness. As PC1 increased from negative to positive the viscosity and yield stress of the samples increased. For example, ketchup had a high value of PC1 and it was found to have a high viscosity and a high yield stress whereas pancake syrup had a negative value of PC1, and it was found to have low viscosity and yield stress. Foods that had a positive value of PC2 were found to be stringy such as caramel topping and sweetened condensed milk, and foods that had a negative value of PC2 were found not by be as stringy such as pancake syrup, chocolate syrup, Catalina salad dressing, and ketchup.

Most methods loaded positively on PC1. All viscosity methods (colored blue in figure 6), except for adhesiveness, and all yield stress methods (colored red in figure 6) loaded at approximately the same value on PC1. Two stringiness methods (colored green in figure 6) loaded slightly negatively on PC1.

Sensory methods were primarily differentiated on PC2 in three different groups. The first group (red circle in figure 6) contained two yield stress evaluation methods: peaking and pour resistance, and one viscosity method: flowability. These methods loaded negatively on

PC2. The second group of methods (blue circle in figure 6) loaded slightly positively on PC2 and this group contained four viscosity methods: pourability, thickness, oral thickness, and consistency, as well as one yield stress method: slurp. The third group (green circle in figure 6) loaded highly on PC2 and contained three stringiness methods: throat adhesivness, hand stringiness, and visual stringiness as well as one viscosity method: adhesivness.

Group one primarily contained methods to evaluate yield stress. All the methods in this group were non-oral procedures. Pour resistance and flowability were grouped together. Although the two methods were intended to measure different textural attributes, the terms have similar definitions. Therefore, panelists may have been evaluating yield stress rather than viscosity when conducting the flowability method, supporting poor training or method development. The peaking method also evaluated yield stress, an expected result since this method was the Sensory Spectrum® term used to visually evaluate the force required to initiate flow (or yield stress) of hand lotions (Meilgaard *et al.* 1991).

Group two (blue circle in figure 6) primarily contained methods of viscosity measurement. Pourability, thickness, and oral thickness seem to be adequate viscosity techniques. This result supports research by Shama *et al.* (1973) who investigated non-oral methods of viscosity stimulus by stirring a sample with a rod, (thickness in the present experiment) and by tilting the sample in a beaker as if to pour (pourability in the present experiment). Also, an oral method of viscosity assessment similar to oral thickness was successfully used by Shama and Sherman (1973) to evaluate viscosity. The consistency method used in this experiment successfully measured viscosity by other researchers

(Meilgaard *et al.* 1991; and Houska *et al.* 1998). In addition, this method is the standard sensory method used to measure viscosity as a textural attribute in Europe (ISO 11036). Therefore, this technique was expected to evaluate viscosity as a textural attribute. Not surprisingly, slurp and consistency were in the same group. Both these methods had similar definitions and procedures. Although panelists received specific training, slurp could be a redundant viscosity method and may not orally evaluate yield stress.

The third group of methods (green circle in figure 6) is most likely evaluating stringiness. Adhesivness, a viscosity method, appeared in this group. Adhesivness was a non-oral method similar in definition to hand stringiness. Therefore, rather than evaluating viscosity, panelists may have been influenced by stringiness.

Methods within each of the three groups were highly correlated (table 14). All correlations were considered to be linear through scatter plot analyses. Correlations between yield stress methods in group one and viscosity methods in group two were noted. Pour resistance, peaking, and flowability were correlated with all methods in group two, except for consistency. This response indicated yield stress methods in group one and viscosity methods in group two, except for consistency, may not be appropriate for assessing yield stress and viscosity as separate textural attributes. However, peaking, pour resistance and flowability were not significantly correlated with the viscosity method consistency, suggesting the consistency method was evaluating viscosity without yield stress influences. Conversely, peaking, pour resistance, and flowability did not measure the same sensory property as consistency.

Methods in groups one and two (red and blue circles in figure 6) were poorly correlated with methods in group three (green circle in figure 6). Therefore, methods designed to measure yield stress and viscosity, with the exception of adhesivness, did not measure the same textural property as throat adhesivness, hand stringiness, and visual stringiness. This observation suggests all methods in group three can differentiate stringiness from viscosity and yield stress for fluid foods in this study.

From this research, consistency, peaking, and visual stringiness are the recommended sensory methods to differentiate viscosity, yield stress, and stringiness for fluid food samples. According to the results, consistency is the best method for evaluating stimuli responsible for viscosity perception, because it was not influenced by stringiness or yield stress fluid properties. Therefore, consistency provides an unbiased evaluation of viscosity. Not surprisingly, consistency was shown by other researchers (Shama and Sherman *et al.* 1973, and Houska *et al.* 1998) to be an adequate test for viscosity. Peaking was the best method for yield stress assessment. This method was not significantly correlated with consistency or hand and visual stringiness, therefore evaluating yield stress separately from viscosity and stringiness. Also, this method was used to visually assess the yield stress of hand creams and lotions (Meilgaard *et al.* 1991). Finally, visual stringiness was the best method for evaluating the stringiness textural component of fluid foods, independent from yield stress and viscosity.

CONCLUSIONS

A sensory protocol was developed to evaluate aspects of viscosity, stringiness, and yield stress as separate textural attributes of fluid foods, despite the influence of rate on sensory assessment. The sensory protocol involved methods and definitions for each textural attribute as well as a complete set of simple model systems used for training and evaluation. Three methods were recommended to assess viscosity, yield stress, and stringiness as independent textural attributes. Although sensory methods have been developed to quantify viscosity, stringiness, and yield stress, it is not known if these methods can be correlated with instrumental measurements.

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Table 1: Methods for viscosity evaluation.

Textural property measured	**Panel term**	**Definition**	**Assessment method**	**Anchor Descriptors**
Viscosity	Pourability	Speed the sample pours from one cup to another	Non-oral	fast -- slow
Viscosity	Flowability	Speed the sample flows in a cup when rotated for 3 seconds	Non-oral	fast -- slow
Viscosity	Thickness	Force required to stir with a spoon back and forth 1 time per second for 3 seconds	Non-oral	low -- high
Viscosity	Adhesiveness	Adhesiveness as the thumb and forefinger slowly separate	Non-oral	low -- high
Viscosity	Consistency	Force required to slurp the sample off a spoon	Oral	thin -- thick
Viscosity	Oral thickness	Thickness of the sample after 3 seconds of tongue manipulation	Oral	thin -- thick

Table 2: Methods for stringiness evaluation.

Textural property measured	**Panel term**	**Definition**	**Assessment method**	**Anchor Descriptors**
Stringiness	Visual stringiness	Degree of stringiness from pouring off a teaspoon	Non-oral	low string -high string
Stringiness	Hand stringiness	Degree of stringiness as thumb and forefinger slowly separate	Non-oral	low string - high string
Stringiness	Throat adhesiveness	Adhesiveness in throat after quickly swallowing	Oral	low – high adhesiveness

Table 3: Methods for yield stress evaluation.

Textural property measured	**Panel term**	**Definition**	**Assessment method**	**Anchor Descriptors**
Yield stress	Pour resistance	Shaking force required to induce flow	Non-oral	easy - difficult
Yield stress	Peaking	Degree of peaking on the back of a teaspoon	Non-oral	no peaks - stiff peaks
Yield stress	Slurp	Force required initiate flow on a spoon by gently slurping	Oral	easy - difficult

Table 4: Viscosity model systems

Reference Value*	Percent 42/43 DE corn syrup in distilled water	Newtonian viscosity and std. deviations (m Pa s) at 25°C
2	0.0%	1± 0
5	60.0%	20 ± 1
8	81.8%	340 ± 60
11	86.7%	1004 ± 101
14	90.9%	2937 ± 113
17	92.3%	4616 ± 373

* Corresponds to a 19-point scale, calculated using equation 1

Table 5: Stringiness model systems

Reference Value*	Percent stock CMC in distilled water	Emperical "S-value"** (mm) and standard deviation at 25°C
4	0.0%	4.01 ± 0.03
6	85.0%	6.21 ± 0.04
7.5	90.0%	7.53 ± 0.10
9	97.5%	9.30 ± 0.05
13	100.0%	13.10 ± 0.68

* Corresponds to a 19 point scale
** evaluation rate = 25 mm/min

Table 6: Yield stress model systems

Reference value*	Percent PGS	Yield stress and standard deviations at 25°C (Pa)
1	4.0%	0.1 ± 0.1
3	5.0%	2.2 ± 0.1
5	6.0%	7.3 ± 0.4
8	7.0%	15.8 ± 1.1
10	8.0%	25.1 ± 1.1

* Corresponds to a 15-point scale, calculated using equation 2

Table 7: Commercial samples used in the viscosity experiment

Sample	Brand
Pure maple syrup	Maple Gold®
Evaporated milk	PET®
Light corn syrup	Karo®
Apple Sauce	Motts®
Half and half cream	Store brand
Chocolate milk	Store brand
Ketchup	Heinz
Sweetened condensed milk	Eagle®
Caramel topping	Smuckers®
Chocolate syrup	Hershey's®
Catalina salad dressing	Kraft®
Pancake syrup	Aunt Jemima®

Table 8: Analysis of variance of the mixed model for viscosity

Covariance parameter estimates of random effects	
Replication	0.00
rep*subject	0.37
rep*period	0.05
rep*food	0.01
rep*method	0.00
residual error	3.40

Test of fixed effects

Effect	Num df	F value	p value
subject	17	0.71	0.75
period	11	0.49	0.85
food	11	96.61	< 0.0001
method	5	18.02	< 0.0001
food*method	55	4.08	< 0.0001

Table 9: The significance of method for each food in the food and method interaction for viscosity.

Food	Numerator df	Denominator df	F value	p value
Half and half	5	323	0.11	0.98
Light corn syrup	5	320	0.26	0.93
Chocolate milk	5	322	0.29	0.91
Pure maple syrup	5	320	0.49	0.78
Evaporated milk	5	322	0.52	0.76
Caramel topping	5	321	0.92	0.47
Chocolate syrup	5	323	1.62	0.15*
Pancake syrup	5	323	1.63	0.15*
Sweetened condensed milk	5	324	2.00	0.07*
Catalina salad dressing	5	322	7.80	< 0.001*
Ketchup	5	323	15.30	< 0.001*
Apple sauce	5	323	30.92	< 0.001*

* Indicates significance ($p \leq 0.15$)

Table 10a: Least squares mean and standard error viscosity intensities

Method	Ketchup	Chocolate syrup	Catalina	Pancake syrup	Caramel	SCM
Consistency	15.3 ± 0.6	9.3 ± 0.9	11.9 ± 0.7	9.3 ± 1.0	13.1 ± 0.8	14.5 ± 0.9
Oral thickness	14.3 ± 0.9	8.4 ± 0.8	11.7 ± 0.9	8.5 ± 1.0	12.3 ± 0.8	11.7 ± 0.8
Thickness	17.0 ± 0.9	8.6 ± 1.0	12.9 ± 0.9	10.0 ± 0.8	12.9 ± 0.9	13.4 ± 0.7
Adhesiveness	10.4 ± 0.9	8.7 ± 0.7	11.3 ± 1.0	11.1 ± 0.8	13.4 ± 0.9	13.4 ± 0.8
Flowability	19.3 ± 0.9	11.3 ± 1.0	16.6 ± 0.8	8.4 ± 0.8	12.5 ± 0.8	14.4 ± 0.9
Pourability	19.0 ± 0.9	10.4 ± 0.9	15.5 ± 0.8	8.9 ± 0.7	14.4 ± 0.8	15.0 ± 0.9

Table 10b: Least squares means and standard error stringiness intensities

Method	Ketchup	Chocolate syrup	Catalina	Pancake syrup	Caramel	SCM
Hand stringiness	4.3 ± 0.4	6.3 ± 0.4	4.7 ± 0.4	6.4 ± 0.4	10.3 ± 0.4	8.5 ± 0.4
Visual stringiness	3.1 ± 0.4	7.2 ± 0.4	4.2 ± 0.4	7.2 ± 0.4	12.7 ± 0.4	11.1 ± 0.4
Throat adhesiveness	8.1 ± 0.4	7.6 ± 0.4	6.9 ± 0.4	8.1 ± 0.4	11.8 ± 0.4	12.7 ± 0.4

Table 10c: Least squares means and standard error yield stress intensities

Method	Ketchup	Chocolate syrup	Catalina	Pancake syrup	Caramel	SCM
Peaking	6.7 ± 0.1	1.5 ± 0.1	2.5 ± 0.1	1.2 ± 0.1	2.2 ± 0.1	3.0 ± 0.1
Pour resistance	6.5 ± 0.1	2.1 ± 0.1	2.6 ± 0.1	1.2 ± 0.1	2.1 ± 0.1	3.4 ± 0.1
Slurp	6.3 ± 0.1	2.6 ± 0.1	3.1 ± 0.1	2.3 ± 0.1	3.8 ± 0.1	5.3 ± 0.1

Table 11: Commercial food samples used in stringiness and yield stress experiment

Sample	Brand	Abbreviation
Ketchup	Heinz	Ketchup
Sweetened condensed milk	Eagle®	SCM
Caramel topping	Smuckers®	caramel
Chocolate syrup	Hershey's®	choc. syrup
Catalina salad dressing	Kraft®	Catalina
Pancake syrup	Aunt Jemima®	pan. syrup

Table 12: Analysis of variance of the mixed model for stringiness

Covariance parameter estimates of random effects	
Replication	0.00
rep*subject	0.65
rep*period	0.00
rep*food	0.00
rep*method	0.02
residual error	5.03

Test of fixed effects

Effect	**Num df**	**F value**	**p value**
subject	14	0.96	0.53
period	20	0.70	0.79
food	5	132.33	<.0001
method	2	37.96	0.03
food*method	12	6.48	<.0001

Table 13: Analysis of variance of the mixed model for yield stress

Covariance parameter estimates of random effects	
Replication	0.00
rep*subject	0.00
rep*period	0.03
rep*food	0.01
rep*method	1.06
residual error	1.10

Test of fixed effects

Effect	**df**	**F value**	**p value**
subject	12	8.41	<.0001
period	20	0.96	0.53
food	5	145.95	<.0001
method	2	37.45	0.003
food*method	12	6.67	<.0001

Table 14: Correlation between viscosity, stringiness, and yield stress methods

	o. thick	**thick**	**adhes**	**flow.**	**pour.**	**hand st.**	**string.**	**throat ad.**	**peak.**	**pour res.**	**slurp**
con.	**0.95**	**0.92**	0.45	**0.72**	**0.90**	0.17	0.12	0.54	**0.79**	**0.78**	**0.95**
o .thick		**0.97**	0.26	**0.88**	**0.97**	-0.05	-0.12	0.30	**0.87**	**0.85**	**0.91**
thick			0.24	**0.87**	**0.95**	-0.16	-0.22	-0.24	**0.92**	**0.89**	**0.93**
adhes				-0.09	0.19	**0.79**	**0.78**	**0.90**	-0.10	-0.14	0.26
flow.					**0.94**	-0.45	-0.50	-0.09	**0.87**	**0.87**	**0.77**
pour.						-0.17	-0.22	0.22	**0.86**	**0.86**	**0.89**
hand st.							**0.99**	**0.85**	-0.42	-0.43	-0.05
string.								**0.86**	-0.47	-0.47	-0.08
throat ad.									-0.02	-0.02	0.39
peak.										**0.99**	**0.89**
pour res.											**0.90**

con - consistency
o. thick - oral thickness
adhes - adhesiveness
flow - flowability
pour - pourability
hand st - hand stringiness
string - stringiness
throat ad - throat adhesivness
peak - peaking
pour res - pour resistance
slurp - slurp

Figure 1: Sample 19-point category scale with word anchors.

Consistency

Definition: Place 1 tsp. of sample on a spoon and position close to lips. Draw air in gently to induce flow of liquid. Evaluate the required force.

Sample_________

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
thin																		thick

food	Panelists 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	c	e	d	b	a	f	c	d	e	b	f	a	d	f	b	e	a	c
2	d	c	f	a	b	e	e	a	d	f	c	b	e	d	c	a	b	f
3	f	b	e	c	d	a	b	c	f	a	e	d	c	b	a	f	e	d
4	b	a	c	f	e	d	d	f	a	c	b	e	b	e	f	c	d	a
5	e	f	a	d	c	b	a	b	c	e	d	f	a	c	e	d	f	b
6	a	d	b	e	f	c	f	e	b	d	a	c	f	a	d	b	c	e
7	f	a	c	b	d	e	b	f	c	e	d	a	e	d	f	b	a	c
8	c	d	a	e	b	f	c	e	f	d	a	b	b	c	d	a	e	f
9	d	e	f	a	c	b	f	a	d	b	c	e	f	b	c	e	d	a
10	a	b	e	c	f	d	d	b	e	a	f	c	c	a	e	d	f	b
11	b	c	d	f	e	a	e	c	a	f	b	d	a	e	b	f	c	d
12	e	f	b	d	a	c	a	d	b	c	e	f	d	f	a	c	b	e

a = consistancy
b = oral thickness
c = thickness
d = pourability
e = flowability
f = adhesiveness

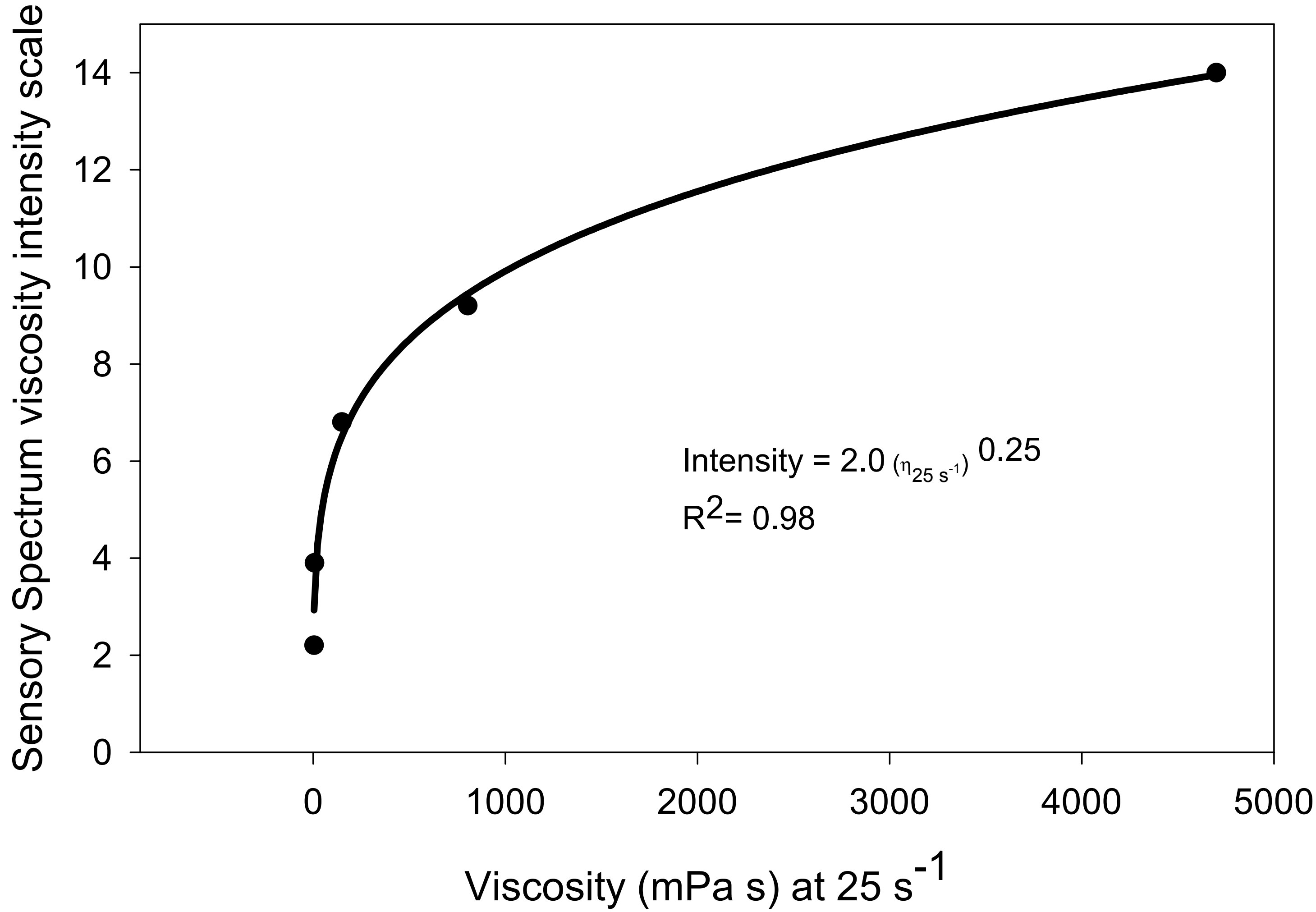

Figure 3: Relationship between Sensory Spectrum viscosity standard reference and physical viscosity at 25 s^{-1} determined at 25°C.

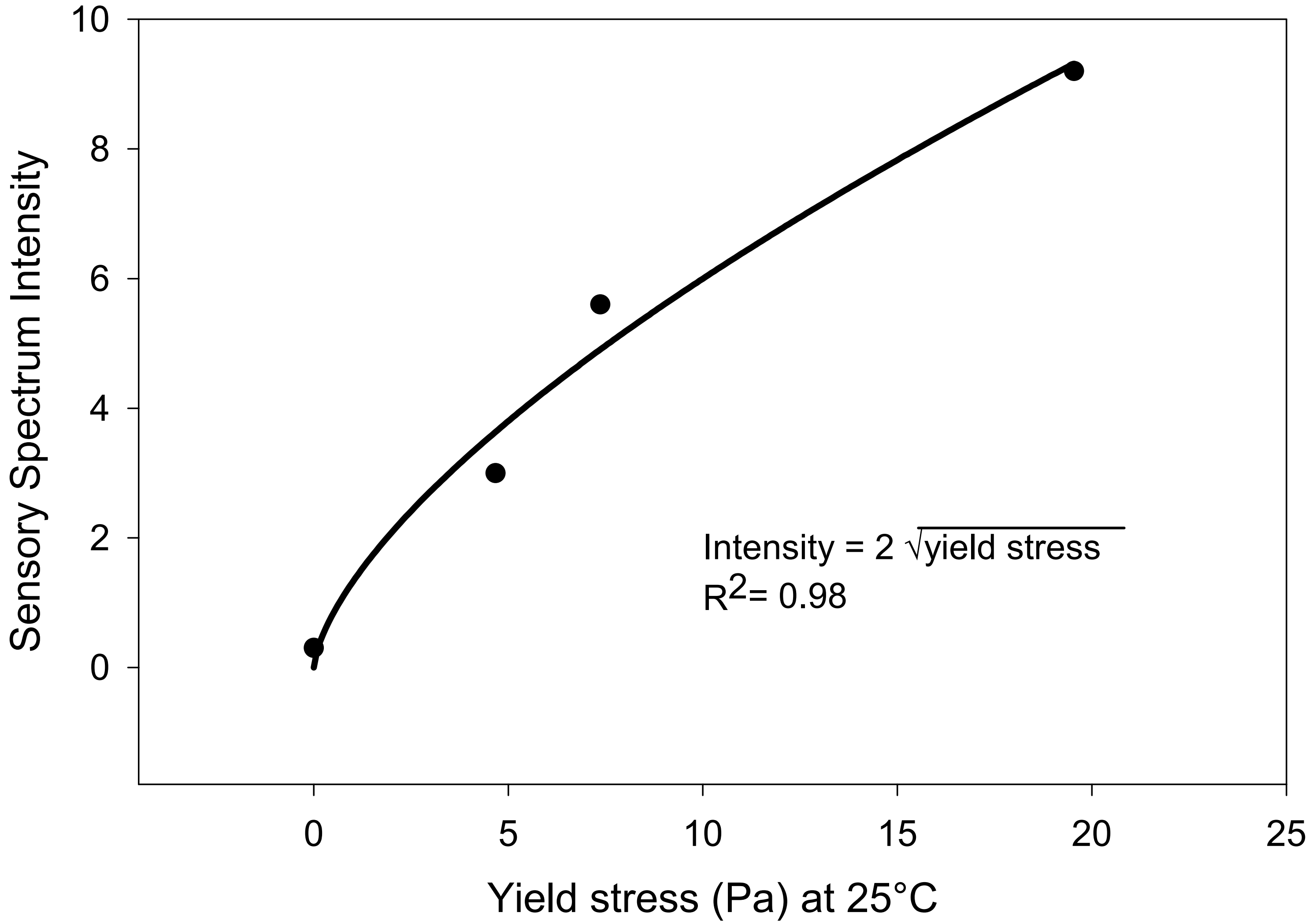

Figure 4: Relationship between Sensory Spectrum integrity of shape intensities for lotions and hand creams and yield stress determined at 25°C.

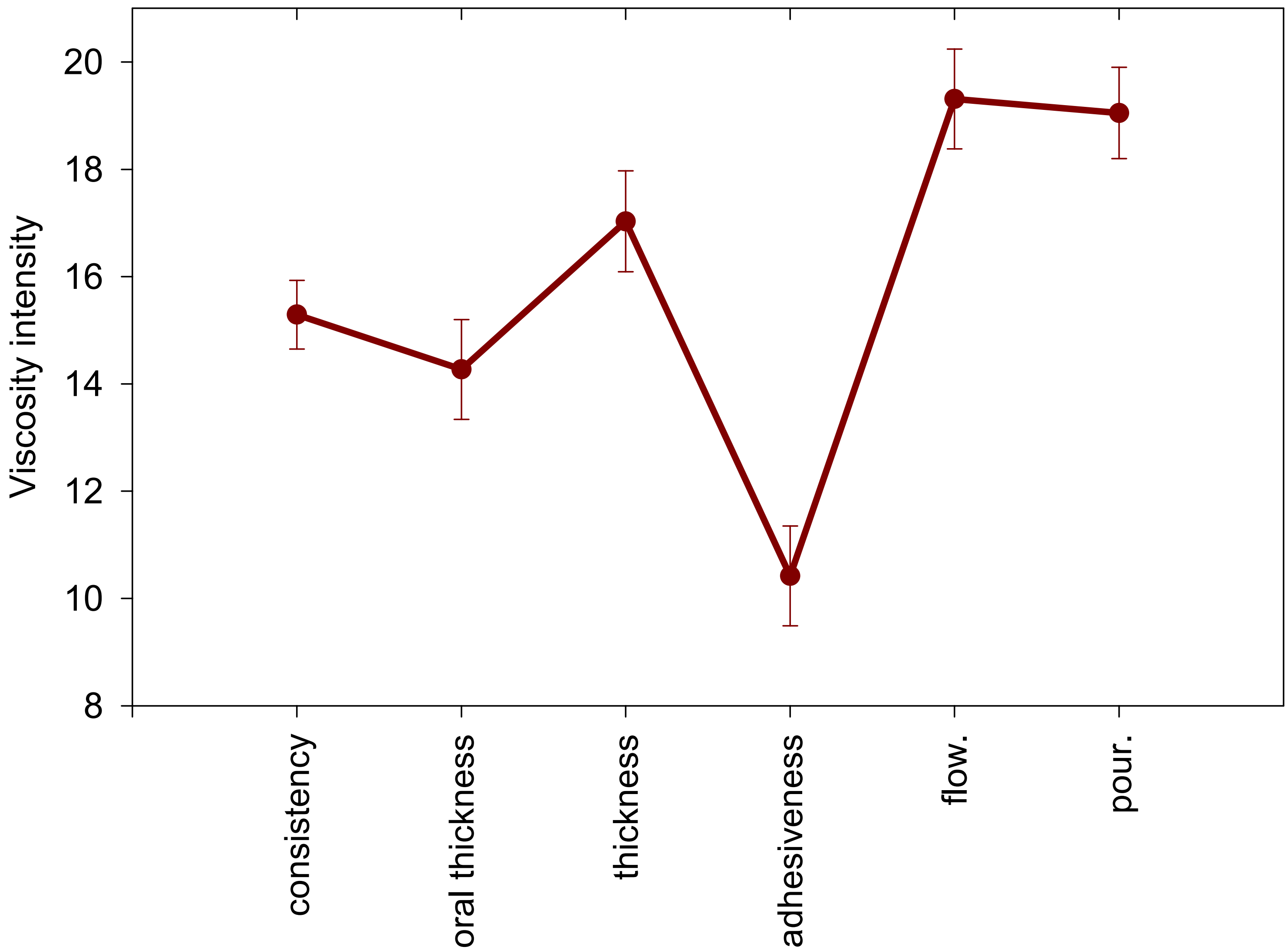

Figure 5: Least squares means for ketchup as a funciton of method of viscosity assessment.

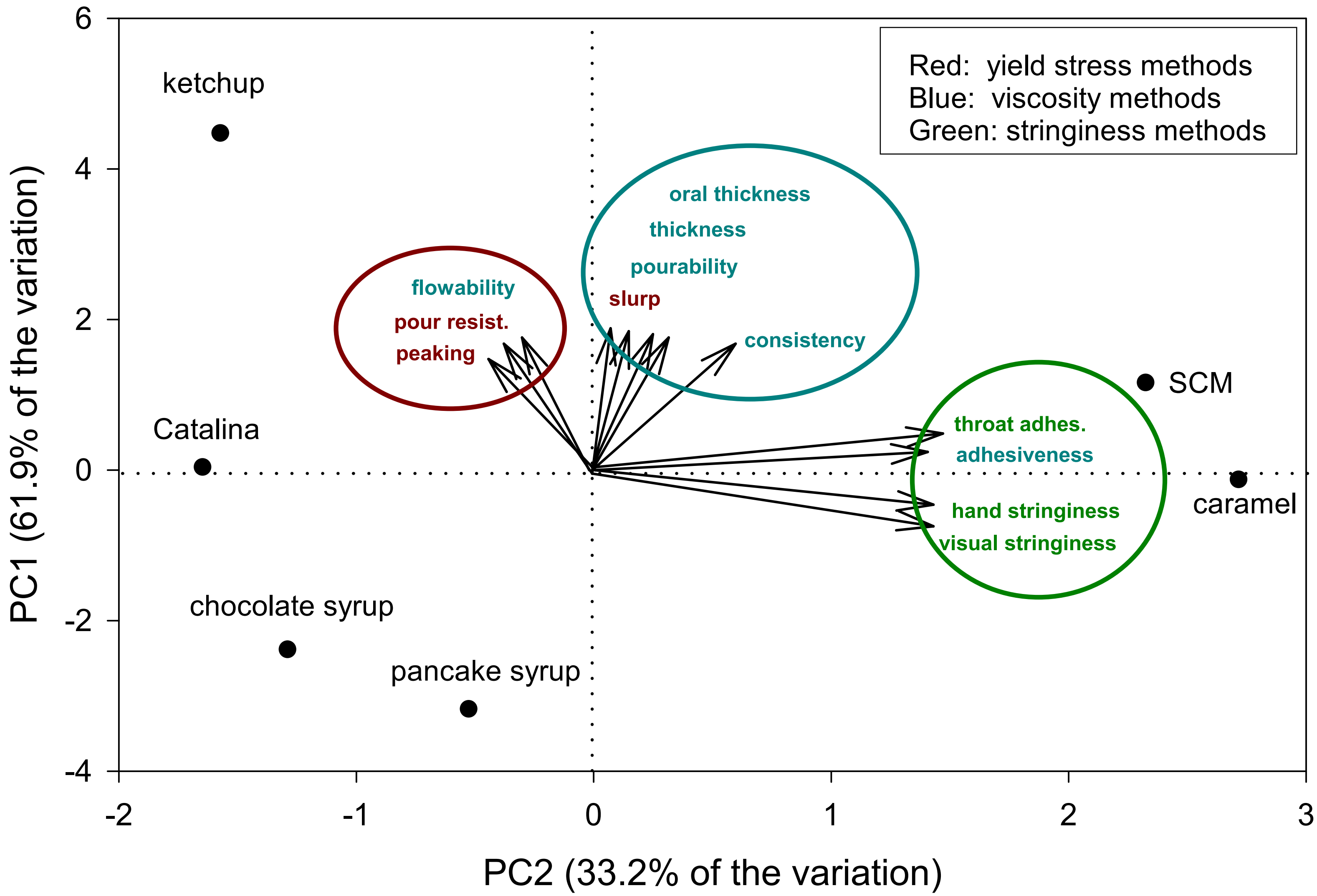

Figure 6: Biplot of sensory methods as a function of sample means.

III

A Texture Profile Analysis for Fluid Foods

ABSTRACT

The relationship between sensory and instrumental texture measurements of fluid foods was studied. From previous research, instrumental as well as sensory analyses identified the most appropriate methods of viscosity, stringiness, and yield stress evaluation. Multivariate analyses showed good correlation between most appropriate methods for instrumental and sensory viscosity ($r = 0.90$), yield stress ($r = 0.96$), and stringiness ($r = 0.78$). Principal component analysis showed differentiation of viscosity, yield stress, and stringiness methods, indicating these properties measured separate textural attributes of fluid foods. Texture maps were created for sensory and instrumental techniques to visually assess the texture profile of fluid foods. The profiling technique showed the texture of fluid foods can be compared based on viscosity, stringiness, and yield stress measurements, concluding that sensory and instrumental methods measured similar textural attributes. This procedure provides a tool to quantify the texture of fluid foods and to understand textural changes based on factors such as processing conditions and ingredient selection.

INTRODUCTION

The International Organization for Standardization defines texture as “all mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile, visual and auditory receptors” (ISO 5492, 1992). Texture clearly ties together several intrinsic attributes, like structure, with a set of human interaction variables, like chewing and handling, to result in a complicated process of many stimuli in combination. Therefore, texture lends itself to both rheological and sensory evaluation. Rheological and sensory tests can be designed to exert several different stresses on a sample, thereby causing a myriad of flow behaviors. As a primary criteria of food quality and acceptability (Bourne, 1982), texture is important. Therefore, perception of food texture is a test by which quality is judged and an important factor when selecting or rejecting products (Rosenthal, 1999).

If texture is a quality tool to govern product acceptability, then instrumentation can be employed to measure specific rheological properties related to texture. These instruments could be useful in quality control or sensory panel settings, where costs associated with human training and assessment are high. However, Bourne (1975) suggested that rheological measurements do not explain the complex aspects of texture experienced by humans. For example, Bourne (1975) stated that a single large deformation, such as a puncture test, results in breaking a sample into several pieces. Although this test may give an indication of hardness or fracturability, an important textural property, it does not define overall texture. When an individual eats food, the sample is chewed beyond the initial fracture point, and the stimulus resulting from mixture with saliva through subsequent bites completes the overall texture perception. Therefore, it is important to understand the relationship between instrumental tests designed to assess a single textural attribute and sensory perception of that attribute.

Relations between Sensory and Instrumental Methods of Fluid Food Texture:

The first consideration of fluid food texture was part of the Texture Profile Analysis (TPA) technique developed by Szczesniak and co-workers (1963). This study considered viscosity as a basic textural attribute. Definitions for oral viscosity were developed along with a set of standard food materials serving as viscosity references for panel training and evaluation. Physical as well as sensory viscosity measurements were taken for each reference food to determine if sensory and instrumental responses were correlated. Szczesniak (1963) found excellent correlation between physical and sensory viscosity for foods on the standard reference scale, therefore it was shown that physical and sensory viscosity evaluation techniques could be related.

After Szczesniak's (1963) important finding, several researchers began to investigate additional variables influencing the relationship between physical and sensory viscosity. Previous research showed shear rate directly affects physical viscosity. Most fluid foods are shear thinning, therefore, an increase in the shear rate causes decreased viscosity. Shama and Sherman (1973), Shama *et al.* (1973), Cutler *et al.* (1983), Christensen (1979), and Houska *et al.* (1997) investigated shear rates associated with oral and non-oral methods of sensory viscosity assessment to show the importance of shear rate selection on the correlation of physical and sensory viscosity.

Other researchers investigated the nature of the sensory and physical viscosity relationship. Christensen (1979) and Cutler *et al.* (1983) determined the relationship between physical viscosity and oral viscosity judgements to be non-linear. Both researchers found the relationship to be a power function. A similar trend was observed in the previous chapter for the relationship between physical and Sensory Spectrum™ viscosity intensities.

Researchers typically investigate relationships between sensory and physical viscosity measuring physical viscosity with rotational viscometers. Shama *et al.* (1973) concluded the sensory method of stirring a sample was analogous to the situation encountered by rotational viscometry. This assumption was based on both methods measuring resistance to flow in similar ways.

The previous chapters established stringiness to be a separate rheological and sensory attribute. The instrumental "S-value" for determining stringiness was pioneered by Henry and Katz (1969) and was used to measure the stringiness of semi-solid foods. The researchers concluded stringiness to be independent of viscosity by showing differentiation in the stringiness of semi-solid foods and hydrocolloids with identical viscosities. Henry *et al.* (1971) applied the "S-value" technique to a variety of commercial desserts with the intent of correlating stringiness with sensory attributes. In this experiment Henry *et al.* (1971) conducted the "S-value" test at 13 mm/min to correlate with an unspecified sensory method of stringiness assessment. The researchers found excellent correlation ($r = 0.90$) between the

"S-value" and the unspecified sensory method, concluding stringiness to be an important textural attribute of desserts.

In previous chapters, yield stress was determined to be an independent rheological and sensory attribute of fluid foods from the lack of interrelation with chosen methods of viscosity and stringiness evaluation. Daubert *et al.* (1998) pointed out possible yield stress problems related to consumer acceptance. For example, if the yield stress of ketchup is too high it will not flow out of the bottle and if the yield stress of salad dressing is too low it will not stay on lettuce. Therefore, understanding the textural relevance of yield stress is important.

Kokini and Dickie (1982) studied the spreadability of commercial foods like butter, jelly, and frosting, because spreadability was hypothesized to be a key textural attribute affecting consumer acceptance. The researchers used sensory and instrumental methods to correlate spreadability with a knife to instrumental assessments of stress. Daubert *et al.* (1998) investigated the vane method as an appropriate tool to assess yield stress measurements as a predictor of spreadability. Daubert *et al.* (1998) concluded that yield stress was related to spreadability, and the vane method was an appropriate tool for the determination of spreadability as a textural parameter.

Objectives:

Most fluid food research has focused on viscosity as the primary attribute contributing to texture. Therefore, the relationship between physical viscosity and sensory measurements has been well characterized. However, Szczesniak (1979) stated that viscosity alone was totally inadequate to describe the textural nuances of beverages. Furthermore, previous chapters concluded that at least two additional rheological properties, yield stress and stringiness, are components of fluid food texture. Therefore, one objective of this study was to understand the relationship between instrumental and sensory method of yield stress and stringiness. Another objective was to develop a visual representation of the overall textural "pattern" of fluid foods based on viscosity, stringiness, and yield stress to understand how specific attributes influence overall texture perception. Finally, the textural "pattern" of individual foods will be compared using maps of instrumental and sensory methods to determine if these separate measurement techniques quantify similar attributes.

MATERIALS AND METHODS

Commercial Samples:

Commercial food samples were chosen to represent a wide range of rheological and textural attributes of interest (table 1). Samples were purchased at a local grocery store in bulk, and the same brands were consistently purchased. All foods were stored at 25°C in an incubator (Percival Scientific model I – 36NL, Perry, IA) until evaluation.

Instrumental Methods:

Three separate instrumental methods were used to measure rheological properties. Rotational coaxial viscometry was used to determine steady shear viscosity, the empirical "S-value" was used to assess stringiness, and the vane attachment on a controlled stress rheometer was used to measure yield stress.

Viscosity:

Viscosity was measured using rotational coaxial viscometry at 25°C with a Stress Tech controlled stress rheometer (ATS Rheosystems, Bordentown, NJ / Rheologica Instruments AB, Lund, Sweden). Three individual replications from each food container were sheared at 25 s^{-1} using a CC 25 couette assembly.

Stringiness "S-value":

The "S-value" empirical stringiness index was performed using methods described by Henry and Katz (1969). This method records the stringiness index by stretching a sample at either 100 mm/min or 25mm/min. This test was conducted by wetting a roughened plastic disc to the surface of the sample, after which the plastic disc was separated from the sample in tension i.e. an upward direction. As the disc separated from the surface, the sample adhered to the disc forming a strand. The sample stretched between the plastic disc until rupture. At that point the test was immediately terminated, and the distance traveled by the plastic disc was recorded as the "S-value" or stringiness of the sample. Tests were completed in triplicate for each sample. Chapter I includes a complete description of the "S-value" materials and methods.

Yield stress:

Yield stress was determined for each sample using the Stress Tech controlled stress rheometer (ATS Rheosystems, Bordentown, NJ / Rheologica Instruments AB, Lund, Sweden) at 25°C with a four-blade vane attachment: 37 mm high, 13.5 mm diameter. Yield stress was determined by subjecting the sample to a stress sweep between 0.1 to 5 Pa. The minimum stress required to initiate flow was recorded as the yield stress. The yield point was selected when the apparent viscosity displayed a sudden decrease. Tests were completed in triplicate for each sample. A complete description of yield stress materials and methods is available in chapter I.

Sensory Methods:

Descriptive analysis was performed by thirteen to eighteen trained panelists using the texture profile method described by Meilgaard *et al.* (1991). Three separate studies were conducted, and each study measured a different textural attribute: viscosity, stringiness, and yield stress. Separate training was completed for each individual textural property. During training, panelists were presented with a variety of foods as well as model systems to define oral and non-oral methods of evaluation. In addition, model systems (see chapter II) were presented at each session to serve as intensity reference material anchors. One or two oral and non-oral methods were selected for each textural property (see chapter II). All samples were presented at 25°C under normal lighting conditions in two-ounce sample cups coded with random three-digit numbers. All experiments were conducted in duplicate.

Data Analyses

All statistical analyses were conducted using SAS (Version 8.1) and JMP (Version 4.0.2) statistical software (SAS Institute, Inc., Cary, NC). Linear correlations (PROC CORR) were carried out to determine relationships between instrumental and sensory tests. In addition, principal component analysis of the standardized responses (PROC PRINCOMP) was performed to visually determine the relationship between instrumental and sensory methods as a function of sample means. Biplots were produced from principal component data using Sigma Plot (Version 5.0, SPSS, Inc., Chicago, IL). In the biplot the first two principal components of the standardized responses were plotted against each other and labeled with the food name. Overlaid on this scatter plot were vectors for each of the method variables. The lengths of these vectors were related to the standard deviations of the original variables and the location reflected the correlations between the response variable and the two principal components. A small angle between a vector and a principal component axis corresponds to the variable being highly correlated with the principal component.

Texture maps based on the “pattern” of viscosity, stringiness, and yield stress intensities were created to visually compare the texture. Two different kinds of texture maps were developed: sensory and standardized instrumental texture maps. Sensory texture maps were created using sensory means of each food for consistency, visual stringiness, and peaking. Standardized instrumental texture maps were created using the relationships developed between sensory intensity and instrumental measurements.

RESULTS AND DISCUSSION

Instrumental Methods:

Chapter I investigated instrumental methods for assessment of rheological properties that may influence fluid food texture. Shear viscosity, imperfect squeezing flow for biaxial extensional viscosity, and an empirical stringiness index ("S-value") were compared at different rates to determine the effect of rate on the measurement. In addition, a vane attachment on a controlled stress rheometer was used to evaluate yield stress. Results indicated that the rate of evaluation significantly impacted rheological measurements. Principal component and correlation analyses identified imperfect squeezing flow for biaxial extensional viscosity to be highly correlated with shear viscosity at each evaluation rate. Therefore, imperfect squeezing flow was considered to be interrelated with shear viscosity, and this method was not considered further.

Chapter I concluded shear viscosity at 25 s^{-1}, the "S-value" at 100mm/min, and yield stress determined with the vane attachment to be the most appropriate rheological methods to assess viscosity, stringiness, and yield stress as separate attributes. These methods were suggested based on the greatest differentiation between principal component analyses, indicating a lack of interrelation.

Sensory Methods:

Chapter II investigated sensory methods to determine viscosity, stringiness, and yield stress as separate textural properties. Trained panelists identified six viscosity, three yield stress, and three stringiness methods of evaluation. Simple model system references were developed to aid in training and during evaluation for each textural attribute.

Results indicated that foods could be differentiated based on oral and non-oral methods for viscosity, yield stress, and stringiness evaluation. One method from each group was selected based on the ability to describe viscosity, stringiness, and yield stress parameters as separate textural attributes. The selected sensory methods (table 2) were consistency to evaluate viscosity, peaking to determine yield stress, and visual stringiness to assess stringiness. These methods were chosen due to the lack of interrelation, indicating their effectiveness of measuring separate aspects of fluid texture.

Relations between Instrumental and Sensory Tests:

Chapter I identified appropriate methods to evaluate viscosity, stringiness, and yield stress as separate rheological attributes. Furthermore, chapter II identified sensory methods to evaluate viscosity, stringiness, and yield stress as separate textural attributes of fluid foods. Until now, the relationship between instrumental and sensory techniques designed to measure similar textural attributes was not explored. Therefore, principal component analysis as a function of sample means was conducted to examine the relationship between instrumental and sensory methods. Principal component analysis (PCA) is a multivariate statistical technique designed to reduce a large number of original variables into subset groupings of variables relatively independent of one another. The analysis is conducted by finding linear combinations accounting for the highest proportion of variation (Tabchnick and Fidell, 1989), and the results display the data to visually assess the related variables.

Figure 1 is a biplot of sensory and instrumental methods chosen for viscosity, stringiness, and yield stress evaluation as a function of food sample means. This figure revealed that a high proportion of the total variation, 94.0%, was explained by linear combinations making up two principal components (PC), 51.2% and 42.8% for PC1 and PC2. Vectors (arrows in figure 1) represented sensory or instrumental methods and the scatter plot (foods in figure 1) represented food samples.

All methods loaded positively on PC 2 at approximately the same value, therefore methods were primarily differentiated by PC 1. Principal component 1 separated methods into three subgroups: the first subgroup (circled red in figure 1) contained yield stress and peaking; the second subgroup (circled blue in figure 1) contained consistency and viscosity; finally, the third subgroup (circled green in figure 1) contained visual stringiness and "S-value." Subgroup differentiation in figure 1, the circled parings, showed sensory and rheological methods were developed to measure fluid food properties beyond shear viscosity.

Viscosity:

Figure 1 indicated the sensory and instrumental methods, consistency and shear viscosity at $25s^{-1}$, were grouped together. Not surprisingly, table 3 shows these methods were highly correlated (r = 0.90). These observations suggested instrumental shear viscosity at 25 s^{-1} was an appropriate method for predicting consistency, the chosen sensory viscosity method. This observation supported two key findings. First, an equation was developed to investigate the relationship between published Sensory Spectrum™ viscosity intensity, generated with a method similar to consistency (Meilgaard *et al.* 1991) and physical viscosity at 25 s^{-1}.

$$\text{Sensory intensity} = 2.0(\eta_{25s^{-1}}\,(\text{mPa s}))^{0.25} \qquad \text{eq.1}$$

This power law relationship was used in chapter II to predict sensory intensity values from physical viscosity measurements at 25 s^{-1} (mPa s) to develop viscosity model systems for sensory training and evaluation. Therefore, in the present experiment the high correlation between physical viscosity at 25 s^{-1} and sensory intensity using the consistency method validated the non-linear relationship between physical viscosity and sensory perception. Secondly, several researchers (Shama and Sherman, 1973; Shama *et al.* 1973; Cutler *et al.* 1983; Christensen 1979; and Houska *et al.* 1997) stressed the importance of shear rate selection for instrumental and sensory correlation. This concern was due to shear dependent behavior (shown in chapter I), and depending on the method of evaluation, sensory methods were most likely conducted over a range of shear rates (shown in chapter II). Therefore, it was important that instrumental and sensory methods be conducted at similar rates. The high correlation (r = 0.90) suggests that physical and sensory viscosity methods were performed within a similar range. In further support, other researchers (Shama and Sherman, 1973) also concluded similar ranges of rates for oral perception of viscosity.

Stringiness:

Henry *et al.* (1971) showed high correlation (r = 0.90) between the “S-value” at 13 mm/min and an unspecified sensory stringiness test. However, Henry *et al.* (1973) did not comment on the specific nature of the relationship between the “S-value” and sensory intensity. Therefore, due to a lack of data, time, and experience it was speculated sensory and instrumental stringiness shared the following relationship

$$\text{“S-value” (mm)} = \text{Sensory stringiness intensity} \qquad \text{eq. 2}$$

In chapter II model systems were developed for sensory training and sample evaluation to encompass the stringiness range of foods. Model systems were created based on the linear relationship between sensory stringiness intensity and the “S-value” (eq. 2). Previous research on the “S-value” method (Henry and Katz , 1969) suggested the “S-value” be conducted at 25 mm/min because this rate produced the greatest precision. Therefore, the “S-value” was conducted at 25mm/min to determine stringiness intensity for all foods and model systems assuming this testing rate would be the most precise as well a highly correlated with sensory results. However, table 3 indicated “S-value” at 100mm/min to be better correlated (r = 0.78) with visual stringiness intensity than the “S-value” at 25 mm/min (r = 0.37). This response suggested visual stringiness was conducted at an evaluation rate closer to 100mm/min than 25mm/min. Also, chapter I supported the result that stringiness was better differentiated at higher evaluation rates.

Yield Stress:

According to table 3, instrumental yield stress and the sensory peaking method were highly correlated (r = 0.96). This find was not surprising because model systems given to panelists for yield stress training and evaluation were prepared from the relationship between physical yield stress and a visual assessment procedure used by Meilgaard *et al.* (1991) to evaluate the yield point of lotions and creams. The following equation

$$\text{Visual sensory yield stress intensity} = 2\sqrt{\text{yield stress (Pa)}} \qquad \text{eq. 3}$$

indicated the relationship between physical yield stress and visual sensory yield stress intensity was non-linear. The high correlation between peaking and yield stress supported the relationship in equation 3.

Mapping the Textural "Shape" of Fluid Foods:

Chapters I and II showed viscosity, stringiness, and yield stress were separate components of fluid foods that could be measured with specific instrumental and sensory techniques. In addition, the present experiment showed instrumental and sensory methods designed to measure viscosity, stringiness, and yield stress were well correlated. Therefore, a texture map for fluid foods was created based on instrumental as well as sensory methods for viscosity, stringiness, and yield stress. A texture map is a visual representation of the texture of fluid foods, and in this case was based on viscosity, stringiness, and yield stress. These maps may not represent the overall texture of fluid foods, as there are other properties contributing to overall texture. However, the map helps illustrate and quantify fluid food texture.

Figure 2 represents texture maps for foods in this experiment. The relative textural "pattern" of a fluid is defined as the sensory or standardized instrumental mean on three axes. A sensory texture map contains the sensory methods consistency, visual stringiness, and peaking on the axes; and the instrumental texture map contains standardized instrumental means for viscosity, stringiness, and yield stress on the axes. Table 3 indicates values used to create sensory and standardized instrumental texture maps.

Table 4 shows the sensory and standardized instrumental texture maps were prepared using the suggested instrumental and sensory tests for viscosity, stringiness, and yield stress. The only exception was the "S-value" axis. The "S-value" axis was created with the "S-value" measured at 25mm/min, rather than the recommended 100mm/min. The lower rate was used to assign model system intensities as suggested by Henry and Katz (1969). Therefore, visual stringiness intensities were based on the assumed linear relationship between the "S-value" at 25mm/min and sensory stringiness intensity (eq. 2).

Figure 2 reveals that most sensory and standardized instrumental texture maps had similar patterns, in both size and shape. Visual comparison of the texture maps showed most foods had the same general texture "pattern." This observation suggests that sensory and instrumental techniques designed to evaluate viscosity, stringiness, and yield stress were measuring similar attributes. The similarity in shape and size between sensory and standardized instrumental maps was supported by the correlations found in table 2. The similarity of the texture maps for sensory and instrumental methods was especially obvious for caramel topping, sweetened condensed milk, pancake syrup, and chocolate syrup. However, for ketchup and Catalina salad dressing visual stringiness and the "S-value" had the least amount of correspondence. For both foods, the "S-value" recorded a higher stringiness value than visual stringiness. This result suggests the "S-value" was more sensitive at detecting the stringiness of ketchup and Catalina salad dressing than the visual stringiness method.

In addition to comparisons between sensory and standardized instrumental texture maps, figure 2 shows texture maps can be used for visual comparison between foods. Texture "patterns" can be compared to determine similarity and differences in texture. For example, the sensory map of caramel topping (figure 2a) was different than the sensory map of ketchup (figure 2b). The texture of caramel topping can be described as stringier and less viscous than ketchup, however ketchup had a higher yield stress than caramel topping.

Despite good overall agreement in the general shape between sensory and standardized instrumental texture maps for most foods, these maps can be improved. The present experiment shows the correlation between visual stringiness and “S-value” at 100mm/mm to be much better than the “S-value” at 25mm/mm (table 3). Therefore, the relationship between the “S-value” and visual stringiness would be improved if model systems were created at the 100mm/min.

CONCLUSIONS

The relationship between methods to quantify viscosity, stringiness, and yield stress as separate rheological as well as separate sensory properties of fluid foods was investigated. Rheological and sensory methods were highly correlated suggesting both techniques measured similar attributes of texture. This correlation for viscosity supported findings by other researchers, however the correlations between rheology and sensory methods for stringiness and yield stress suggest these properties contribute to the texture of fluid foods. A visual representation of the influence of viscosity, stringiness, and yield stress on fluid food texture was created and called a texture map. These maps can be used to compare the textural "pattern" of different foods and to visually compare sensory and rheological methods. Applications of this texture profiling technique provide a fundamental approach for fluid food texture comparisons.

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Table 1: Commercial food samples

Sample	Brand	Abbreviation
Ketchup	Heinz	Ketchup
Sweetened condensed milk	Eagle®	SCM
Caramel topping	Smuckers®	caramel
Chocolate syrup	Hershey's®	choc. syrup
Catalina salad dressing	Kraft®	Catalina
Pancake syrup	Aunt Jemima®	pan. syrup

Table 2: Methods chosen for sensory evaluation of viscosity, stringiness, and yield stress.

Textural property measured	**Panel term**	**Definition**	**Assessment method**	**Anchor Descriptors**
Viscosity	Consistency	Force required to slurp the sample off a spoon	Oral	thin -- thick
Stringiness	Visual stringiness	Degree of stringiness from pouring off a teaspoon	Non-oral	low string -high string
Yield stress	Peaking	Degree of peaking on the back of a teaspoon	Non-oral	no peaks - stiff peaks

Table 3: Sensory and instrumental correlations

	Consistency	**Peaking**	**"S-value"$_{25\ mm/min}$**	**"S-value"$_{100\ mm/min}$**	**Viscosity$_{25\ 1/s}$**	**Yield stress**
Visual stringiness	0.12	-0.47	0.37	**0.78**	0.18	-0.62
Consistency		**0.79**	0.37	0.37	**0.90**	0.63
Peaking			-0.01	-0.19	0.64	**0.96**
"S-value"$_{25\ mm/min}$				**0.85**	0.64	-0.22
"S-value"$_{100\ mm/min}$					0.59	-0.41
Viscosity$_{25\ 1/s}$						0.44

Table 4: Values used to create texture maps

	Standardized instrumental values ± stdev			Sensory Intensity ± stdev		
	Viscosity*	**"S-test"****	**Yield stress*****	**Consistency**	**Visual Stringiness**	**Peaking**
ketchup	15.1 ± 1.3	7.5 ± 0.6	7.8 ± 0.2	15.3 ± 1.6	3.1 ± 2.2	6.7± 0.7
chocolate syrup	11.0 ± 2.2	8.9 ± 1.5	1.7 ± 0.9	9.3 ± 2.0	7.2 ± 2.3	1.5 ± 0.7
Catalina	13.4 ± 2.4	10.6 ± 1.1	3.0 ± 0.9	11.9 ± 1.7	4.2 ± 2.2	2.5 ± 0.7
pancake syrup	10.1 ± 1.1	5.6 ± 2.3	0.6 ± 0.2	9.3 ± 2.4	7.2 ± 2.2	1.2 ± 0.7
caramel	13.9 ± 1.9	9.3 ± 0.5	1.6 ± 0.6	13.1 ± 1.9	12.7± 2.2	2.2 ± 0.7
SCM	16.0 ± 1.2	12.6 ± 1.8	2.4 ± 0.5	14.5 ± 2.2	11.1 ± 2.2	3.0 ± 0.7

* measured at 25 s^{-1}, calculated using eq. 1
** measured at 25 mm/min
*** calculated using eq. 3

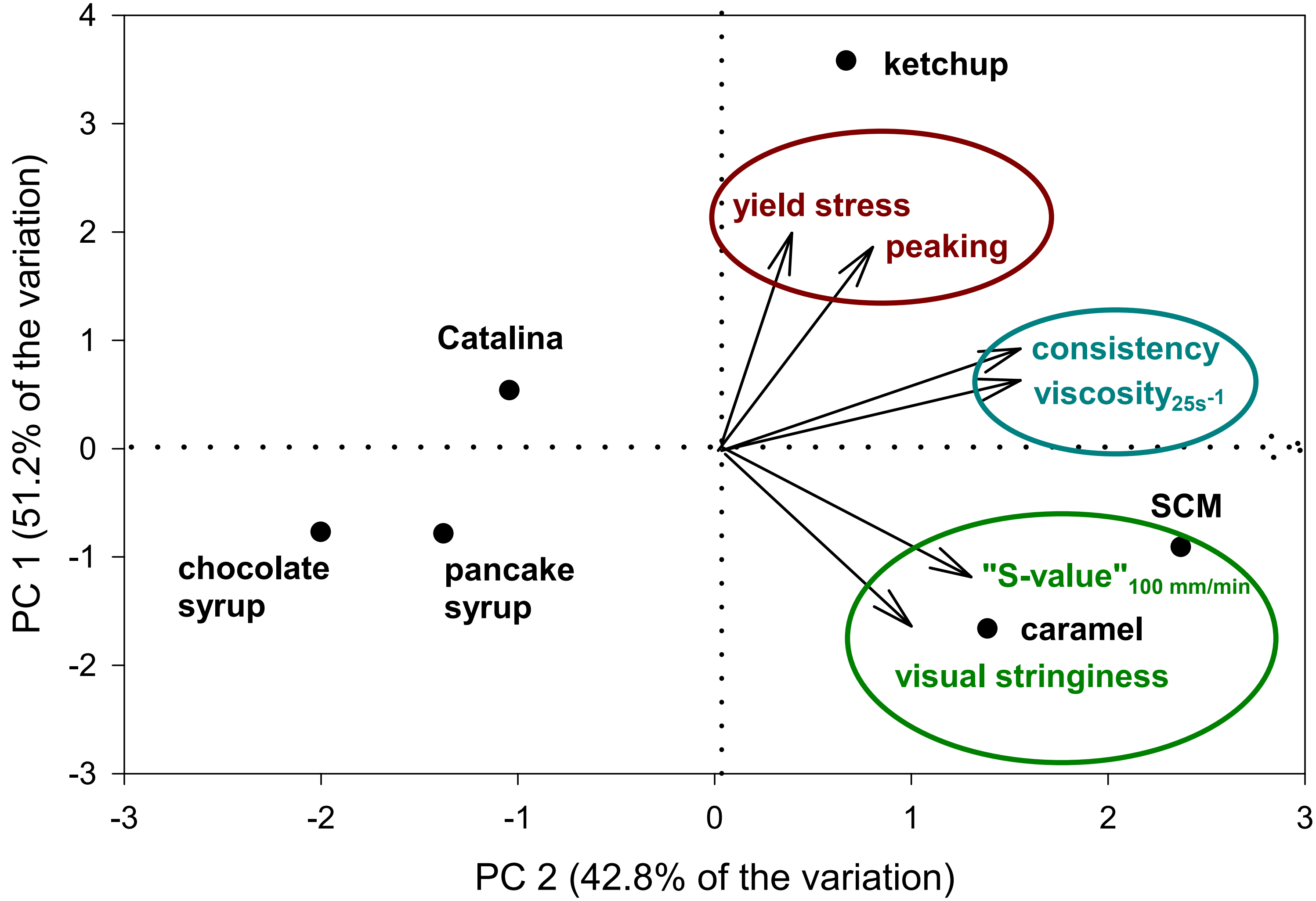
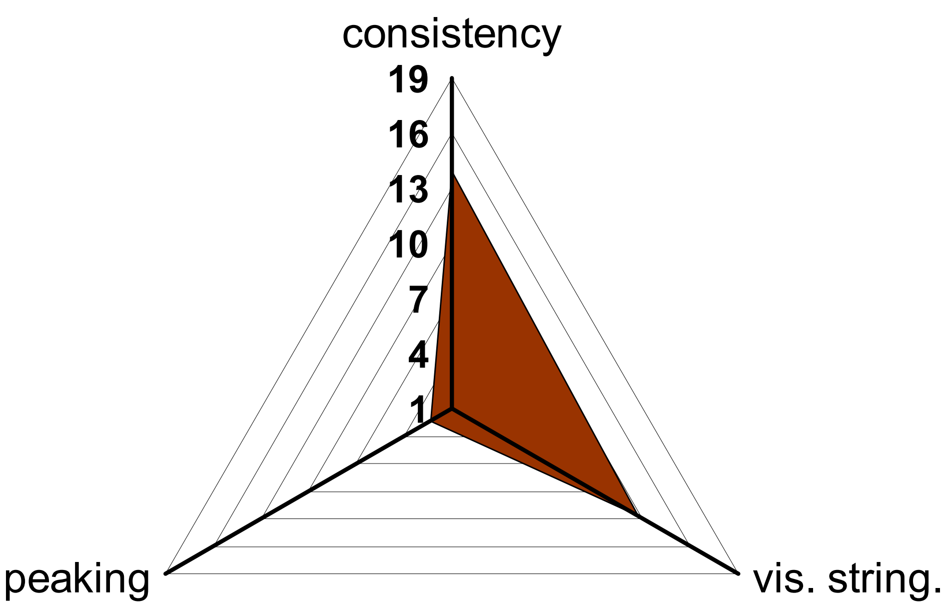


Figure 1: Biplot of sensory and instrumental methods as a function of sample means

Figure 2a: Sensory and standardized instrumental texture map of caramel topping.

Sensory texture map



Standardized Instrumental texture map

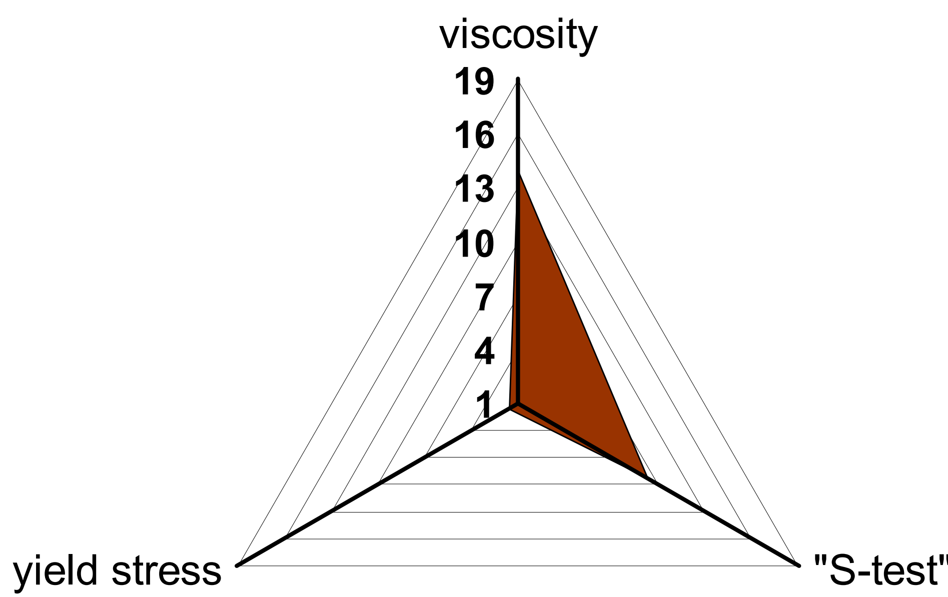
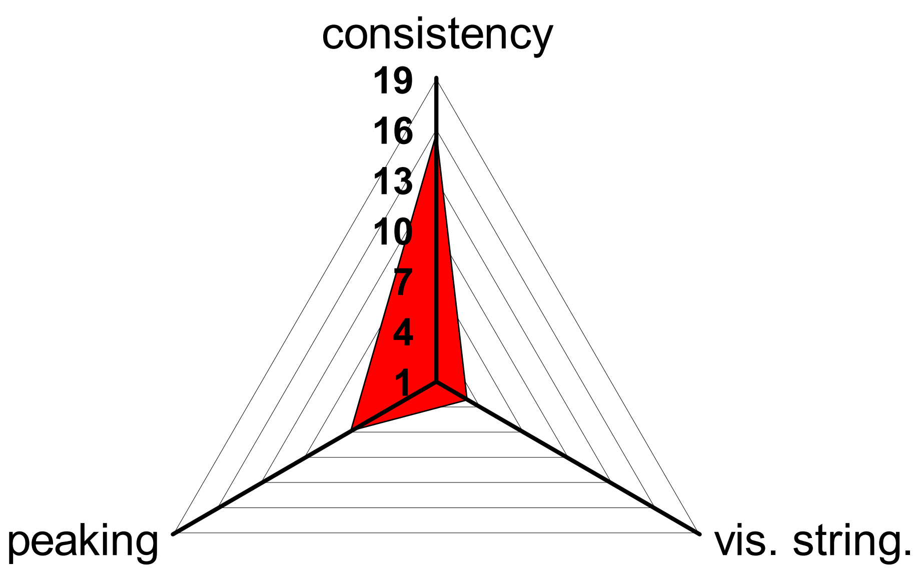


Figure 2b: Sensory and standardized instrumental texture maps for ketchup.

<u>Sensory texture map</u>



<u>Standardized Instrumental texture map</u>

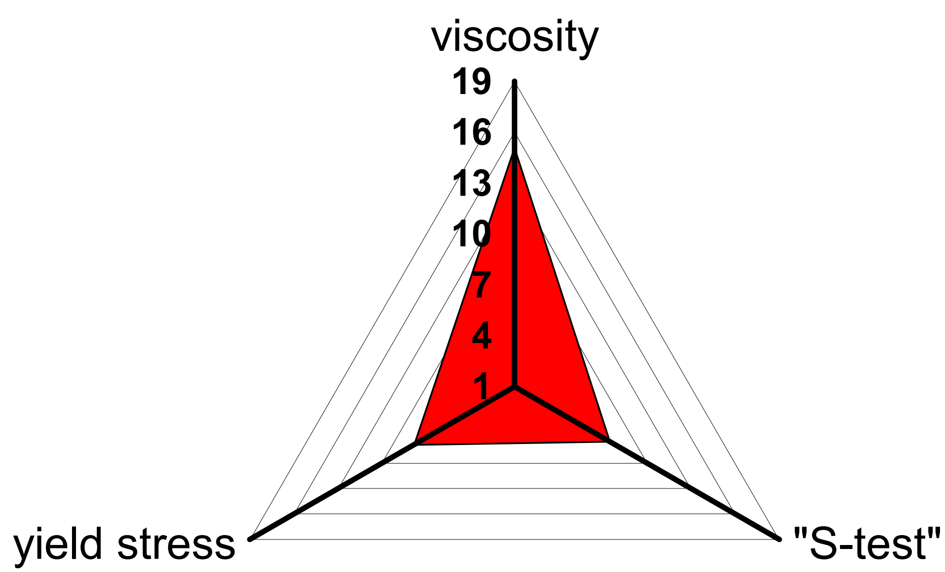
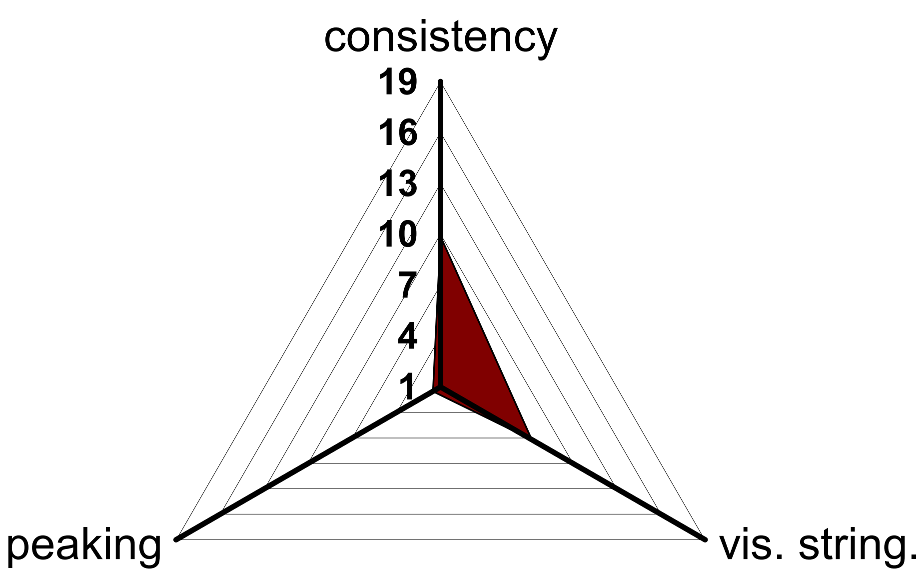


Figure 2c: Sensory and standardized instrumental texture map for chocolate syrup.

Sensory texture map



Standardized Instrumental texture map

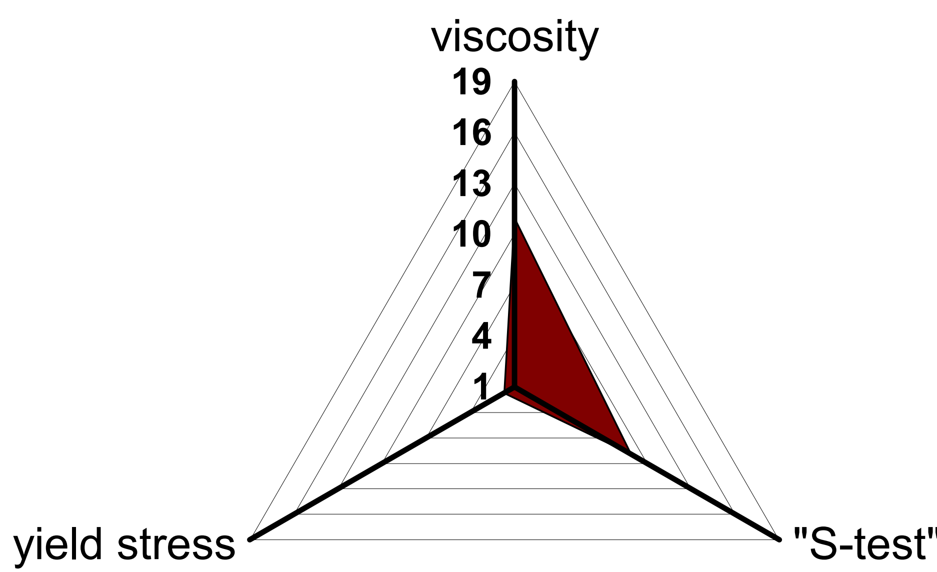
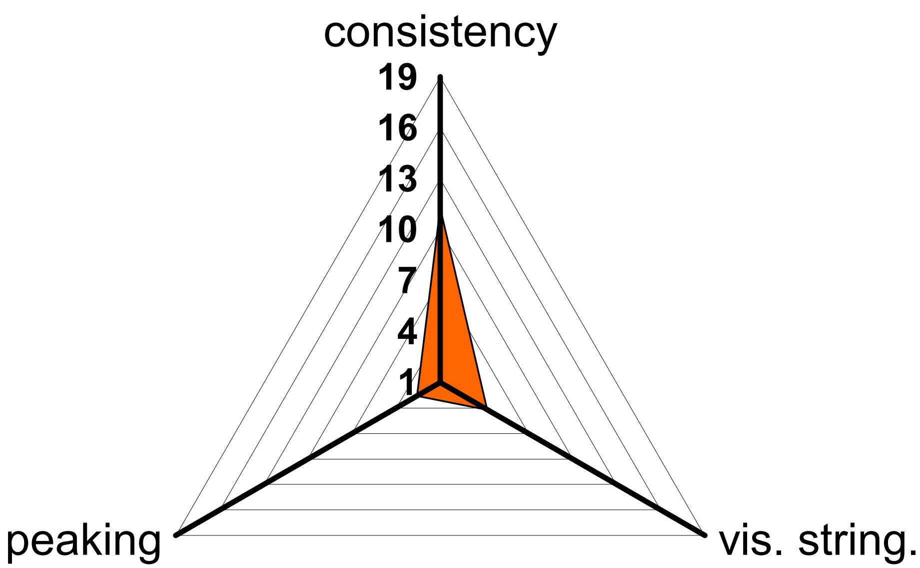


Figure 2d: Sensory and standardized instrumental texture map for Catalina salad dressing

<u>Sensory texture map</u>



<u>Standardized Instrumental texture map</u>

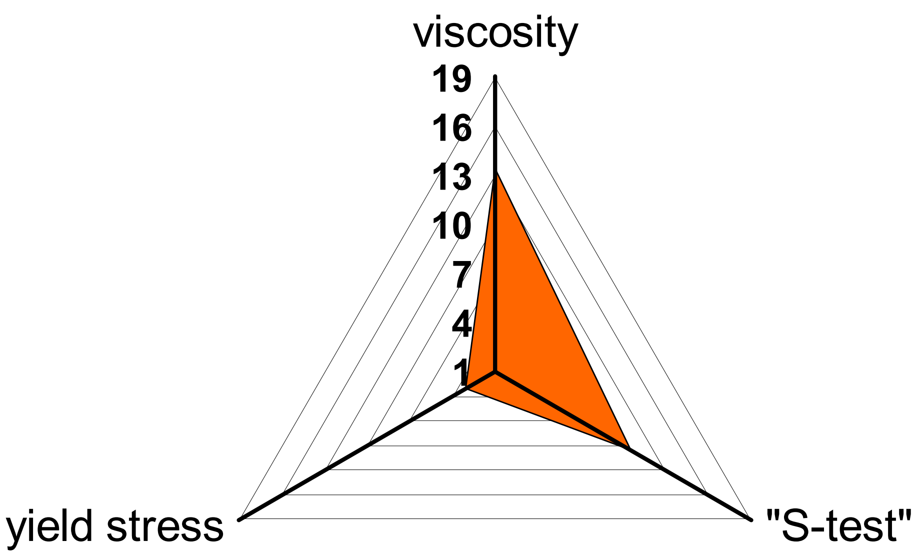


Figure 2e: Sensory and standardized instrumental texture map for pancake syrup.

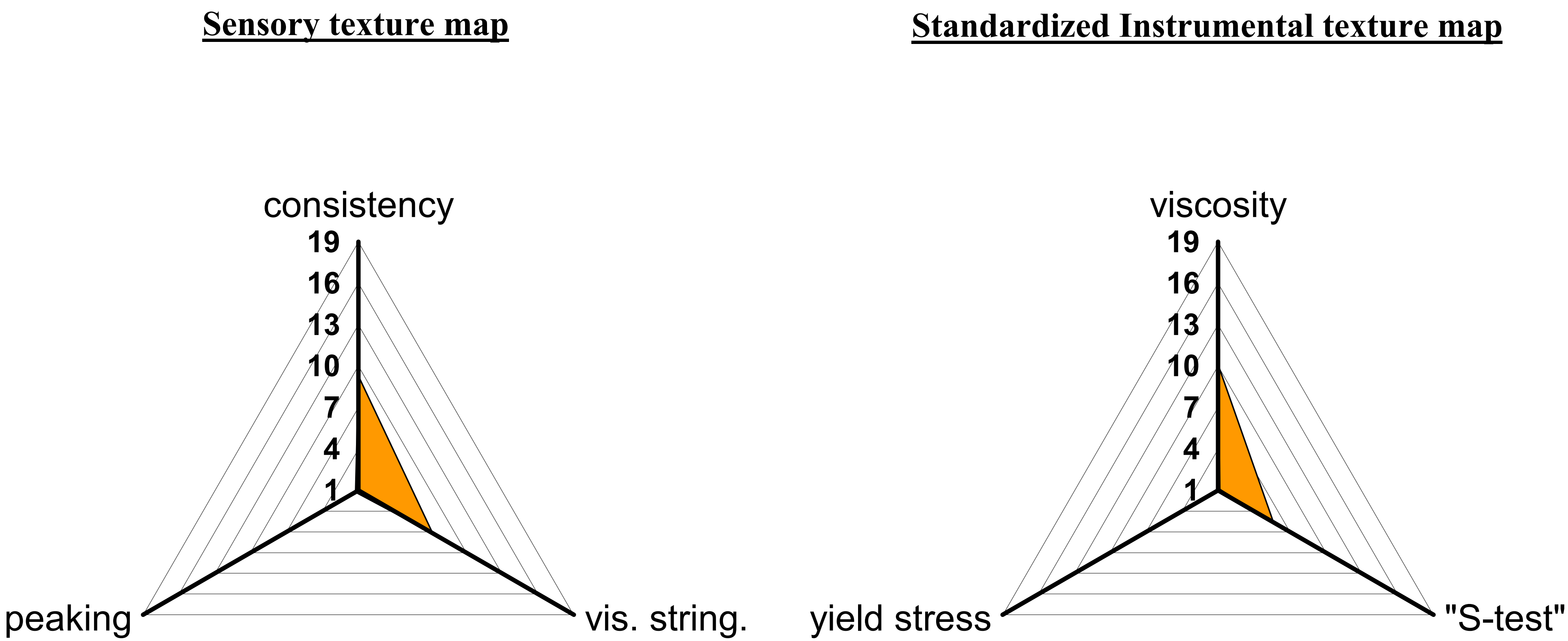
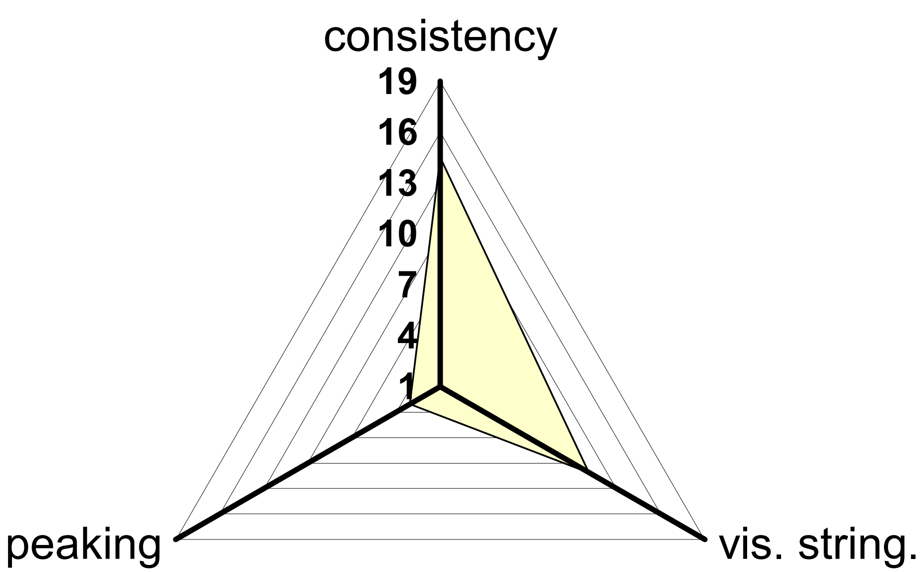
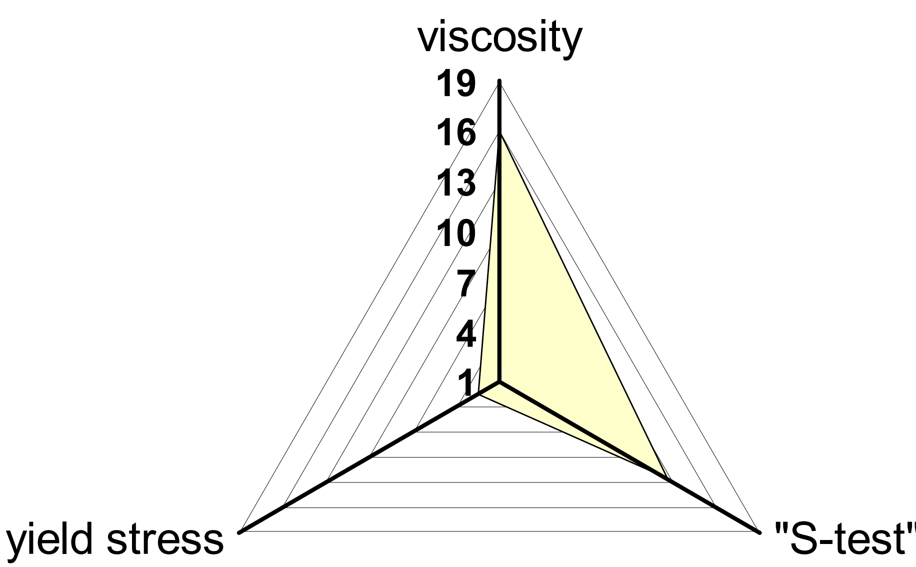


Figure 2f: Sensory and standardized instrumental texture maps for sweetened condensed milk.

Sensory texture map



Standardized Instrumental texture map



IV

Summary

SUMMARY

Past research on fluid food texture has primarily focused on viscosity. However, fluids possess a myriad of flow behaviors depending on intrinsic material properties and the type of applied stress. Therefore, instrumental methods were selected to identify rheological properties, in addition to viscosity, as potential contributors to fluid food texture. Instrumental techniques included rotational viscometry, imperfect squeezing flow for biaxial extensional viscosity, an empirical stringiness index, and a vane attachment to determine yield stress. The results produced an instrumental protocol to evaluate stringiness and yield stress, in addition to viscosity, as separate rheological attributes that may be important to fluid food texture.

Sensory methods including terminology, definitions, and reference materials for viscosity have been well characterized, therefore, there was a desire to develop sensory methods to quantify additional rheological properties. The results yielded specific sensory methods as well as model systems to quantify viscosity, stringiness, and yield stress intensities for fluid foods, as well as identifying these properties as individual textural attributes.

Texture lends itself to both rheological and sensory studies. An understanding of the relationships between these techniques is necessary to determine if both methods measure similar textural attributes. Therefore, a greater understanding of the relationship between instrumental and sensory methods was desired. In addition, there was a need to visually

compare the textural “pattern” of fluid foods to examine the effects of viscosity, stringiness, and yield stress on texture. Results showed good correlation between instrumental and sensory methods indicating these methods evaluated similar attributes. In addition texture maps were developed to visually compare the similarity and differences in the textural “pattern” of fluid foods based on sensory and instrumental methods. The development of texture maps facilitated textural comparisons between fluid foods as well as comparisons between sensory and instrumental methods.

SUGGESTED RESEARCH

Further research should be conducted to investigate the relationship between stringiness intensity and the "S-value". In the present experiments, this relationship was assumed to be linear, however Stevens' power law suggested the relationship between physical stimulus and sensory intensity to be non-linear. An accurate relationship between physical stringiness and sensory intensity could aid in the development of model systems used for panel training and evaluation as well as for the prediction of sensory intensity from instrumental measurements.

In the present experiments, an empirical index was used to quantify the stringiness of fluid foods. Stringiness is the perception of extensional flow behavior, which results in extensional viscosity. Extensional viscosity is a fundamental rheological property and there are several fundamental methods available for extensional viscosity measurement. Further research should be conducted to investigate if fundamental rheological methods such as fiber spinning, opposing jet, or entrance flow can describe extensional viscosity as a textural attribute of fluid foods.

Finally, fluid food flow behavior is not limited to the rheological properties examined in the present experiment. Additional material properties besides viscosity, stringiness, and yield stress may also contribute to fluid texture. These material properties include viscoelastic behaviors as well as physical properties like surface tension. These material functions may result in flow behaviors that influence the overall texture of fluid foods.