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RHEOLOGY AND SENSORY ANALYSIS OF HOT CEREALS

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ABSTRACT

RHEOLOGY AND SENSORY ANALYSIS OF HOT CEREALS

By

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The vane method was used to determine the rheological behavior of hot cereals. Five cereals were evaluated: Nabisco 2 ½ Minute Cream of Wheat (COW), Nabisco Instant Original Cream of Wheat (ICOW), Malt-o-Meal Co. Malt-o-Meal (MOM), Quaker Oats Co. Quick One Minute Quaker Oats (1MIN), and Quaker Oats Co. Instant Regular Oatmeal (IOAT). The apparent yield stress of the prepared cereals was calculated using the vane method from raw data collected with a low speed rotational viscometer. The effects of time (3 to 20 minutes) and cooling on the apparent yield stress were observed. As time (hydration time) increased and temperature decreased, the apparent yield stress of each cereal increased. A descriptive analysis panel was used to generate scores relating to four sensory parameters: thickness (stirrability), stickiness to spoon, stickiness to self, and viscosity. The sensory scores were compared to the apparent yield stress values. Through regression analysis, it was determined that there is no correlation between any of the sensory parameters and the instrumentally obtained apparent yield stress values for any of the cereals, at any of the hold times studied. The apparent yield stress method is, however, an effective technique for evaluating and comparing the rheology of hot cereals.

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1. Introduction

Rheological properties of food materials have significant impact on consumer acceptance of the particular product. Consumers make judgments about products based on sensory perceptions. "Texture and mouthfeel are major determinants of consumer acceptance and preference for foods and beverages" (Guinard and Mazzucchelli 1996). Consumers may not like chewy steak, mushy apples, or pasty oatmeal. All of these problems involve the texture of the food. To monitor and evaluate issues such as these, it is first necessary to define the problem.

The definition of texture varies depending on the source. Szczesniak (1963) published an article discussing this issue in which eight different definitions for the term "texture" were enumerated. Two key elements were distilled from the plethora of ideas: physical structure and mouthfeel (Szczesniak 1963). From this she created a method of classification for texture where characteristics are divided into three categories: 1) mechanical characteristics, 2) geometrical characteristics, and 3) other characteristics (relating to moisture and fat content). Mechanical characteristics refer to the reaction of food to stress, such as the stress of mastication. These characteristics can be described by the terms "hardness, cohesiveness, viscosity, elasticity, adhesiveness, brittleness, chewiness, and gumminess." Geometrical characteristics are most often observed visually in the arrangement of the constituents of the food. They can be divided into two groups: qualities related to particle size and shape, and qualities related to shape and orientation. "Other" characteristics involve mouthfeel and other factors that do not fit into the first two classes, such as oiliness and greasiness. This expanded definition of texture lends itself to both instrumental and sensory evaluation of food. The next step after defining the parameter is to measure texture parameters of food. This can be done quantitatively through instrumental methods.

Several instrumental methods exist to characterize food texture. The method used depends upon the parameters that one desires to explore. The parameter of interest to this thesis is yield stress (σ_o). Yield stress is defined as the maximum shear stress required to initiate flow (Steffe 1996). One simple way to measure yield stress is by the vane method. Using a vane and sample cup of correct proportions, the vane is lowered into the sample and rotated at very low speed. The torque on the spindle is measured, and a yield stress is reached at the maximum torque recorded before initiation of flow.

Texture perceptions in food are too complex to evaluate simply by instrumental means. To give meaning to the objective measurements, they must be related to sensory evaluation. Sensory data can be collected using a descriptive analysis panel, however; sensory panels are often time consuming and expensive. Hence, industry would prefer to use instruments that are simple and generate reproducible results. Understanding the relationship between texture of food and sensory perception allows growth in several areas of food science including product development, process engineering, and quality control.

One segment of the food industry that could benefit from characterization of texture by instrumental and descriptive analysis is the hot cereals area. Currently, companies use only subjective techniques to evaluate the flow behavior of this product. A simple quantitative method that correlates to sensory parameters is needed. In response to this need, three objectives were formulated for the current research:

1) Develop experimental protocol to characterize flow behavior of hot cereals using the vane method to measure a yield stress parameter;
2) Evaluate the sensory characteristics of hot cereals with a trained panel using descriptive analysis;
3) Evaluate the relationship between instrumental measures of yield stress and sensory evaluation data.

2. Literature Review

2.1. Breakfast Cereals

Hot cereals are often forgotten at the breakfast table while the more convenient cold, or ready-to-eat (RTE) cereals are preferred. However, as an alternative to breakfast foods other than RTE cereal, hot cereals are an inexpensive option that are undeniably a force in the market. Table 2.1 shows the annual trends in consumption of hot cereal between 1995-1998. Traditional grains used for hot cereals are wheat, rice, corn, oats, and barley. The hot cereals of interest to the current work are oatmeal and wheat-based, farina products.

Table 2.1*: US Sales by Calendar Year of All Hot Cereals (Excluding Corn Grits)[a,b]

Product	1995	1996	1997	1998
Total hot cereals	347 (100.0%)	358	373	357 (100.0%)
Total hot oatmeal	271 (78.1%)	286	303	293 (82.1%)
Total hot other[c]	76 (21.8%)	72	70	65 (18.2%)
Total standard (non-instant) hot cereals	234 (67.4%)	232	239	225 (63.0%)
Total standard oatmeal	170 (49.0%)	180	190	180 (50.4%)
Total old-fashioned rolled oats	57 (16.4%)	64	69	66 (18.5%)
Total quick oatmeal	105 (30.2%)	114	116	109 (30.5%)
Total instant hot cereal	113 (32.6%)	126	134	132 (37.0%)
Total instant oatmeal	101 (29.1%)	106	113	112 (31.4%)
Total instant non-oatmeal	12 (3.5%)	20	21	20 (5.6%)

*Taken from Caldwell *et al.* 2000.
[a]A.C. Neilsen data courtesy of The Quaker Oats Co.
[b]Data (other than %) are in millions of pounds (1.0 million lb = 453,600 kg).
[c]Primarily wheat-based, farina products.

2.1.1. Oat-Based Cereals

Ninety-five percent of oat crops are used for animal feed, but the remainder is consumed by humans (Caldwell 1973). Before the oats reach the breakfast table, they are processed to shorten the amount of cooking time required for preparation. The treatment of oats involves chemical methods that modify the oat starch for rapid gelatinization, and/or physical methods that involve grinding, heat treatment, or addition of gums to improve hydration and dispersability of fine particles (Daniels 1974).

The basic process for preparing oatmeal is described in the following section. Whole oats are received, then separated and cleaned to remove trash, weeds, chaff, and dust. Oats are then hulled, typically by an impact huller, which uses centrifugal force to cause oats to strike the wall of the huller. The impact causes the groat to separate from the hull. Groat is composed of starchy endosperm, and makes up 50-55% of the whole oat. After hulling, the groats may be pearled or scoured, then dried and conditioned with heat to inactivate enzymes that may cause rancidity. The groats are sized next: the largest are used to make old-fashioned rolled oats. Remaining groats are cut into three to five pieces with a process called steel-cutting. Steel-cutting creates smaller pieces that hydrate more rapidly, without creating a lot of fine flour that would lead to a pasty hydrated product (Caldwell 2000).

Three types of products arise from oat processing: old-fashioned rolled oats, quick oatmeal, and instant oatmeal. In making old-fashioned rolled oats, the whole (uncut) groats are steamed to a moisture content of 10-12%. They are then flaked on flaking rolls, and dried and cooled for the final product. Quick oatmeal undergoes the same treatment, however the starting material is steel-cut groats, which are then rolled thinner than the old-fashioned rolled oats. For instant oatmeal, steel-cut groats are used again and the flakes are thinner yet. The groats are also exposed to additional heat treatment that pregelatinizes the starch. A hydrocolloid gum is usually added to improve hydration of the instant cereal (Caldwell 2000).

Several methods were patented in the past forty years for the optimized process of making oatmeal for hot cereal. In 1961, Quaker Oats Co. patented the use of edible polysaccharide gums, which are dry mixed into the rolled oats. Upon addition of boiling water, the gums hydrate rapidly and form gelatinous films on the oat flakes (Huffman and Moore 1961). In 1970, Tressler developed a treatment that reduced the cooking time of oats from ten to twelve minutes down to thirty to forty seconds. After the oats are rolled, they are exposed to two treatments that crack the flakes to form internal capillaries that rapidly absorb boiling water (Tressler 1970). The two treatments are: 1) a dry heat treatment, ideally 300°F for ten to eighteen minutes, to remove the "raw" flavor and to make the flakes highly absorptive, and 2) placing the flakes under high pressure to produce thin, small flakes that also absorb water more rapidly. The pressure should be sufficient to flatten the flakes to half their original thickness (Tressler 1970). Also in 1970, National Oats Co., Inc. patented the use of slow-coating starches such as potato, tapioca, wheat, corn, and waxy-maize to permit boiling water to complete the gelatinization of the flakes while providing a coating which gives uniform texture and flavor to cooked oatmeal (Hanser and Martin 1970). In 1972, Nabisco, Inc. obtained three patents: addition of cereal hydrolysate, addition of oat fractions, and addition of pregelatinized starch. These patents decrease hydration time of the oatmeal (Ronai and Spanier 1972a, 1972b, 1972c).

2.1.2. Wheat-Based Cereals

Wheat, or farina-based hot cereals are second in popularity to oatmeal. Farina is defined in the United States Federal Code of Federal Regulations (1999) as:

> "(a) Farina is the food prepared by grinding and bolting cleaned wheat, other than durum wheat and red durum wheat, to such fineness that, when tested by the method prescribed in paragraph (b)

> (2) of this section, it passes through a No. 20 sieve [0.850mm openings], but not more than 3 percent passes through a No. 100 sieve [0.150mm openings]. It is freed from bran coat, or bran coat and germ, to such extent that the percent of ash therein, calculated to a moisture-free basis, is not more than 0.6 percent. Its moisture content is not more than 15 percent."

In short, farina is wheat endosperm in granular form (Caldwell 2000). Farina comes from hard wheat, typically hard red spring or winter wheats. The endosperm of soft wheats disintegrates in hot water and would lead to a pasty and unacceptable cereal.

During the milling of wheat, the first stream off the mill is the hard chunk of endosperm. This is referred to as the middling stream, and constitutes farina, which hydrates in boiling water. Instant farina products mirror the process for instant oatmeal. The whole wheat middling is saturated with water, pressure-cooked, flaked on flaking rolls, and dried.

The process is constantly being optimized to create an instant farina with the same texture as the whole farina (Caldwell 2000). In the 1930's and 1940's, Cream of Wheat Corporation found that addition of disodium phosphate and pepsin reduced the cooking time of whole farina (Caldwell 2000). Cantor *et al.*, in 1959, obtained a patent to incorporate a gum or a thickening agent into the cereal. Gums such as arabic, karaya, guar, and tragacanth decrease the amount of water needed by one third, and cut hydration time down from three minutes to thirty seconds. The added agents help suspend the farina particles in the hot water to increase the surface area available for hydration and gelatinization. In 1970, The Quaker Oats Co. patented a heat treatment process to denature wheat proteins in farina (Hyldon 1970). A year later, Ralston Purina patented a process for instant wheat cereal in which milled wheat was tempered at 85-104.4°C to a moisture content of 15-16% before being flaked in rolls to 0.007-0.008 inch thickness.

Once the flakes are dried to 8-9% moisture, they rehydrate instantly in boiling water (Spring, Jr. 1971). Nabisco Brands, Inc. patented technology for the process of preparing instant, flaked wheat farina. The process includes mixing farina and guar gum, adding water and then tempering with agitation. The mix is then cooked at 110-120°C to gelatinize the starch before it is dried, tempered, and flaked (Karwowski 1985, 1986, 1987).

2.2. Starch

The primary component of hot cereals is starch. Starch is the major stored form of carbohydrates in plants. In cereal grains in particular, the endosperm of the kernel contains most of the starch (Shannon and Garwood 1984), which is stored as granules. These granules are 2-150 μm in diameter and are partially crystalline in nature (Zobel 1984). Although primarily carbohydrate, starch granules also contain small amounts of lipids, proteins, and ash (French 1984).

Starch granules develop in organelles called amyloplasts. When there is one granule per amyloplast, it is called a simple granule; the presence of two or more granules in an amyloplast is called a compound granule. In addition to varying in granule structure, starch also varies in relation to species, cultivars, growth environment, and genetic mutations (Shannon and Garwood 1984).

2.2.1 Starch Molecules

The molecules that compose starch are amylose and amylopectin. Generally, amylose is present in the amount of 15-30%, depending on the plant source (Table 2.2). On the basis of amylose content, starch can be divided into three categories: waxy starch having 0-8% amylose, normal starch having 20-30% amylose, and high-amylose starch having greater or equal to 50% amylose (Jane 2000).

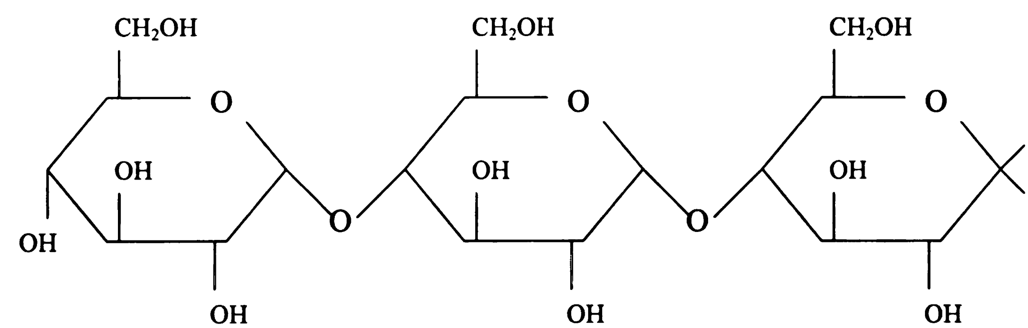
Table 2.2. Amylose Content of Starches*

Starch	Amylose (%)
Barley	22
Corn	28
Oat	27
Rice	18.5
Wheat	26

* Taken from Young 1984.

Amylose is essentially a linear polysaccharide composed of (1→4)-linked α-D-glucopyranosyl units (Fig. 2.1a), with a total average molecular weight of 250,000 daltons (Zobel 1984). Some studies have found that amylose may also have some slight branching (Shannon and Garwood 1984). Amylopectin is also (1→4)-linked α-D-glucopyranosyl, but it has branches at (1 →6)-linkages over 5% of the structure (Fig. 2.1b), and the molecular weight ranges from 50 million to 100 million Daltons (Zobel 1984). Amylopectin is the main contributor to the crystallinity of starch granules (Swanson 2000).

(a)



(b)

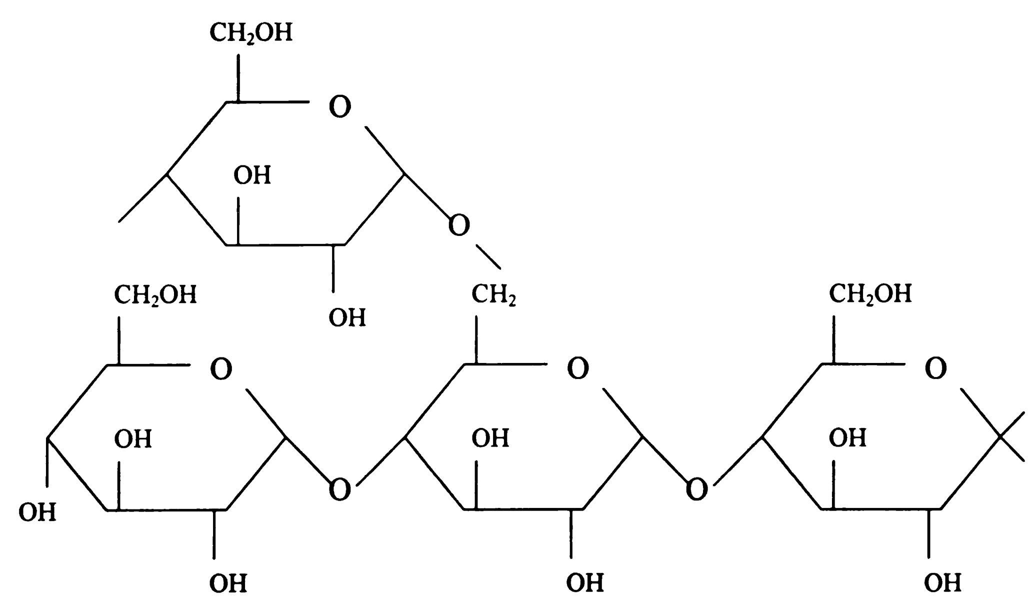


Figure 2.1. Chemical structures of (a) amylose and (b) amylopectin (Jane 2000).

When exposed to heat and water, amylose is unstable and quickly precipitates to initiate gelation. Rigidity develops as the starch gel cools and ages. Amylose gels are firm and require temperatures of 115-120° to reverse (Zobel 1984). The branched structure of amylopectin gives it greater stability in water (Young 1984). Gelation of amylopectin occurs at a much slower rate and requires higher concentrations and temperature. The gels are soft and reversible at 50-85° (Zobel 1984). The properties of amylose and amylopectin are summarized in Table 2.3.

Table 2.3. Properties of amylose and amylopectin*

	Amylose	Amylopectin
Molecular shape	Essentially linear (with few branches)	Branched
Molecular weight	~10^6 daltons	~10^8 daltons
Retrograde	Rapidly	Slowly
Film property	Strong	Weak and brittle

*Taken from Jane 2000.

Gel structure not only depends on individual starch fractions, but also on the interactions and synergy of the two together. For example, waxy starch, which is 0-8% amylose, produces a clear paste that disperses easily because amylose is not present to intertwine with amylopectin. Normal starch, which is so called because it is within the mid-range of amylose content with 20-30% amylose, produces a stronger gel (Jane 2000).

Jane and Chen (1992) explored the role of amylose present in different concentrations and with different lengths, as well as amylopectin with different branch chain lengths on gel strength. They found that higher concentrations of amylose led to stronger gels. Amylopectin with greater branch chain lengths also tended to produce stronger gels. This was explained by the branch chains interacting with amylose: longer length branches interact to a greater extent.

2.2.2 Gelatinization

Without the addition of heat and water, hot cereal is just powder. This section will describe what happens to the starch in the hot cereal when the consumer prepares the product for consumption. When dry starch is exposed to water at 0-40°C, the granules absorb a small amount of the water and undergo limited reversible swelling (French 1984). When heat is added in the presence of excess water, above a characteristic temperature the starch granules irreversibly swell and the amylose is solubilized. When this solution cools, the amylose associates to form a matrix in which the swollen granules are embedded (Ellis and Ring 1985). The umbrella term for the phenomenon is "gelatinization." One definition of gelatinization comes from Daniel and Weaver (2000):

> "Starch gelatinization is the collapse (disruption) of molecular order within the starch granule manifested in irreversible changes in properties such as granular swelling, native crystallite melting, loss of birefringence and starch solubilization. The point of initial gelatinization and the range over which it occurs is governed by starch concentration, method of observation, granule type and heterogeneity within the granule population under observation."

When starch is heated with excess water, several processes occur. French (1984) gives a comprehensive overview:

> As water is imbibed, "swelling begins in the least organized, amorphous, intercrystallite regions of the granule. As this phase swells, it exerts tension on neighboring crystallites and distorts them. Heating leads to uncoiling, or disassociation, of double helical regions and break-up of amylopectin crystallite structure. The liberated side chains of amylopectin become hydrated and swell laterally, further disrupting crystallite structure. The starch molecules are unable to stretch longitudinally, and may even contract to approach random coil formation. Increased molecular mobility with further hydration permits a redistribution of molecules; and the smaller, linear amylose molecules may diffuse out. Further heating and hydration weaken the granule to the point where it can no longer resist mechanical or thermal shearing, and a sol results."

This process takes place over a temperature range of 10-15°C (French 1984). The leaching out of the amylose takes place at a temperature of 57-100°C, while the granule is still intact (Young 1984).

Gelatinization and subsequent cooling is accompanied by an increase in viscosity. Traditionally, this thickening was believed to be the result of swollen granules coming into contact with each other and inhibiting flow. Other research indicates that it is the exudate, amylose, forming a network outside of the granule that causes the system to become viscous (Miller *et al* 1973).

2.2.3 Starch Characteristics from Wheat and Oat Species

The type of gel formed when a gelatinized starch solution cools depends on the molecular components of the starch, which varies with plant species. Wheat and oat starches are distinct from each other. In wheat, the starchy endosperm composes 82% of the kernel. The endosperm also contains some protein, pantothenic acid, riboflavin, and minerals (Swanson 2000). Doublier (1987) described wheat as 0.003% protein, 0.008% lipid, and 28% amylose. The percent of amylose in wheat ranges from 17-29%, depending on the cultivar (Shannon and Garwood 1984). Wheat starch is composed of simple granules, which come in two types depending on the growth stage of the plant. The first granules produced in the endosperm cells develop into large lenticular, disc-shaped granules. After two weeks, additional granules are produced which are small (<10μm) and spherical. The large granules make up only 12.5% of the total starch by number, but 93.0% by weight (Shannon and Garwood 1984). Upon hydration plus heat, the lenticular granules transform into a saddle shape, but do not thicken (French 1984). The small granules swell as spheres.

Oat endosperm, which constitutes 50-55% of the grain (Caldwell 1973), has more protein and oils than other cereals (Swanson 2000). Oat granules are compound. They start out as round granules, but become angular as they are packed together in the amyloplast. For oats, swelling occurs in three dimensions, with the swollen granules appearing as larger versions of the unswollen granules (Williams and Bowler 1982). Also, in oat starch, contrary to other cereals, amylose and amylopectin are leached simultaneously. As a result, oat gels have a stronger internal network at equivalent concentrations of other cereal starches, such as wheat (Doublier *et al* 1987). Table 2.4 summarizes the properties of granules from different cereals.

Table 2.4. Some properties of whole granular starches*.

Source	Gelatinization temperature range (°C)	Granule shape	Granule size (nm)	Amylose content (%)
Barley	51-60	Round or elliptical	20-25 2-6	22
Wheat	58-64	Lenticular or round	20-35 2-10	23-27
Oat	53-59	Polyhedral	3-10	23-24
Corn	62-72	Round or polyhedral	15	28
Rice	68-78	Polygonal	3-8	17-19

*Taken from Swanson 2000.

2.3. Yield Stress

The texture of fluid foods is often used by the food industry as a benchmark for quality in product development and consumer acceptance of new foods, and in grading and quality control of traditional products (Timbers and Voisey 1987). Production of commercial foodstuffs must be reproducible to satisfy consumers. An effective way to determine reproducibility is to measure the rheological properties, which can be correlated to performance of the materials in storage stability, ease of pumping, and sensory perception, to name a few (Walton 2000). Marr and Pederson (1999), in their research on low-fat and full-fat mayonnaise, found that rheological properties are related to product quality. Similarly, in a paper concerning objective and subjective methods of characterizing the rheological properties of buffalo cream butter, Kulkarni (1986) explained that 40% of the grading in butter comes from rheological attributes.

Industries appreciate simple low-cost tests that produce a single value that can easily be translated into practical significance relevant to product usage (Barnes 2001). One such rheological parameter that fits these criteria is yield stress (σ_o). As a point of reference, Barnes (1999) gives us a list of approximate yield stresses of some common fluid foods:

σ_o (Pa)	Product
15	Ketchup
25	Spaghetti sauce
60	Mustard and apple sauce
90	Mayonnaise
125	Tomato paste

During storage and preparation, many foods form an internal network structure due to chemical changes over time. These changes can result in weak gels that may explain the phenomenon of yield stress in terms of structural deformation and breakage of network bonds (Rao and Steffe 1997). Yield stress has traditionally been defined as the stress below which no flow takes place. This definition has been challenged by modern rheometry, which can take measurements at very low shear rates. The measurements show that low levels of flow do occur at stresses below the "yield stress." This information prompted Barnes (1999) to conclude that in reality, a yield stress does not exist because, given the appropriate time range, everything flows. To illustrate his point, he refers to a Biblical quote of the prophetess Deborah: " 'the mountains flow before the Lord,'" meaning that even rocks would flow if the time scale of observation is extended to geological scale.

For engineering quality control purposes, yield stress is accepted as a reality. Useful definitions of yield stress include: 1) the minimum shear stress required to initiate flow at the shear rate used (Briggs 1996, Walton 2000). 2) The maximum stress that can be applied before the structure breaks down (Daubert 1998). 3) The stress that must be exerted to just move one fluid layer past another (Missaire 1990).

2.3.1. Static versus Dynamic Yield Stress

There are two commonly recognized types of yield stress values: dynamic and static. Static yield stress is taken on a material at rest while dynamic measurements are taken on a material where the internal network system has been destroyed. Since the static measurements are taken on an undisturbed sample, the yield stress values are usually larger in magnitude than dynamic measurements. Figure 2.2 illustrates the concept of static and dynamic yield stresses (Steffe 1996).

Yield stress is an important consideration in the food industry because it directly anticipates how a fluid will flow over a range of shear stress values over a given time

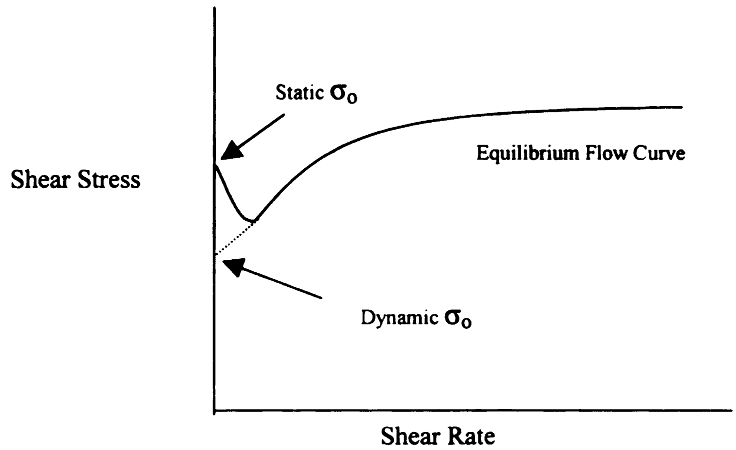


Figure 2.2. Static and dynamic yield stresses.

scale (Rao and Steffe 1997). Several studies have found that yield stress is important in coating solid surfaces and in keeping small particles in suspension (Yoo *et al.* 1995) as well as for predicting pumping requirements for a desired flow rate (Lang and Rha 1981). Yield stress can also be used to calculate the thickness of layers of fluid food products leftover on the wall of vessels in a food processing system (Barnes 1999). Lang and Rha (1981) studied yield stresses of hydrocolloid dispersions and found them to be associated with the use of hydrocolloids as binders through retaining their shape. Yield stress has also been directly related to spreadability of products such as cream cheese (Breidinger and Steffe 2001) and butter (Mortensen and Danmark 1982) and plays a role in sensory evaluation and consumer acceptance of these products.

2.3.2. Methods to Measure Yield Stress

There are numerous ways to measure yield stress. Steffe (1996) details several of the methods, but cautions that yield stress values are defined by the techniques used for measurement and the values from one method will not necessarily match those from another. Therefore, it is essential to specify the conditions of the test when reporting the results to allow for reproducibility.

Traditional methods to determine yield stress involve extrapolation of shear rate ($\dot{\gamma}$) and shear stress (σ) data according to flow models. Popular equations for this purpose are

$$\text{Bingham: } \sigma = \sigma_o + \eta_p \dot{\gamma} \tag{1}$$

$$\text{Casson: } \sqrt{\sigma} = \sqrt{\sigma_o} + \sqrt{\eta_p \dot{\gamma}} \tag{2}$$

$$\text{Herschel-Bulkley: } \sigma = \sigma_o + K(\dot{\gamma})^n \tag{3}$$

where the intercept of each equation is the yield stress (σ_o). Taking measurements for these equations involves destructive shear on the product, which can affect the yield stress values; therefore, a direct determination may be more desirable.

Established methods for direct determination include cup and bob, plate coating, and the centrifugal slump test. Wendin *et al* (1997) used a cup and bob to measure the yield stress of mayonnaise. In another study, Wendin and Hall (2001) employed a cone and plate to measure the yield stress of salad dressing. Marr and Pedersen (1999) measured the yield stress of mayonnaise with parallel plates. Omura and Steffe (2001) used a centrifugal viscometer to predict yield stress of fluid foods by measuring the slump in the materical induced from centrifugal acceleration. Mortenson and Danmark (1982) used three methods to determine yield stress of butter: direct measurements using a disc penetrometer and a sectilometer, and indirectly using measurements from a cone penetrometer. All three methods correlated closely with spreadability of butter. Several of these tests have limitations. For example, a cup and bob apparatus may experience wall slip, and plate coating is limited by the adhesive properties of the plate surface (Lang and Rha 1981).

2.3.3. Vane Method

The vane method was developed by Dzuy and Boger (1985) to address some issues from indirect and direct determination methods. The technique measures the stress to initiate flow from a vane immersed in the test material (Steffe 1996). The vane and sample cup dimensions must meet certain specifications to achieve essentially an infinite cup. Steffe summarized dimensional requirements (Figure 2.3): $1.5 \leq h/d \leq 4.0$; $Z_2/d \geq 0.5$; $Z_1 = 0.0$ or $Z_1/d \geq 1.0$ if the vane is completely immersed in the sample; $D/d \geq 2.0$ where D is the diameter of the container if circular, or the minimum crossectional dimension if some other shape is used.

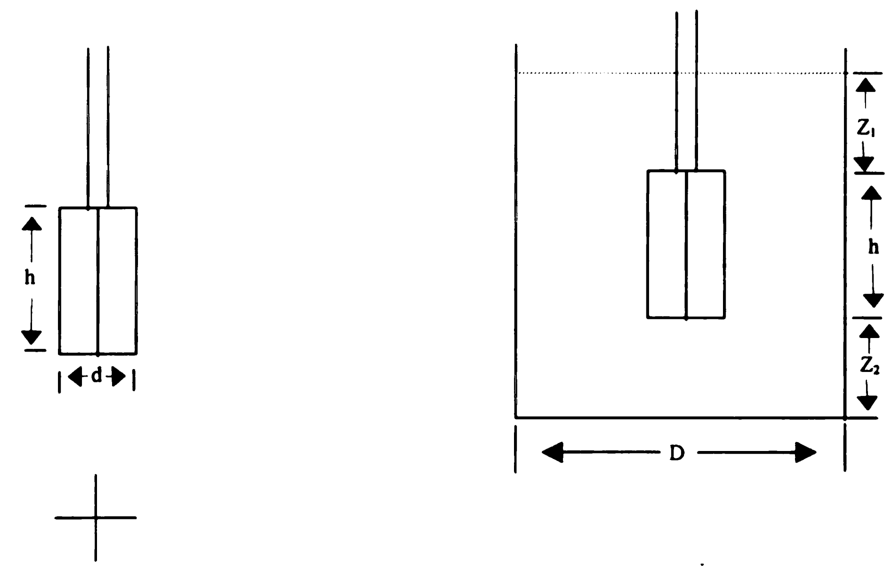


Figure 2.3. Cup and vane dimensions for the vane method.

The vane circumscribes a cylinder in the sample with the boundaries defined by the edges of the vane blades. Material within the cylinder acts as a solid body and the material outside experiences shear (Barnes 1999). The test material yields along a cylindrical surface as the torque on the spindle per unit time is recorded. The total torque (M_o) to overcome yield stress may be described as (Steffe 1996)

$$M_o = \frac{\pi d^3}{2}\left(\frac{h}{d} + \frac{1}{3}\right)^{-1} \sigma_o \tag{4}$$

therefore,

$$\sigma_o = \frac{2M_o}{\pi d^3}\left(\frac{h}{d} + \frac{1}{3}\right)^{-1} \tag{5}$$

A typical torque-time curve resembles graph show in Figure 2.4.

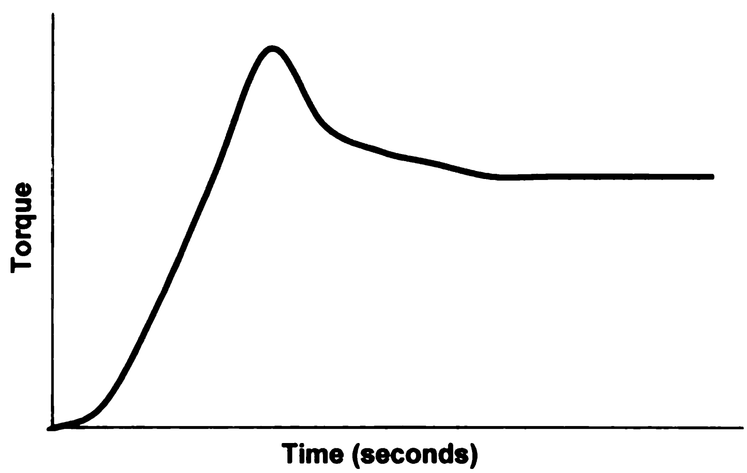


Figure 2.4. Torque-time curve at constant angular velocity.

The vane geometry confers some distinct advantages. The presence of blades rather than a smooth cylinder eliminates the effects of slip. Submerging the vane in the sample causes negligible effect on the property being measured because the actual yielding surface is located at the outer edge of the blade, near the surface (Breidinger and Steffe 2001). Another advantage of the vane method is that oftentimes, the original food container can serve as the sample cup, providing it meets the vane-vessel dimensions.

There are two ways to take yield stress measurements using the vane method: by controlled-shear rate ($C\dot{\gamma}$) or controlled-shear stress ($C\sigma$). For $C\dot{\gamma}$, the vane is rotated in the sample at a very low (<1.0rpm) constant speed. In the $C\sigma$, the torque is increased step-wise until the point at which strain increases rapidly. Yoo *et al* (1995) found that yield stresses taken by the $C\dot{\gamma}$ method were more reproducible than those taken by the $C\sigma$ method. $C\dot{\gamma}$ measurements also proved to be more sensitive for both dynamic and static yield stresses in determining the extent of structure development. The researchers concluded by saying, "The $C\dot{\gamma}$ method appears to be superior to the $C\sigma$ method, since it is simple, unequivocal, and sensitive to determine the yield stresses and the dimensionless yield numbers of food dispersions."

Several studies have validated the vane method as a reliable technique to measure yield stress. Missaire (1990) used a six-blade vane to measure the yield stress of unstructured and structured food suspensions. This study found that in unstructured suspensions the vane method and Casson's equation produced yield stresses of comparable magnitude. In structured suspensions, the vane-determined yield stresses were much higher. Rao and Steffe (1997) concluded that the vane method at a controlled shear rate gives more reliable values for yield stress than extrapolation from the Casson equation. A six-bladed vane was used by Cantu-Lozano *et al* (2000) to compare yield stresses of apple pulp suspensions to produce stresses calculated by the Casson model. Values from each method were nearly identical.

The vane method has now become an accepted technique to measure yield stresses of foods. Several recent studies have taken advantage of the technique to characterize food. The vane method was used by Qiu and Rao (1988) to correlate yield stress with pulp content and particle size of apple sauce. Wilson *et al* (1993) suggested yield stress as a rapid and simple method for quality assurance purposes with molten chocolates. Briggs *et al* (1996) used the vane method to determine the "scoopability" of ice cream as a direct result of yield stress. Daubert *et al* (1998) measured yield stresses of thirteen spreadable food products. Higher yield stresses were found in products which were more difficult to spread. Kovalenko and Briggs (2002) determined that the vane method is a rapid and inexpensive way for effectively detecting textural differences of soy-based yogurts.

2.4. Sensory

Instrumental measurements alone are insufficient for the characterization of food products due to the complexity of food systems. Instruments are incapable of detecting the interactions of flavor, texture, and other components of food, which create the effect perceived by humans. Sensory evaluation tests are designed to use humans as instruments capable of yielding analytical data.

2.4.1. Evolution of Sensory Science

Sensory science for the food industry began to develop early in the 20th century. In 1936, a researcher by the name of Moir demonstrated the role of color in food acceptability (Moskowitz 1983). He served a dinner for the food group of the Society of Chemistry and Industry where foods were prepared in the conventional manner. Some of the dishes, however, were unusual colors. Several of the scientists indicated feelings of nausea after eating the oddly colored food, even though there was nothing wrong with it.

With the coming of World War II more focus was placed on sensory science as the feeding of the military became important. Food was shipped and stored for months at a time, resulting in a decrease in food quality. The morale of soldiers was affected by the quality of the food, so it became necessary to understand methods to assess and improve product acceptability (Moskowitz 1983).

Sensory evaluation evolved further as a science through the eventual amalgamation of concepts taken from psychology, such as scaling techniques and psychophysics, with trade practices, such as grading. In the late 1940's and early 1950's, techniques began to emerge which allowed food products to be analyzed by scaling methods that were determined by sensory perceptions (Moskowitz 1983).

2.4.2. Descriptive Analysis

Descriptive analysis is one method of sensory evaluation that has become widely used. Einstein (1991) gives the following definition of descriptive analysis: "Descriptive analysis is the sensory method by which the attributes of a food material or product are identified, described, and quantified using human subjects who have been specifically trained for this purpose." Moskowitz (1983) highlights one advantage of descriptive analysis over consumer panels by saying that it encourages a broader range of terms to be generated to describe a product; otherwise, consumer panels may limit themselves to buzz words used in advertising. O'Mahony (1991) describes descriptive analysis as "a system where particular sensory characteristics of a food are identified and defined for trained panelists using physical standard stimuli." These characteristics are measured using one of several scaling techniques.

In general, trained judges are used to describe intensity of product attributes, while untrained judges are more useful in hedonic applications (Roberts and Vickers 1994). Training panelists standardizes the concepts used for judgment. Untrained subjects do not have a common language for communication; therefore, the same perception could be given several different definitions by different judges (O'Mahoney 1991, Munoz and Civille 1998). Lawless (1991) says "a term should be used in the same way by an individual upon repeated occasions (intraindividual consistency), be used in the same way by different individuals on a panel (interindividual consistency), and be used by the panel consistently upon subsequent evaluation sessions or experimental replications (consistency of panel mean scores across replicates)." Training a descriptive analysis panel is an effective way to create the desired consistency of terminology.

There are several accepted methods of descriptive sensory analysis. Although these methods were developed for flavor and textural attributes, textural studies will be emphasized in this discussion because they relate directly to the objective of the current work. In the 1940's, Arthur D. Little, Inc. developed the Flavor Profile Method (FPM), which allowed generation of sensory data concerning the use of seasonings in cooked foods (Einstein 1991). The information was applied to product development projects. Over the years, several other methods were born from the FPM, including the Texture Profile Method, Quantitative Descriptive Analysis® (QDA), and Spectrum™.

2.4.2.1. Texture Profile Method

The Texture Profile Method (TPM) was developed in the 1960's under the direction of Dr. Alina Sczcesniak at the General Foods Technical Center (Szczesniak 1963, Szczesniak *et al* 1963). The method is based on rheological principles and applies descriptive analysis to the sensory evaluation of food texture (Lawless 1991, Munoz *et al* 1992, Brandt *et al* 1963). Properties of food texture are placed into one of three categories: mechanical attributes, geometrical attributes, and attributes related to moisture and fat (Munoz *et al* 1992). Szczesniak *et al* (1963) developed scales with points anchored by foods that represent a specific intensity of an attribute. Screening procedures select a minimum of ten panelists who are trained for approximately130 hours over a six to seven month period (Murray *et al* 2001). Panelists use one of several scaling methods to generate data.

The original TPM standard scales involved only oral judgments to assess the entire texture of the product from first bite through mastication, but in later modifications of the TPM, non-oral assessments were also considered. Munoz (1986) explains that manual characteristics are important as an evaluation technique because consumers use such methods to judge certain quality aspects of food products.

2.4.2.2. Quantitative Descriptive Analysis®

Quantitative Descriptive Analysis® (QDA) was developed in the 1970's as a modified version of the FPM that allowed statistical analysis of profile data. Participants in this type of panel are users and likers of the products in question, and reference standards are used only as necessary (Murray *et al* 2001). The panel leader trains a panel over a period of ten to fifteen hours, and then data are collected by rating attribute intensities on an unstructured line scale.

2.4.2.3. Spectrum™ Method

Also in the 1970's, Gail Vance Civille designed the Spectrum™ Method. This method involves extensive training in which the full "spectrum" of product attributes are considered rather than focusing on just flavor or texture (Murray *et al* 2001). The Spectrum™ Method also makes use of universal scales made up of points of food reference samples. Non-oral judgments can also be made with the Spectrum Method as well as with TPM. In 1999, Civille participated in a study with Drake and Gerard, which determined that either hand evaluation or mouth evaluation can be used to discriminate cheese texture (Drake *et al* 1999).

2.4.2.4. Free Choice Profiling

Free Choice Profiling (FCP) is a technique that was developed on the 1980's by Williams and Arnold at the Agricultural and Food Council in U.K. (Meilgaard *et al* 1991). Each panelist creates his or her own list of descriptors and does not use other terms. This method takes less training time than other systems. A study done on a model system using menthol solution found that similar results were found between descriptive analysis and FCP for nasal and oral sensory parameters of the solution (Gwartney and Heymann 1996).

2.4.2.5 Generic Descriptive Analysis

Generic descriptive analysis, as the name implies, is a general method of descriptive analysis that takes bits and pieces from the established techniques to best suit the project at hand. A descriptive analysis consists of the following universal factors:

- *Screening to select panelists:* The screening may include a discrimination sensory evaluation and a personal interview. It is important that the panelist be able to differentiate between the products or attributes of products, which is determined by a discrimination test. Even more importantly, the subject must have the motivation to participate in the descriptive panel. Piggott (1991) recommends using a panel of about twelve members, Moskowitz (1983) suggests greater than or equal to ten participants, and the QDA® typically uses ten to twelve panelists (Einstein 1991). Meilgaard *et al* (1991) suggests that the best panelists should be chosen from participants with the best potential rather than those with the highest performance in a selection test. Some tests that can be used for selection are detection/discrimination tests, description tests, and ranking/rating tests.
- *Training:* Training sessions are used to generate terms and develop procedures as well as to create standard definitions of descriptors. The most successful vocabularies are the lists chosen by assessors (Piggott

1991). Moskowitz (1983) discusses four ways to create a list of descriptors: 1)Unprompted Description – the panelist sits alone with the product and creates a personal list of terms that describe the product. 2) Focus Group Interviews – discussions follow a pre-specified guide that covers specific points. 3) Prompted Description in the form of a Kelly Repertory Grid – in this method, the panelist is presented with three items, in pairs, and creates a list of similarities and differences between the combinations. 4) Prompted Description in the form of a checklist – panelists are asked to narrow down a list of terms by categorizing them as critical or non-critical.

- *Assessment:* A variety of scales can be used to measure product attributes in descriptive sensory analysis. Meilgaard *et al* (1991) discusses three commonly used scales: 1) *Category scales* are limited sets of words or numbers with equal intervals between categories. 2) *Line scales* use a six-inch or fifteen-centimeter long scale. Panelists make a mark on the line to indicate the intensity of a product attribute. 3) *Magnitude estimation (ME) scales* are based on free assignment of the first number, and all following numbers are proportional to the first. QDA® uses a six inch line scale with word anchors at each end. Spectrum™ uses line scales with ends labeled "none" and "extreme." TPA uses any of the three scales described above.

2.5. Correlative Studies

Descriptive analysis can be very time consuming and expensive to perform, so many industries use correlation studies (between sensory and physical properties) with the hopes of reducing the number of descriptive analysis panels needed. Kokini (1985) explains the usefulness of such methods by explaining "if textural attributes could be related to a single physical parameter or a combination, then these parameters could be used to monitor quality during processing and storage. Measurements of physical properties are quicker to perform and vary much less than sensory data." Quality control is just one reason that correlations are desirable. Other goals are to predict consumer response, to understand what is being perceived in sensory texture assessment, and to develop improved/optimized instrumental test methods that will lead to a texture testing apparatus that duplicates sensory evaluation (Szczesniak 1987).

It is necessary to be careful when making correlations to determine the relationships that actually exist. Any variables can be plugged into a computer program and correlations can be generated, because a computer cannot determine what relationships are logical and valid. Szczesniak (1987) enumerates several factors that affect correlations:

- *Test conditions*: Better correlations are achieved when the instrumental test conditions are very similar to the conditions of the sensory test. The type of test depends on the product and the characteristic being measured.
- *Test Material*: Homogenization of samples can improve correlations by elimination of variation within the product due to location of sampling.

- *Sensory Terms*: Complex terms, which may describe several parameters with one word will decrease the likelihood of finding meaningful correlations.
- *Sensory Scales*: The type of scale used can influence the correlation depending on the range of intensities of the textural parameters.

Correlation studies allow food scientists to determine how humans perceive physical and chemical factors of foods. They are mostly used in the areas of quality control and product development. Moskowitz (1983) reminds us that correlations do not say why the relationships exist. He also adds that if correlations are being used as predictors of consumer attitudes, the predictability will be poor because consumers do not expose themselves to stimulus in a controlled environment. Functional relations are determined by regression analysis that yields the expected sensory ratings for a specific measurement (Moskowitz 1983).

Correlation studies have been carried out for both fluid and nonfluid food systems and model systems:

- Szczesniak *et al* (1963) presented the TPM standard rating scales for hardness, brittleness, chewiness, gumminess, adhesiveness, and viscosity. The scales were all correlated with objective measurements from a General Foods Texturometer or a Brookfield Viscometer. All of the scales displayed good correlation with instrumental measurements of texture.
- Richardson et al (1989) performed a study on the perceived texture of thickened systems with dynamic viscosity measurements. The results found that small deformation measurements of dynamic viscosity under oscillatory shear at a

single frequency correlated directly with panel scores for perceived thickness of both true solution (fluid materials that do not exhibit yield stress) and weak gels. Also, panel scores for sliminess and stickiness were also directly correlated with dynamic viscosity.

- Morris *et al* (1984) found that perceived texture, using the descriptors "thickness" and "stickiness," of random coil polysaccharide solutions correlated well with instrumental measures of maximum viscosity at low shear rates and zero shear viscosity.
- A wide range of foods was used by Muellenet *et al* (1998) to develop a model of the relationship between sensory and instrumental texture profile attributes. High correlations were found between the attributes of hardness and springiness; however, no significant correlations were found for the attributes cohesiveness and chewiness.
- Tang *et al* (1999) correlated instrumentally measured texture parameters of cooked wheat noodles with data from a trained descriptive analysis panel using a generic descriptive analysis technique. Multivariate analysis approaches indicated that overall results from instrumental measurements and sensory analysis of texture were in good agreement.

All of the preceding examples indicate that the concept of correlation of sensory data with instrumental data is a valid method that can yield useful results. Some caution is warranted. Peleg (1983) notes that "the existence of a correlation between sensory and instrumental parameters does not necessarily permit meaningful extrapolation or even interpolation, especially to untested foods of a different textural character." Sherman

(1988) concurs, stating that identical instrumental tests cannot be used for all foods. Adjustments must be made to test conditions based on physiological adjustments made by panelists in sensory assessment.

The current work is particularly concerned with correlations of the instrumentally measured parameter of yield stress with sensory characteristics. Several studies have involved yield stress, correlating it with various sensory parameters:

- Kulkarni and Murthy (1986) correlated yield stress measurements with sensory parameters of butter. In soft butter, yield stress correlated significantly with hardness and stickiness scores.
- Yield stress is directly related to the scoopability of frozen ice cream (Briggs *et al* 1996).
- Wendin *et al* (1997) found that mayonnaise yield stress correlated with thickness and fattiness.
- Yield stress has been found to be related to spreadability in several food products from processed cheese spread to whipped topping (Daubert 1998), and cream cheese (Breidinger and Steffe 2001). Mortensen and Danmark (1982) also showed a high correlation of yield stress with spreadability of butter.
- Wendin and Hall (2001) correlated several sensory parameters with yield stress in salad dressing, including thickness and fattiness.

3. Materials and Methods

3.1. Rheological Measurements

Yield stress measurements were taken using a Brookfield Yield Rheometer called the YR-1 (Brookfield Engineering Laboratories, Middleboro, MA). This rotational viscometer was designed specifically to use the vane method to determine the yield stress of test materials. The system includes software that allows the user to custom design the test program. A temperature probe, as well as three vanes, are also included. Along with temperature, the instrument also measures time interval, % torque, delta torque (%), stress, and strain.

For the current work, five hot breakfast cereals were measured: Nabisco 2 ½ Minute Cream of Wheat (COW), Nabisco Instant Original Cream of Wheat (ICOW), Malt-o-Meal Co. Malt-o-Meal (MOM), Quaker Oats Co. Quick One Minute Regular Oats (1MIN), and Quaker Oats Co. Instant Regular Oatmeal (IOAT). Each cereal was prepared according to package instructions using Nanopure® (Barnstead/Thermolyne Corp., Dubuque, IA) filtered water. Table 3.1 indicates the proportions of cereal and water to prepare a batch of four servings.

Table 3.1. Proportions of water and cereal for sample preparation.

Cereal	Water (mL)	Dry cereal (g)
2 ½ Minute Cream of Wheat	940	150
Instant Cream of Wheat	640	112
Malt-o-Meal	765	130
One Minute Oat	825	190
Instant Oatmeal	600	140

Water was heated in a three quart pot until the temperature of the water reached the boiling point. At this point, the cereal was added while vigorously stirring (approximately 175 strokes per minute) with a wooden spoon to prevent clumping. COW and MOM are stirred for 2 ½ minutes and 1MIN was stirred for 1 minute. For the two instant cereals, ICOW and IOAT, once the water reached the boiling point (100°C), it was removed from the heat and poured into a bowl containing the dry cereal. The resulting instant cereal mix was stirred with a wooden spoon for 1 minute.

After stirring for the specified time, the cereal was immediately poured into square Plexiglas containers. These particular containers were designed for several reasons. Plexiglas was used because the material minimizes heat loss as compared to a metal container. This material is also clear, which allows sample observation as the spindle rotates. In addition, square sample containers eliminate slip of the sample against the container wall. Initial tests were conducted in cylindrical cups, but these tests were unsuccessful due to the slip observed.

Sample containers met the required dimensions (Steffe 1996) for vessel size according to the dimensions of the vanes used: $Z_2/d \geq 0.5$; $Z_1 = 0.0$ or $Z_1/d \geq 1.0$ if the vane is completely immersed in the sample, where d is the diameter of the vane, Z_2 is the distance between the bottom of the vane and the bottom of the sample cup, and Z_1 is the distance between the top of the vane and the top surface of the sample; $D/d \geq 2.0$ where D is the diameter of the container if circular, or the minimum crossectional dimension if some other shape is used.

During testing, a thermocouple was inserted into one container to monitor temperature changes while the vane was submerged in an identical sample. Additional containers holding prepared hot cereal were held at room temperature with a layer of plastic wrap on top of the sample to prevent film formation and minimize evaporative cooling. Samples were held for a series of durations at room temperature before the yield stress was measured. A particular sample was used for only one measurement. Duplicate measurements were taken on identically prepared samples. Nine hold times, covering the period of typical product use, were used: 3, 5, 8, 10, 12, 14, 15, 18, and 20 minutes. These hold times refer to how long the hot sample sat in the measurement container, at room temperature, before the yield stress measurement was initiated.

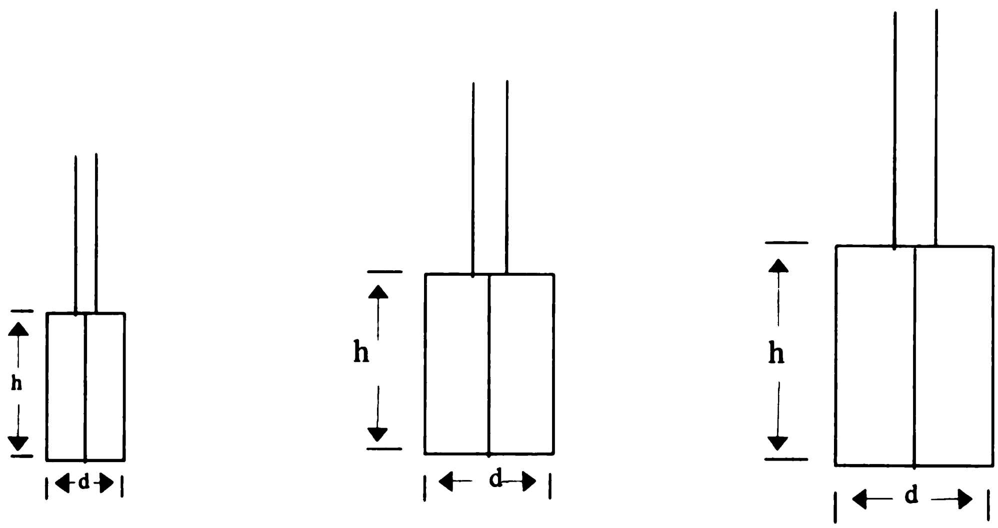
Three different vane sizes (Figure 3.1) and two different container sizes (Figure 3.2) were used to take measurements. The container used depended on the size of the vane necessary based on the torque requirements of the sample. Samples with low torque responses used a larger vane for the measurement, and vice versa. Table 3.2 displays the vane used for each sample.

Table 3.2. Spindle size used for measurement of each sample.

*Spindle 71 (large)**	3min	5min	8min	10min	12min	14min	15min	18min	20min
COW	X								
MOM	X	X	X	X					
*Spindle 72 (medium)**									
COW		X	X	X	X	X	X	X	X
MOM					X	X	X	X	X
ICOW	X	X	X	X	X	X	X	X	X
1MIN	X								
*Spindle 73 (small)**									
1MIN					X	X	X	X	X
IOAT	X	X	X	X	X	X	X	X	X

*Dimensions of spindles are given in Figure 3.1. Spindles 72 and 73 are used in the smaller container, and spindle 71 is used in the larger container.

The 1MIN sample does not have measurements for 5, 8, and 10 minute hold times When the medium vane was used, the torque was "over-range," and when the small vane was used, the torque was "under-range." An over-range reading indicates that the torque response of the sample is too great to be measured by the particular vane. A smaller vane

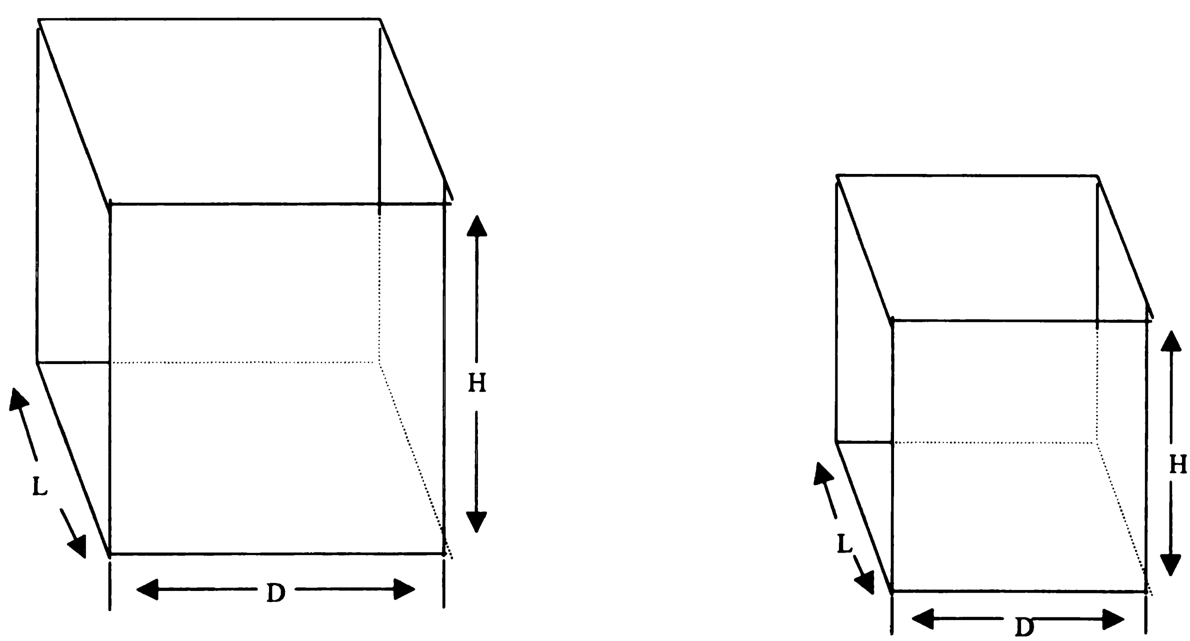


Spindle 73
h = 2.6cm
d = 1.0cm

Spindle 72
h = 4.4cm
d = 2.2cm

Spindle 71
h = 7.0 cm
d = 3.5cm

Figure 3.1. Dimensions of vanes used with Brookfield Yield Rheometer.



H = 12.5cm
D = 7.0cm
L = 7.0cm

H = 9.0cm
D = 5.5cm
L = 5.5cm

Figure 3.2. Dimensions of the sample containers used for measurements.

must be used because the blades have less surface area in contact with the sample, therefore the vane encounters less torque. Under-range readings mean that the vane is too small to read the torque response of the sample. By using a larger vane, more surface area is in contact with the sample and a larger torque reading can be obtained. There is an overlap in the ranges of the spindles; however, the cereal may have been changing too quickly to be measured by the instrument between the times of 5 minutes and 10 minutes.

The experimental protocol programmed using the Yield Rheometer software was as follows: zero the torque response at 0.1 rpm, wait 5 seconds, rotate the vane at 0.1 rpm, end test when torque reduction is equal to 115%. Hence, the test will only end automatically when one torque value is reduced 15% from the previous torque value. Using the torque reduction of 115% insures that the test will continue until the user chooses to terminate it. The spindle was changed as appropriate. The output was transformed into an Excel worksheet and by plotting torque versus time and observing the data points, a peak torque was extracted. Since many of the torque-time curves do not display a clear peak torque (such as the one illustrated in Figure 2.4) with a well-defined yield stress, the value obtained is referred to as the "apparent yield stress (σ_a)."

Two types of tests resulted from the Brookfield YR-1: passed and terminated. The tests that the instrument defined as "passed" met the criteria of a 15% torque reduction between subsequent data points. The maximum torque value from the passed tests was used as the peak torque. The terminated tests did not demonstrate a torque reduction of that magnitude. Although the torque values leveled out or decreased after reaching a peak torque, they did not decrease steeply enough to register a yield stress on the instrument. The peak torque on the terminated tests was defined as the point at which delta torque equaled zero, or the equilibrium stress.

3.2. Descriptive Analysis Measurements

3.2.1. Screening Panel

Screening panels are used to find panelists who are suitable to take part in a more extensive trained panel. An appropriate panelist is one who is interested in participating, available for 80% of the time, is prompt, has general good health, is articulate, and is not averse to the test product (Meilgaard *et al* 1991).

The objective of this test was two-fold: 1) to screen for individuals who were able to discriminate between large differences in thickness in hot cereal and 2) to screen for individuals who were willing to participate in a trained panel based on this exercise. One hundred one subjects participated in this test. Volunteers were students, faculty, and staff of Michigan State University. Subjects were compensated for participation with ice cream coupons.

The two samples used in the study were one pouch of Instant Original Cream of Wheat prepared with 160mL Nanopure water, and one pouch of Instant Original Cream of Wheat prepared with 190mL Nanopure water. Water was boiled and added to Styrofoam bowls each containing one pouch of Instant Original Cream of Wheat. One bowl of each sample was served immediately to the panelist. The subjects participated in a paired comparison test in which they were asked to signify which sample was thicker. The test question was followed by an option to indicate interest and availability in participating in a trained panel based on the exercise. Results from this panel showed that 91% of the participants were able to detect the difference in thickness between two samples. Initially, seventeen of these panelists agreed to take part in the trained descriptive analysis panel.

3.2.2. Trained Descriptive Analysis Panel

Descriptive analysis panel training was divided into three sessions: Session I, Session II, and Test Sessions. Sessions I and II were each offered on two different days to accommodate panelists and encourage participation. Each of the days lasted approximately one hour. After completing Session II, panelists were asked to sign up for three test sessions. The samples used in the test sessions were Nabisco 2 ½ Minute Cream of Wheat (COW), Nabisco Instant Original Cream of Wheat (ICOW), Malt-o-Meal Co. Malt-o-Meal (MOM), Quaker Oats Co. Quick One Minute Oats (1MIN), and Quaker Oats Co. Instant Regular Oatmeal (IOAT). All samples were prepared according to package instructions and then held at room temperature for five minutes before being served.

For Session I, panelists gathered as a group and were presented with one sample each ICOW and IOAT. Five people attended the first day and twelve people attended the second day. They were asked to write down a list of words that described the cereal samples. Table 3.3 lists the complete catalog of terms generated between the two days of Session I.

Each descriptor was discussed within the group and the list of words was narrowed down to those that could logically be correlated with instrumental measures of textural properties. The remaining words were discussed until a definition and a test method was determined for each word. Table 3.4 shows the final list of words from day one and day two of Session I.

Table 3.3. Comprehensive list of descriptors for Nabisco Instant Original Cream of Wheat and Quaker Oats Instant Regular Oatmeal.

ICOW	IOAT
Gritty	Lumpy
Constant consistency	Sticky
Sticks to spoon	Watery
Grainy	Thick
Mounds	Viscous
Little or fine pieces	Slimy
Off white with dark brown flecks	Little lumps in thick semi-viscous fluid
Viscous	Grey brown with flecks of dark brown
No separation (of water and particles)	Mounds on a spoon
Thick	Viscous strands when dropped from spoon
Pasty	Fluid
Unpleasant odor	Coarse
Smooth	Gooey
Flavorless	Not uniform (water separates out)
Creamy	Mild flavor
Heavy	Clumpy
Bland	Runny
Salty	Mushy
Fluffy	Chunky
Dry	

Table 3.4. Descriptor with definitions and testing methods from Days 1 and 2 of Session I.

Day 1	Day2
Descriptor: **Thickness** *Definition:* Resistance to stirring as felt in the hand and arm. *Test Method:* Hold spoon vertical and move in 5 circles.	*Descriptor:* **Stirrability** *Definition:* Amount of force needed to stir cereal at constant speed. *Test Method:* Hold cup steady, stir around with spoon five times.
Descriptor: **Viscous** *Definition:* Resistance to flow. *Test Method:* Lift heaping spoonful, observe degree of mounding on spoon.	
Descriptor: **Stickiness to Self** *Definition:* Degree of adhesion to itself. *Test Method:* Lift spoon through cereal perpendicularly and observe degree of strands/ropiness.	*Descriptor:* **Slimy** *Definition:* Ropelike appearance. *Test Method:* Tap surface with spoon, lift two centimeters, observe degree of ropiness.
Descriptor: **Stickiness to Spoon** *Definition:* Degree to which sample sticks to another object. *Test Method:* Lift spoon vertically out of the cereal and observe the amount of cereal retained on the spoon.	*Descriptor:* **Stickiness to Spoon** *Definition:* Degree to which sample sticks to spoon. *Test Method:* Hold spoon perpendicularly to cup, hold five seconds. Observe amount retained on spoon.
	Descriptor: **Stickiness to Self** *Definition:* Degree of adhesion to itself. *Test Method:* Lift spoonful of cereal, hold at 45 degree angle, and observe uniformity of flow.

Four panelists attended the first day of Session II, and ten attended the second day. The lists in Table 3.4 were merged to create a ballot for the test sessions. The ballot (Figure 3.3) was presented to the panelists during Session II. The line scale used was a 15cm unstructured line scale. The reference mark is 7.5cm from either end and the reference product was 2 ½ Minute Cream of Wheat (COW) for rating wheat-based cereals and Quick One Minute Oats (1MIN) for rating oat-based cereal. Panelists were given the reference sample, which was COW prepared in the conventional manner. The test methods were reviewed and practiced to ensure consistency among panelists.

Panelists were then given a set of four samples of COW, each of which had increasing amounts of dry cereal with equal amounts of water to create samples which represented the range of yield stresses covered by the actual test samples. Panelists individually marked the intensity of each parameter for each sample on the appropriate line scale on the ballot. Marks were discussed afterwards to ensure that all panelists agreed on the measurement of the intensity.

Panelists signed up for three test sessions. They were instructed that each test must be at least one day apart from the prior test. This was done in an effort to prevent panelists from making marks on the line scale simply by remembering where they placed a particular sample in a previous test session. The twelve panelists who completed all sessions were comprised of faculty and students at Michigan State University. Two males and ten females participated. Subjects were compensated with ice cream coupons, candy bars, and chips. Panelists came in singles or in pairs and the tests lasted forty to forty-five minutes.

Thickness (Stirrability)
Definition: Resistance to stirring at a constant speed.

Test Method: Hold cup steady with one hand, hold spoon vertical in sample with other hand. Stir spoon in a circle five times at a moderate speed. Evaluate thickness. Indicate thickness relative to the reference on the line scale:

Low R High

Stickiness to spoon
Definition: Degree to which sample sticks to spoon.

Test Method: Immerse spoon in sample. Lift spoon straight up out of cereal. Hold steady for five seconds. Observe amount of sample retained on spoon. Indicate stickiness to spoon relative to the reference on the line scale:

Low R High

Stickiness to self
Definition: Degree of adhesion of sample to itself.

Test Method: Lift heaping spoonful of sample. Tilt spoon towards yourself at a 45 degree angle, allowing sample to flow off spoon. Observe uniformity of flow. Indicate stickiness to self relative to reference on the line scale:

Low R High

Viscosity
Definition: Resistance to flow.

Test Method: Lift one heaping spoonful of sample. Drop onto lid of sample container. Observe degree to which sample spreads over the surface of the container. Indicate viscosity relative to reference on the line scale:

Low R High

Figure 3.3. Ballot presented to panelists in Session II.

The questionnaire (Figure 3.4) was designed using SIMS2000 Version 3.3, and the test was performed in a controlled environment. The first question, which asked for intensity of color, is a "dumping" question. This question allows the panelist to "dump" all other differences noted into a separate category so they could focus their attention on the parameters of interest (Lawless 1991).

Figure 3.4. Questionnaire for test sessions.

```
To begin, slide Ready side of card under the
          window.  You will be given 6 different sets of
          samples one at a time.  Each set  will consist of
          1 reference sample labeled R and 1 coded test
          sample.
After completion of each set, slide the Finished
          side of the card under the window and you will be
          given the next set of samples.

Remove lid from reference sample and coded sample.
           Visually observe overall color of sample as it is
          presented, without using a spoon.  Indicate
          intensity of color relative to the reference with
          LOW being very pale and HIGH being very dark.


                                        Captions:
          Intensity of Color

          +-----------------------------+-----------------------------+
          LOW                           R                          HIGH


Hold cup steady with one hand, hold spoon vertical
          in sample with other hand.
Stir spoon in a circle 5 times at a moderate
          speed.  Do not scrape sides or bottom of container
          with the spoon.  Indicate thickness relative to
          the reference with LOW being very little
          resistance to stirring, HIGH being very large
          resistance to stirring.


                                        Captions:
         Thickness (stirrability)

          +----------------------------+----------------------------+
          LOW                          R                         HIGH


Immerse spoon in sample.  Lift spoon straight up
          out of sample.
Hold vertically for 5 seconds.  Observe amount of
          sample retained on spoon.  Indicate stickiness to
          spoon relative to the reference with LOW being
          very small amount retained on spoon and HIGH being
          very large amount retained on spoon.
```

```
          Stickiness to Spoon

          +----------------------------+--------------------------------+
          LOW                          R                              HIGH


Lift heaping spoonful of sample.  Tilt spoon
          towards yourself at a 45 degree angle, allowing
          sample to flow off spoon.
Observe uniformity of flow.  Indicate stickiness
          to self relative to reference with LOW being
          particles do not stick to each other and HIGH
          being particles stick strongly to each other.


          Stickiness to self


          +----------------------------+--------------------------------+
          LOW                          R                              HIGH


Lift one heaping spoonful of sample.  Drop onto
          lid of sample container.
Observe degree to which sample spreads over the
          surface of the container.  Indicate viscosity
          relative to reference with LOW being sample
          spreads widely and HIGH being sample keeps its
          shape.


           Viscosity

          +-----------------------------+-------------------------------+
          LOW                           R                             HIGH
```

Figure 3.4 (cont'd).

Test sessions were designated Rep1, Rep2, and Rep3 in reference to each of the three replications. In each replication, one sample of each cereal was presented sequentially, each time with a freshly prepared reference. Samples were coded using a random numbers table (Table 1, Meilgaard 1991). The order of the samples was randomized; however, the order was the same for all panelists within a replication.

Samples for each replication are identified in the order presented for each replication in Table 3.5.

Table 3.5. Reference samples, sample code numbers, and sample identifications for Rep1, Rep2, and Rep3.

Rep1	**Reference (R)**	**Sample**	**Sample Code**
	COW	COW	339
	1MIN	IOAT	413
	COW	MOM	572
	COW	ICOW	574
	1MIN	1MIN	973
Rep2	**Reference (R)**	**Sample**	**Sample Code**
	1MIN	IOAT	576
	COW	ICOW	311
	1MIN	1MIN	975
	COW	COW	776
	COW	MOM	583
Rep1	**Reference (R)**	**Sample**	**Sample Code**
	COW	ICOW	286
	1MIN	1MIN	235
	COW	COW	477
	COW	MOM	782
	1MIN	IOAT	713

4. Results and Discussion

4.1. Rheological Behavior

There are two factors present that are responsible for causing the resistance to flow in prepared cereals: 1) thermal effects, and 2) chemical effects. The effects of these phenomena were evaluated through observations of changes in temperature and apparent yield stress values over time. The results for the rheological portion of this work were analyzed graphically and digitally.

Temperature at peak torque was plotted versus time (Figures 4.1 and 4.2). Temperatures decreased over time in a similar manner for all five samples. The instant cereals (ICOW and IOAT) both have regression curves that are shifted down from their cook-on-stove counterparts. This is because the instant cereals are not boiled during preparation.

The thermal conditions of these tests mimic the effects seen by a consumer; however, there are slight differences. For example, the temperature for the test was measured over twenty minutes, while a consumer may have finished his breakfast before that time lapse. The cooling is caused in part by evaporative heat loss from the surface of the hot cereal. In the test, plastic wrap is used to minimize this loss, and the surface area available for evaporation is smaller than that of a bowl used by the consumer. Additionally, the sample container used in the test is Plexiglas, while a bowl is normally made out of ceramic or glass. These materials are normally better conductors than Plexiglas, causing an increase in heat loss and probably a corresponding increase in yield stress.

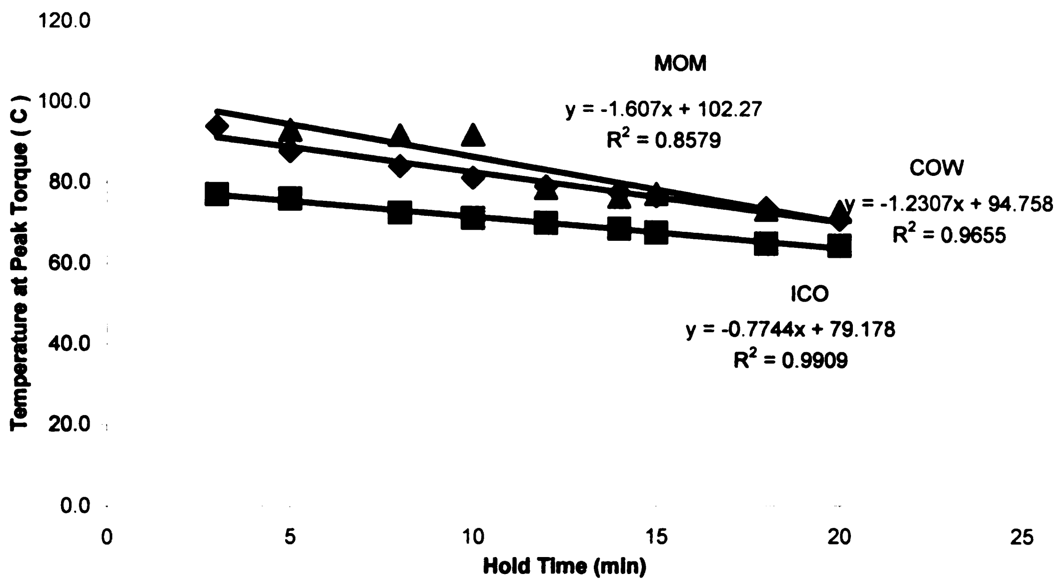


Figure 4.1. Temperature at peak torque versus hold time for wheat-based cereals.

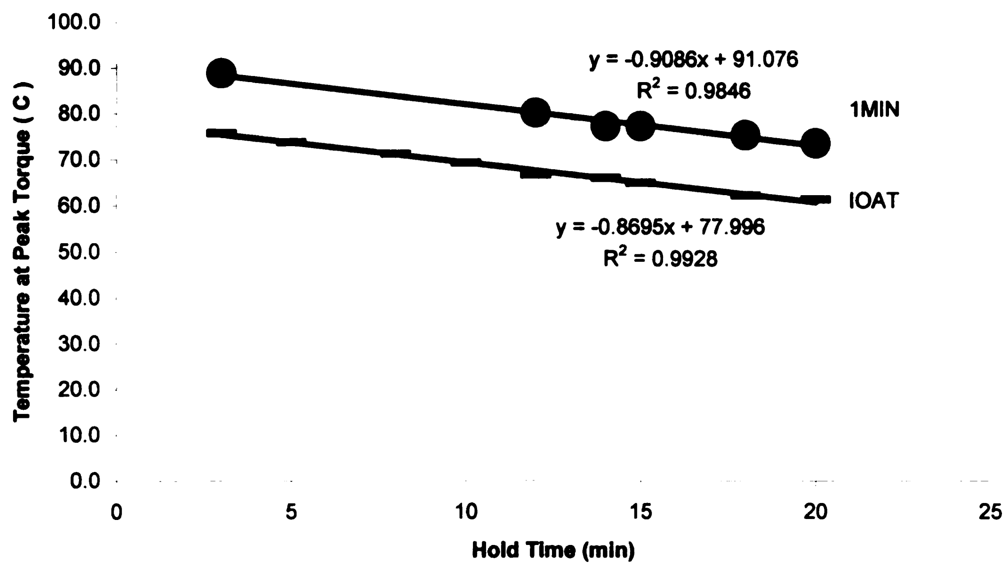


Figure 4.2. Temperature at peak torque versus hold time for oat-based cereals.

An apparent yield stress value was found for each cereal at each hold time. Values from multiple replications ($5 \leq n \leq 10$) were averaged and a scatterplot of apparent yield stress versus hold time was generated (Figures 4.3 and 4.4). Table 4.1 lists each cereal and its respective average apparent yield stress value for each particular hold time. The trend is for the apparent yield stress to increase as hold time increases. For wheat based cereals, ICOW has the largest average apparent yield stress values and MOM has the smallest. For oat based cereals, IOAT has higher average apparent yield stress values than the 1MIN product.

Table 4.1. Average apparent yield stress values

Hold Time		Average $\sigma_a \pm$ STDev	Hold Time		Average $\sigma_a \pm$ STDev
3min	COW[a]	21.7 ± 2.5	14min	COW	40.2 ± 3.1
	ICOW[b]	51.1 ± 7.3		ICOW	63.1 ± 14.0
	MOM[c]	19.4 ± 1.1		MOM	32.6 ± 3.2
	1MIN[d]	108.3 ± 15.5		1MIN	514.2 ± 52.9
	IOAT[e]	476.2 ± 64.8		IOAT	883.9 ± 138.4
5min	COW	30.3 ± 3.7	15min	COW	42.4 ± 5.0
	ICOW	52.9 ± 8.5		ICOW	64.4 ± 8.7
	MOM	20.5 ± 1.5		MOM	30.4 ± 3.4
	1MIN			1MIN	518.9 ± 134.2
	IOAT	613.4 ± 129.8		IOAT	809.1 ± 45.5
8min	COW	30.4 ± 3.8	18min	COW	47.3 ± 6.1
	ICOW	57.1 ± 8.2		ICOW	63.7 ± 13.0
	MOM	23.0 ± 0.8		MOM	35.8 ± 1.4
	1MIN			1MIN	619.8 ± 70.2
	IOAT	714.0 ± 116.0		IOAT	976.3 ± 176.4
10min	COW	31.0 ± 3.4	20min	COW	48.7 ± 3.0
	ICOW	59.0 ± 9.0		ICOW	68.1 ± 10.9
	MOM	24.2 ± 1.8		MOM	38.8 ± 2.6
	1MIN			1MIN	658.7 ± 98.6
	IOAT	742.3 ± 121.1		IOAT	984.0 ± 180.9
12min	COW	40.2 ± 8.6			
	ICOW	61.9 ± 7.3			
	MOM	30.1 ± 1.5			
	1MIN	513.9 ± 35.5			
	IOAT	776.1 ± 73.4			

[a]2 ½ Minute Cream of Wheat
[b]Instant Cream of Wheat
[c]Malt-o-Meal
[d]One Minute Oats
[e]Instant Oatmeal

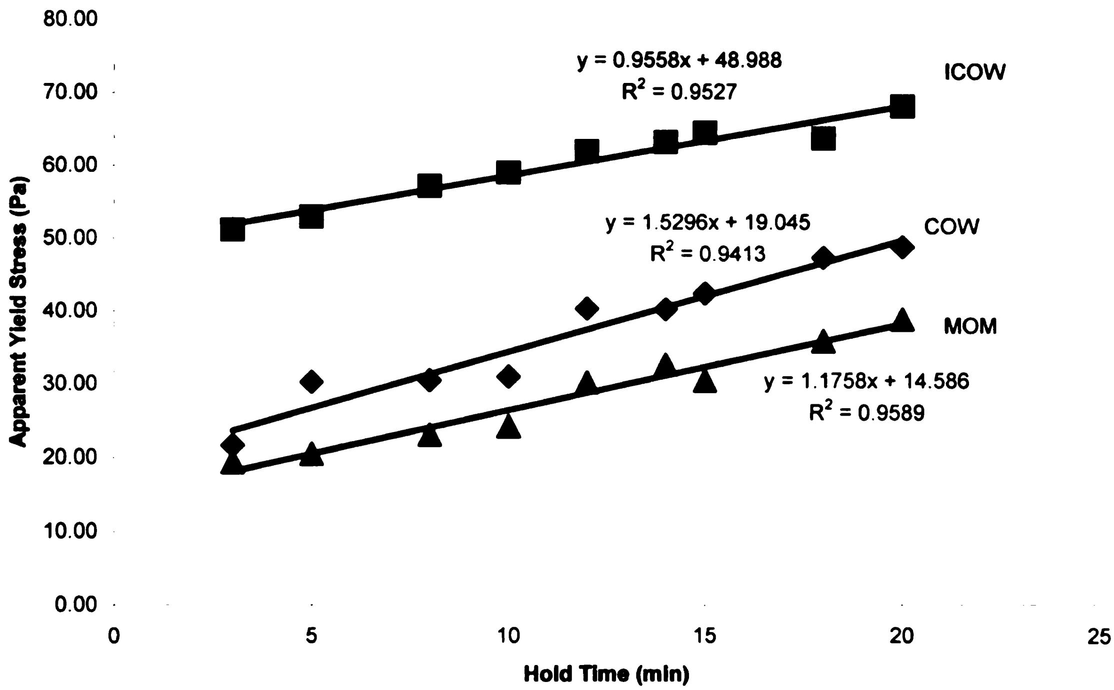


Figure 4.3. Average apparent yield stress versus hold time for wheat-based cereals

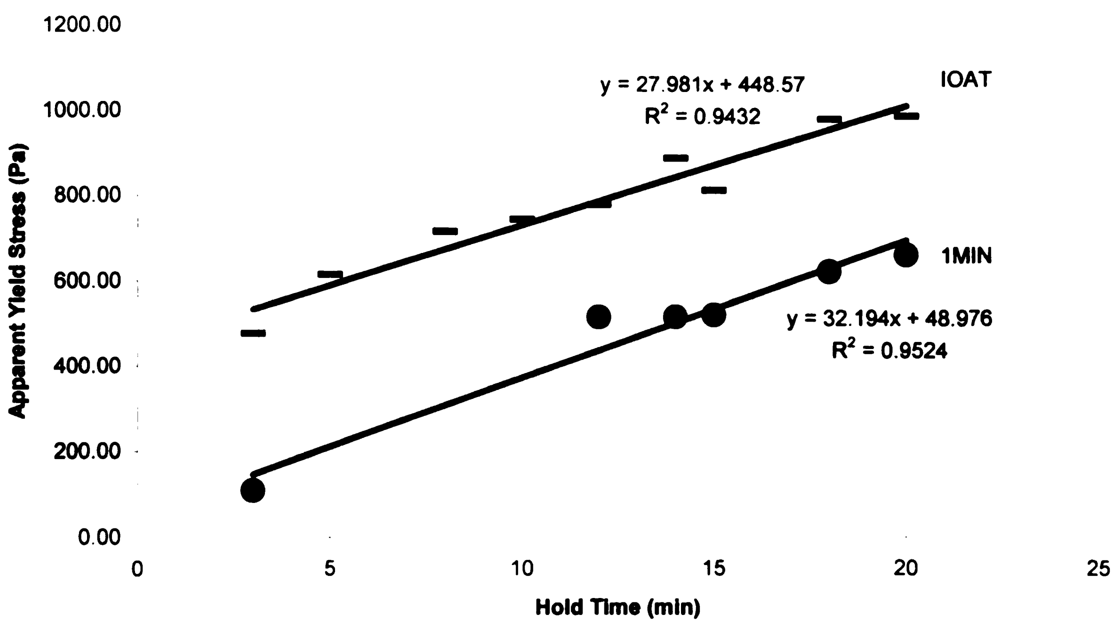


Figure 4.4. Average apparent yield stress versus hold time for oat-based cereals.

These measurements cannot be compared with yield stress values available in the literature because most published research focuses on pure starch solutions rather than food systems. Physical and chemical modifications or the addition of foreign materials should lead to a very large diversity (Doublier 1981), as found here. The term "apparent yield stress" is being used here because no definitive yield stress (requiring a clearly defined peak torque) could be identified in all hot cereal tests. In the literature, researchers have been able to find yield stresses in starch dispersions (Lang and Rha 1981, Evans and Haisman 1980, Bagley and Christianson 1983), however these tests have not involved actual food products and the starches have been cooked for times of fifteen minutes and longer. The tests reported in the current study are based on consumer products, which are cooked for a maximum of two and a half minutes.

The results clearly indicate that the apparent yield stress measurement can be used to characterize and differentiate the flow behaviors of the hot cereals. Instant Cream of Wheat has a much higher intercept than either MOM or COW (Figure 4.3), meaning that ICOW has the highest torque response of the three wheat cereals. The slopes of the trendlines are positive, meaning that all samples thicken over time. ICOW increased at a slower rate (less slope) than either MOM or COW because it is designed to hydrate very rapidly and has limited ability to thicken later. Over the total range of hold times, apparent yield stress measurements for ICOW only increases in value by a third as compared to COW, which increases by 130% and MOM which doubles from three to twenty minutes.

The R^2 values signify the goodness-of-fit of the trendline in regards to the individual data points. All the R^2 values are close to 1 indicating that all trendlines fit the data points very well. It should be noted that ICOW has a larger standard deviation than the other wheat-based cereals. This may be because ICOW tended to clump more than the others; and if the vane contacted a clump, a sharp increase in measured torque may have occurred.

A higher torque response for ICOW over either of the cook-on-stove varieties is expected for two reasons: 1) ICOW is an instant cereal, and as such is designed to hydrate and thicken very rapidly through modification (pregelatinization) of the starch, and 2) ICOW contains guar gum which is often used in food products as a thickening agent.

Instant Oatmeal has a much higher intercept than 1MIN (Figure 4.4), meaning that it is much thicker. The slopes of each line are similar, although 1MIN is slightly steeper. Both slopes are positive, indicating that the oatmeals both thicken over time. The R^2 values are near 1, signifying that the trendlines fit the data points very well. The same trend is seen with the oat cereals as with the wheat cereals. The instant oatmeal (IOAT) is designed to hydrate and thicken rapidly through chemical and physical modifications as well as the addition of guar gum. This could explain why, as time increases, although the apparent yield stress measurements for IOAT are higher than for 1MIN, the values for IOAT double while for 1MIN the apparent yield stress increases by five times.

Stanley (1987) states that both the human reaction to, and the mechanical properties of, food texture are the result of forces acting in an underlying organized structure. Chemical components interact to form a microstructure that contributes to the physical and sensory properties of the material. With a food product, as opposed to a pure solution, the interactions of components becomes much more complex and difficult to describe.

Chemical changes in the constituents of the cereal when it is prepared cause an increase in apparent yield stress. Over time, two processes of particular importance are starch hydration and gelatinization. Both wheat and oat starches gelatinize well below the boiling point of water (58-64°C and 53-59°C, respectively). Daniels (1974) stipulates that hydration of the cereals for the final prepared breakfast product must take place with water at a temperature higher than 79.4°C or the starch will not gelatinize. Therefore, it is safe to say that the temperature reached by exposing the cereals to water at its boiling point (100°C) is adequate to initiate gel-forming behavior in the starch molecules.

As the cereal is immersed in boiling water, the starch granules imbibe water and swell. As the granules occupy more volume, resistance to flow is expected to increase. Also as the granules absorb water, the amylose molecules solubilize and leach out of the granules. As the material ages and cools, the amylose molecules interact, contributing to structure within the cereal. This structure development also leads to an increase in apparent yield stress. How much of the increase in resistance is due to cooling, and how much is due to hydration is unknown for hot cereals.

4.2. Descriptive Analysis

Panel training was divided into two sessions, each offered on two days, to accommodate panelists and encourage participation. Dividing a panel in half for separate but identical training does not decrease the value of the panel. Heymann (1994) found that consistent results can be found across two independently trained panels. Therefore, data are reliable from two different well-trained panels as long as the same sample preparations are used. The same result was found here. Each Session I group developed a nearly identical ballot (Table 3.4). During both days of Session II the participants scored practice samples on the line scale in the same area around the references. The panel training was limited to only two hours, while traditional descriptive analysis training takes place over 10 hours or more. The limited training does not qualify the panelists as experts, but should not be a detriment to the test because it has been found that a well instructed panel can perform almost as well as an expert panel (Moskowitz 1996).

The sensory results for the trained descriptive analysis panel were analyzed with SAS, using *proc glm* to perform analysis of variance. Typically *proc glm* is used for unbalanced designs; however, it was used as a tool in this research because it is more conservative than *proc anova* for balanced designs. The panelists were presented with a 15cm line scale, with a reference sample indicated by a mark at the 7.5cm point. Scores for all cereals were assigned relative to this reference. Each of the twelve panelists performed the sensory evaluation in triplicate, generating thirty-six scores for each sensory parameter of each cereal. Results of the scoring are displayed in Tables 4.2-4.5 and Figures 4.5-4.8.

Table 4.2. Results of descriptive analysis panel scores for wheat cereals and oat cereals for the parameter "thickness (stirrability)."

Thickness (stirrability)			
Definition: Resistance to stirring at a constant speed. Test Method: Hold cup steady with one hand, hold spoon vertical in sample with other hand. Stir spoon in a circle five times at a moderate speed.			
	Average	Standard Deviation	Variation
COW	7.1	1.3	1.7
ICOW	9.2	2.4	5.7
MOM	11.6	1.9	3.7
1MIN	7.0	2.1	4.4
IOAT	7.9	2.4	5.5

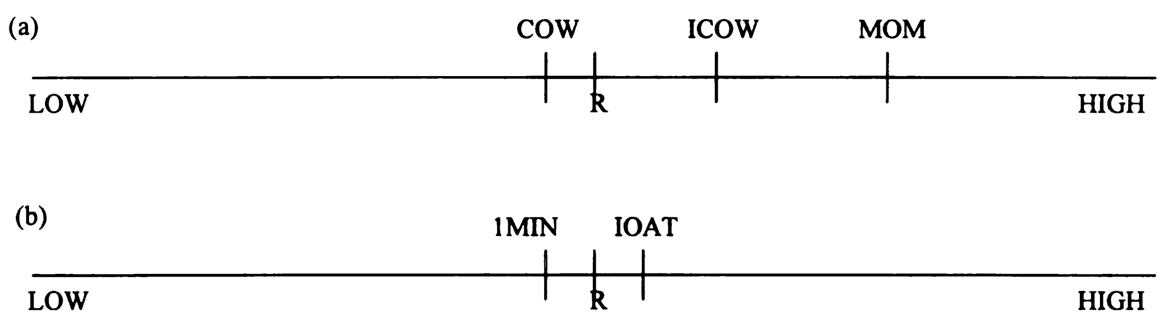


Figure 4.5. Scalar illustration of results of descriptive analysis scores for wheat cereals (a) and oat cereals (b) for the sensory parameter "thickness (stirrability)."

Table 4.3. Results of descriptive analysis panel scores for wheat cereals and oat cereals for the parameter "stickiness to spoon."

Stickiness to spoon			
Definition: Degree to which sample sticks to spoon. Test Method: Immerse spoon in sample. Lift spoon straight up out of cereal. Hold steady for five seconds. Observe amount of sample retained on spoon.			
	Average	Standard Deviation	Variation
COW	6.7	1.7	2.9
ICOW	8.0	2.7	7.0
MOM	11.5	1.9	3.4
1MIN	6.9	1.6	2.6
IOAT	7.4	1.9	3.8

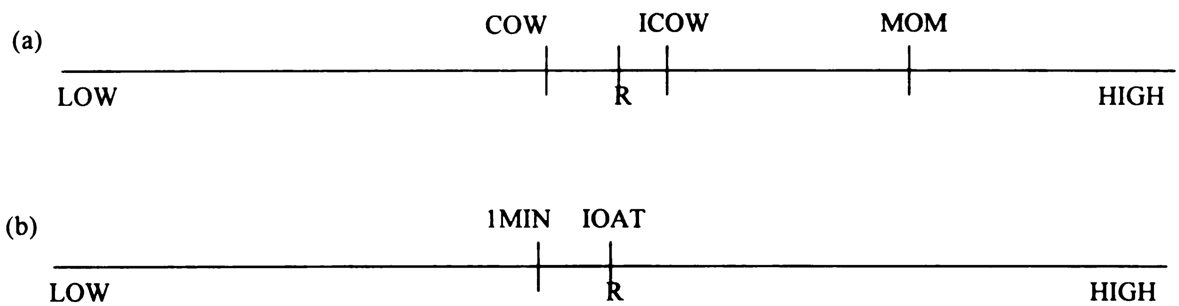


Figure 4.6. Scalar illustration of results of descriptive analysis scores for wheat cereals (a) and oat cereals (b) for the sensory parameter "stickiness to spoon."

Table 4.4. Results of descriptive analysis panel scores for wheat cereals for the parameter "stickiness to self."

Stickiness to self			
Definition: Degree of adhesion of sample to itself. Test Method: Lift heaping spoonful of sample. Tilt spoon towards yourself at a 45-degree angle, allowing sample to flow off spoon. Observe uniformity of flow.			
	Average	Standard Deviation	Variation
COW	6.7	2.0	4.1
ICOW	9.3	3.1	2.6
MOM	10.8	2.6	6.6
1MIN	7.2	1.6	2.4
IOAT	7.1	2.4	5.7

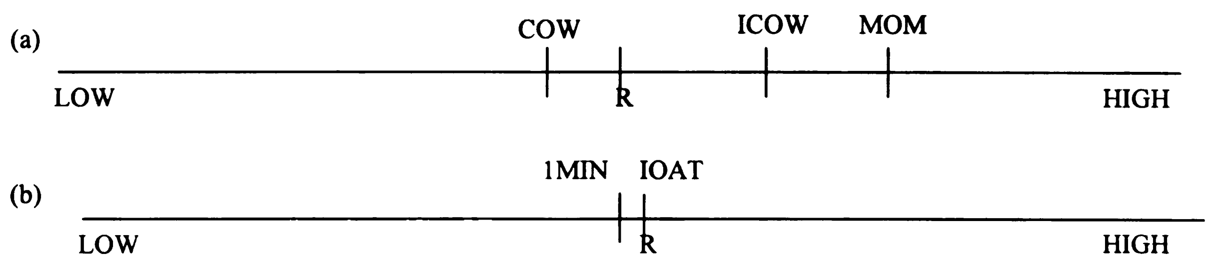


Figure 4.7. Scalar illustration of results of descriptive analysis scores for wheat cereals (a) and oat cereals (b) for the sensory parameter "stickiness to self."

Table 4.5. Results of descriptive analysis panel scores for wheat cereals for the parameter "viscosity."

Viscosity			
Definition: Resistance to flow. Test Method: Lift heaping spoonful of sample. Drop onto lid of sample container. Observe degree to which sample spreads over the surface of the container.			
	Average	Standard Deviation	Variation
COW	6.5	1.8	3.2
ICOW	10.1	2.6	6.5
MOM	10.2	2.3	5.5
1MIN	7.3	1.5	2.4
IOAT	5.6	2.4	5.8

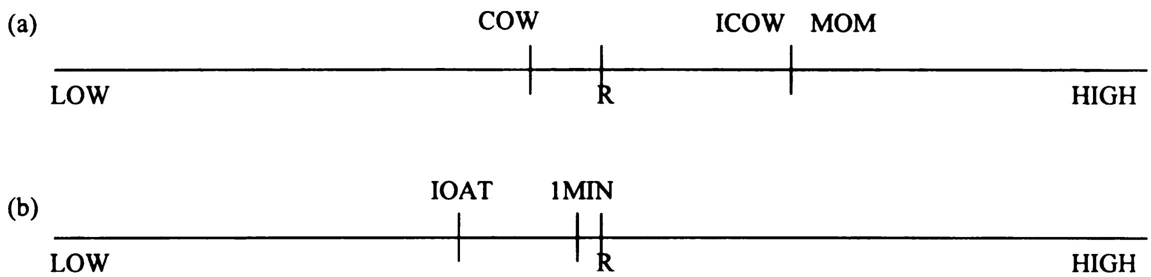


Figure 4.8. Scalar illustration of results of descriptive analysis scores for wheat cereals (a) and oat cereals (b) for the sensory parameter "viscosity."

Analysis of variance was performed to indicate where the panelists found significant differences between cereals. The ANOVA model used took into account the variations due to differences in scores between subjects. This helps eliminate the effect caused by panelists using different parts of the scale. For example, Panelist A may use a limited range of the line scale focused around the reference point while Panelist B may make use of the entire line. Without accounting for this factor, the results would be skewed and we would be unable to determine if the difference in cereals was due to the samples themselves being different or to the variation in how the panelists used the line scales. Some degree of variation is inevitable since each unit consists of one assessor. One source of variation is the order in which the samples are presented (Piggott, *et al* 1998).

Analysis of variance results for thickness for wheat cereals yields a p of <0.0001 indicating that there is a significant difference between at least two of the cereals (Appendix Table 7.14). Some of the variation observed is due to the subject ($p = 0.0010$) (Appendix Table 7.15). The results of the statistical analysis also indicates the least significant means, which determine where the difference between the cereals exists due to treatment. For wheat cereals and the thickness parameter, at $\alpha = 0.01$, there is a significant difference in scores between COW, ICOW, and MOM (Appendix Table 7.16).

The ANOVA results for stickiness to spoon for wheat cereals gives a p of <0.0001 indicating that there is a significant difference between at least two of the cereals (Appendix Table 7.17). The variation observed is not due to the subject ($p = 0.0531$) (Appendix Table 7.18). For wheat cereals and the stickiness to spoon parameter, at $\alpha =$ 0.01, there is a significant difference in scores between COW, and MOM and also between ICOW and MOM. At $\alpha = 0.05$, there is a significant difference between COW and ICOW (Appendix Table 7.19).

The ANOVA result for stickiness to self for wheat cereals indicates that there is a significant difference between at least two of the cereals (p of < 0.0001) (Appendix Table 7.20). The variation observed is not due to the subject ($p = 0.2277$) (Appendix Table 7.21). For wheat cereals and the stickiness to self parameter, at $\alpha = 0.01$, there is a significant difference in scores between COW, and ICOW and between COW and MOM. At $\alpha = 0.05$ there is a significant difference between ICOW and MOM (Appendix Table 7.22).

For viscosity for wheat cereals, the ANOVA results give a p of <0.0001 indicating that there is a significant difference between at least two of the cereals (Appendix Table 7.23). The variation observed is not due to the subject ($p = 0.3313$) (Appendix Table 7.24). For wheat cereals and the viscosity parameter, at $\alpha = 0.01$, there is a significant difference in scores between COW and ICOW and between COW and MOM. There is no significant difference between ICOW and MOM ($p = 0.9576$) (Appendix Table 7.25).

For the wheat-based cereals, the trained panel found that for thickness, stickiness to spoon, and stickiness to self, there is a significant difference between COW, ICOW, and MOM. For all three parameters, COW had the lowest intensity and MOM had the highest intensity of the particular attribute. The last parameter, viscosity, was not able to distinguish between ICOW and MOM; however, this attribute still followed the trend of COW having the least intensity of the three samples.

Analysis of variance was also used on the oat cereals. Even though there were only two samples, it was necessary to use ANOVA to determine the variation in scores due to the subject. For thickness for oat cereals, a p of 0.3153 indicates that there is not a significant difference between the cereals (Appendix Table 7.26). The ANOVA results for stickiness to spoon for oat cereals give a p of 0.2400 indicates that there is not a significant difference between the cereals (Appendix Table 7.27). The ANOVA results for stickiness to self are a p of 0.4319 indicating that there is no significant difference between the two cereals (Appendix Table 7.28). For viscosity, the p of 0.0348 indicates that there is a significant difference between cereals at $\alpha = 0.05$ (Appendix Table 7.29). A p of 0.3982 for the subject and 0.0007 for the treatment indicates that all variation between cereals is due to the samples, not the variation among subjects (Appendix Table 7.30). Panelists had a difficult time distinguishing between 1MIN and IOAT. Viscosity was the only successful method for determining differences. For this attribute, IOAT was rated at a lower intensity than 1MIN.

Instant cereals are designed to hydrate and thicken more rapidly than the cook-on -stove cereals. To this end, the starch is pregelatinized by way of steam treatments and the cereal flakes are rolled thin to allow them to absorb water more quickly. Thickeners are also added: both ICOW and IOAT contain guar gum, which hydrates rapidly in hot water. Therefore, it would be expected for the sensory panel and the yield stress values to indicate that the instant cereals are higher in all categories than the cook-on-stove cereals, as is the case for the wheat cereals. During the time period during which the sensory test occurred, the instant cereals may reach higher values because they thicken more rapidly. Cook-on-stove varieties may reach the same thickness later as the native starch sets up unaided.

4.3. Correlation of Rheological and Sensory Parameters

For the best correlations between instrumental and sensory measurements, the sensory evaluation methods should mimic the instrumental tests. Non-oral sensory methods were emphasized in this test to imitate the use of the vane, which rotates in the sample. Samples were prepared and allowed to rest for five minutes before being given to the panelists. This served two purposes: 1) Consumers who eat hot cereal usually wait for it to cool down before consumption. Szczesniak (1987) reminds us that tests should be designed with the consumer in mind, so we tried to mimic the conditions that the consumer would experience; 2) The materials and methods for the rheological measurements stipulate a hold time for a minimum of three minutes before the first data are collected to allow the structure of the sample to develop.

Since the R^2 values were near 1 for all the apparent yield stress versus hold time curves, it was possible to use the lines themselves to generate the data points for use in the correlation. The time used in the equation was selected as the average age of the sample that the panelists evaluated. Panelists evaluated the cereal when the samples were between five and ten minutes old. The average time was found and used in the line equation from Figures 4.3 and 4.4 to find the estimated apparent yield stress value at that particular time. This is approximately the apparent yield stress value that the panelist was evaluating. If a different time had been picked, the results would have been similar.

Table 4.6 displays the times and equations used for each cereal as well as the resulting apparent yield stress values that were calculated from the regression analysis. The results for the correlation analysis for the sensory data and the apparent yield stress values were analyzed using *proc glm* in SAS to perform regression analysis (Table 4.7).

It should be kept in mind that correlations do not reflect a cause-and-effect relationship, merely that two variables change in unison (Szczesniak 1987). All correlation coefficients obtained in this test are 0.40 and below meaning that there is no correlation between instrumental values and the sensory scores. Figures 4.9-4.16 display sensory parameter versus apparent yield stress value.

Table 4.6. Equations and cereal ages used to find apparent yield stress value evaluated by sensory panel.

	Equation	t = age (minutes)	σ_a
2 ½ Minute Cream of Wheat	σ_a=1.5296t + 19.045	8.5	31.6
Instant Cream of Wheat	σ_a =0.9558t + 48.988	8	57.5
Malt-o-Meal	σ_a =1.1758t + 14.586	7.75	23.5
One Minute Oats	σ_a =32.194t + 48.976	8	306.5
Instant Oatmeal	σ_a =27.981t + 448.57	8.5	686.4

Table 4.7. Correlation coefficient for regression analysis for wheat- and oat-based cereals for four sensory parameters.

	Thickness (Stirrability)	Stickiness to spoon	Stickiness to self	Viscosity
Correlation coefficient of wheat-based cereals	0.20	0.3	0.04	0.2
Correlation coefficient of oat-based cereals	0.20	0.1	0.01	0.4

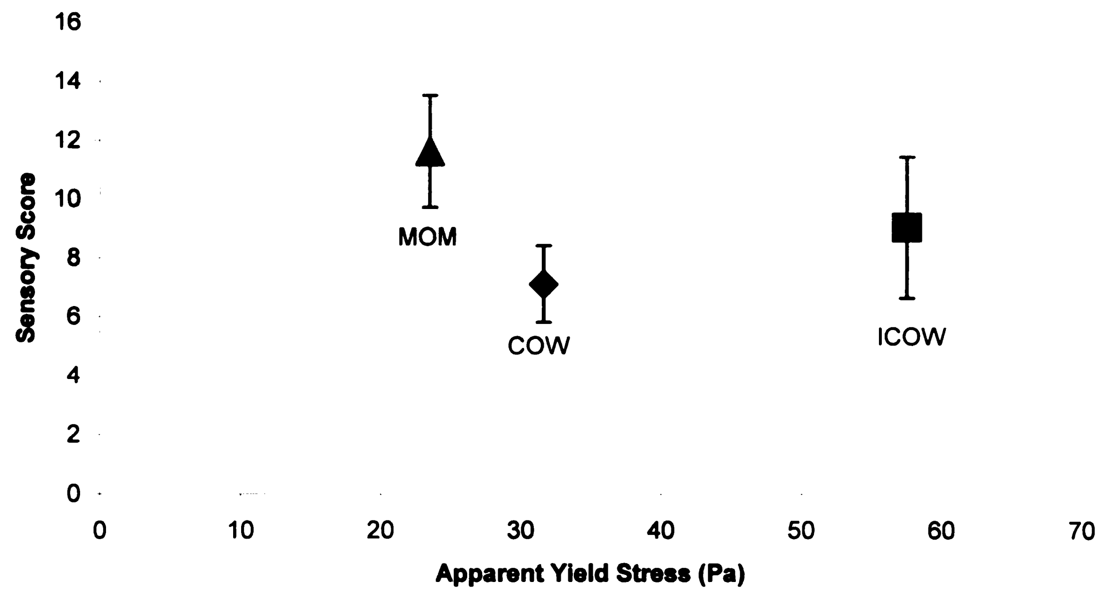


Figure 4.9. Average sensory score ± one standard deviation for thickness of wheat-based cereals versus apparent yield stress measurements.

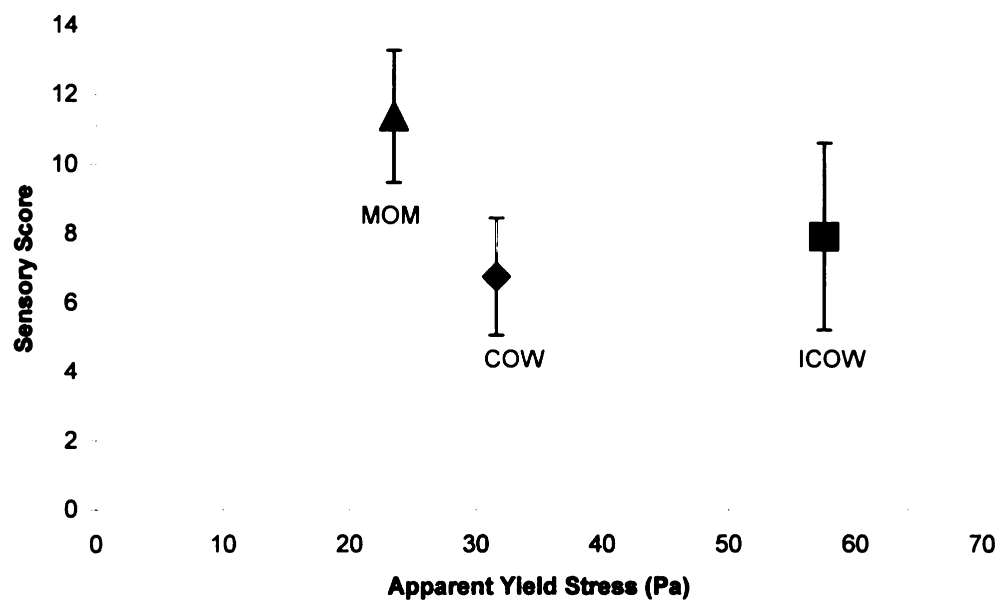


Figure 4.10. Average sensory score ± one standard deviation for stickiness to spoon of wheat-based cereals versus apparent yield stress measurements.

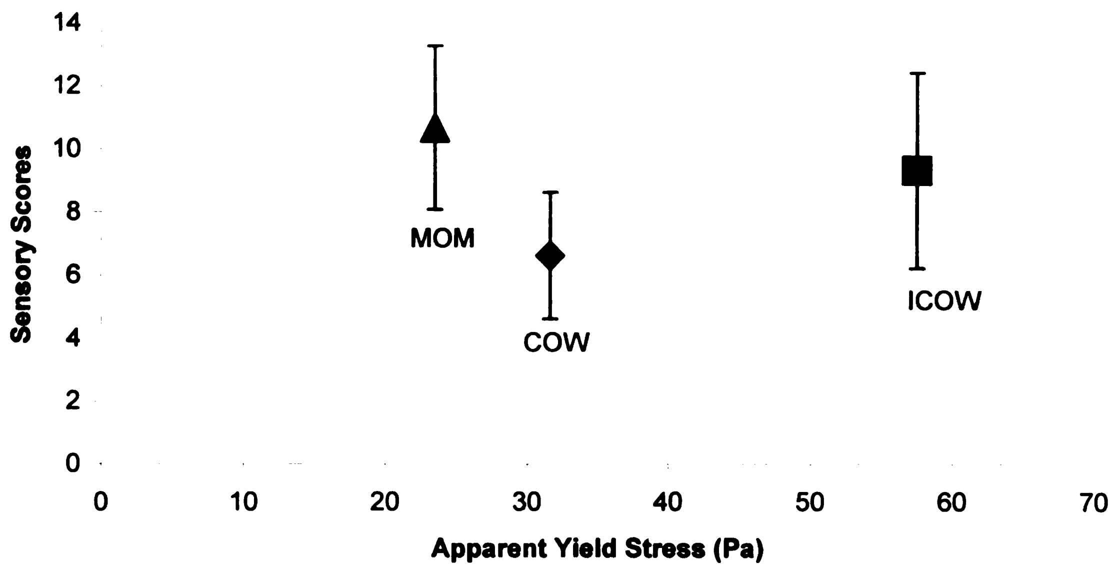


Figure 4.11. Sensory scores for stickiness to self for wheat-based cereals versus apparent yield stress measurements.

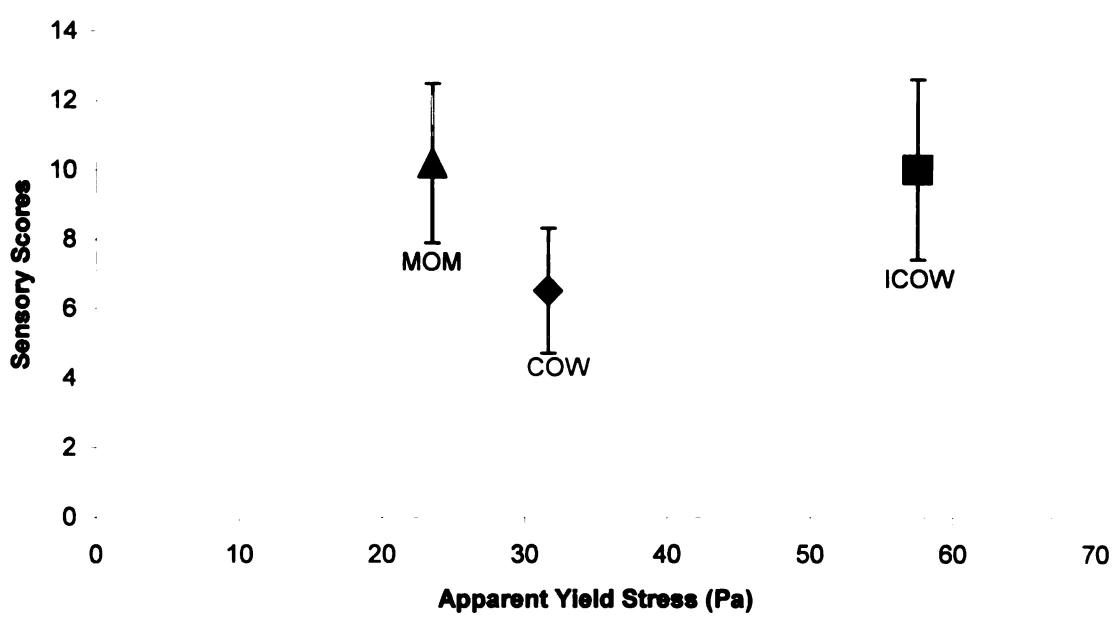


Figure 4.12. Average sensory score ± one standard deviation for viscosity for wheat-based cereals versus apparent yield stress measurements.

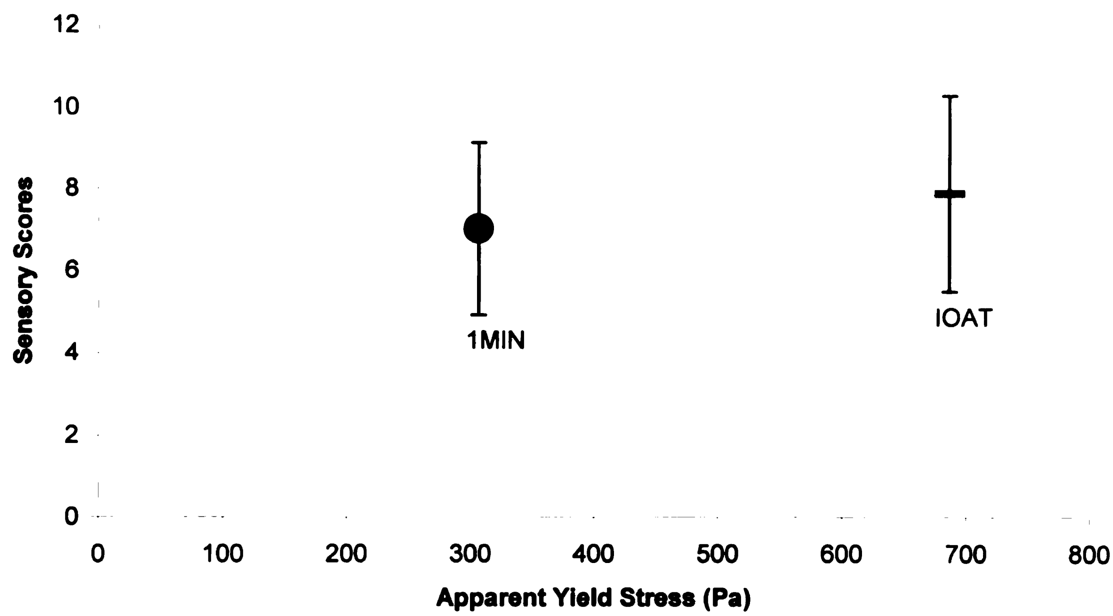


Figure 4.13. Average sensory score ± one standard deviation for thickness for oat-based cereals versus apparent yield stress measurements.

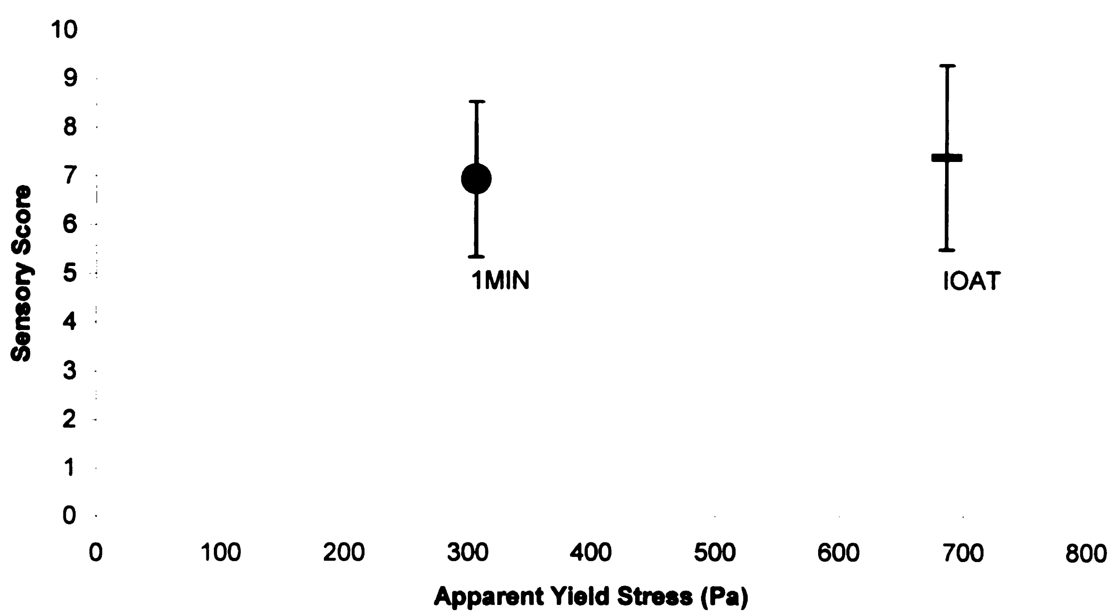


Figure 4.14. Average sensory score ± one standard deviation for stickiness to spoon for oat-based cereals versus apparent yield stress measurements.

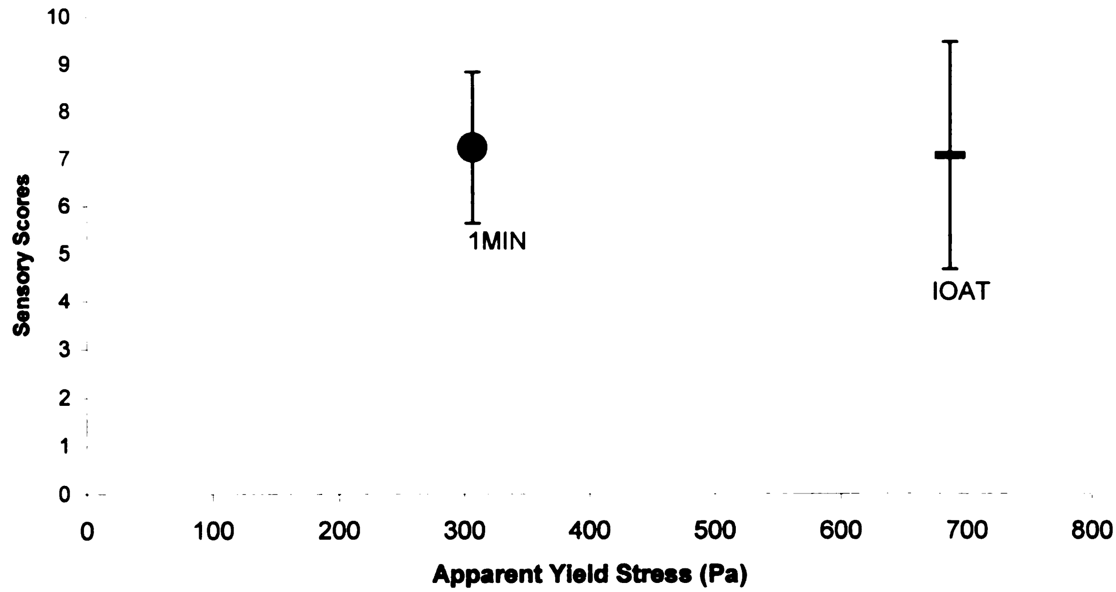


Figure 4.15. Average sensory score ± one standard deviation for stickiness to self for oat-based cereals versus apparent yield stress measurements.

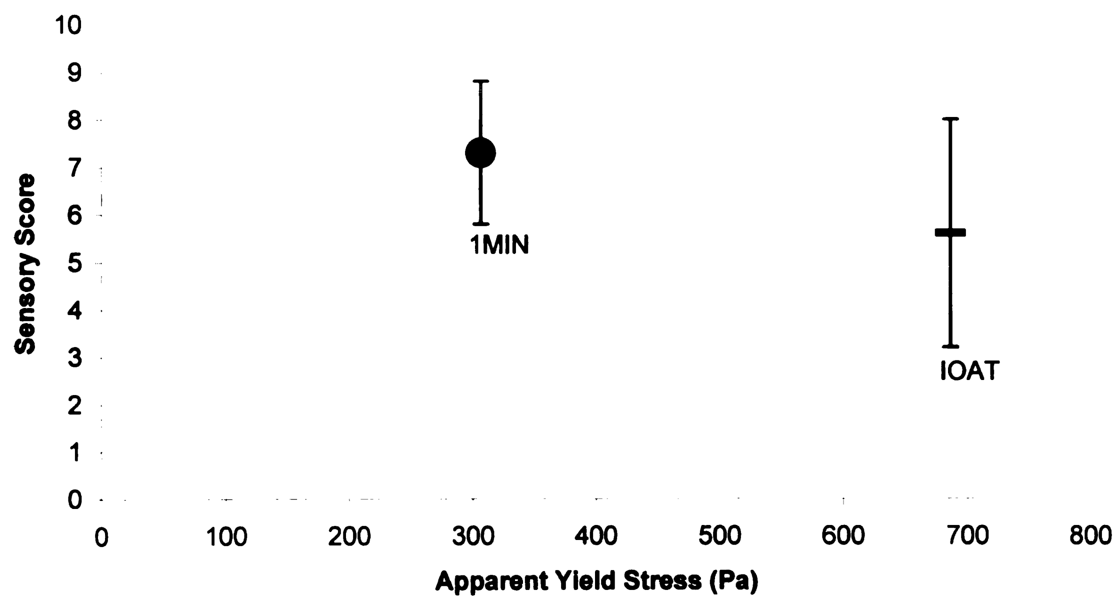


Figure 4.16. Average sensory score ± one standard deviation for viscosity for oat-based cereals versus apparent yield stress measurements.

There are explanations for why the sensory scores did not correlate with the apparent yield stress. Sensory terms are very complex and often reflect several sensations, contributing to the difficulty in finding meaningful correlations (Szczesniak 1987). It may be necessary to use more than one physical measurement to describe a particular sensory perception, rather than just relying on an apparent yield stress. The conclusion to be drawn is that the sensory parameters chosen do not closely represent the same characteristic that the vane method measures. Perhaps oral judgments could be explored to correlate with apparent yield stress measurements.

The lack of correlation does not mean that instrumental analysis is a poor method for characterizing hot cereals. On the contrary, there is a clear difference in hot cereal flow behavior based on the rheological method. Hence, the vane method to calculate an apparent yield stress can be used effectively for quality control and product development applications. For example, if a company is interested in introducing a new product as a line extension, and they would like to retain the same flow properties in the new product that are present in the existing product, this test allows the characteristics of the new product to be objectively evaluated as the ingredients are modified. In this way, the behavior of the new product can be monitored to insure that it has the same flow behavior as the traditional product.

It would be possible to implement a quality control test based on the vane method. Although the correlation results were not effective for either wheat-based or oat-based cereals, the rheological data is still valuable. The hold time recommended for evaluation would be between five and ten minutes for wheat cereals, and at twelve minutes for oat cereals, as these times are short enough to be convenient in industry and also produce consistent results.

5. Future Research

Attempting to characterize the flow behavior of these hot cereals gave rise to several issues that were not addressed in this work. A couple of recommendations for future work can be made:

1. Changes in both hydration and temperature clearly affect the thickening behavior of the hot cereals. As a result of observations during this research, the hypothesis is that time allowed for hydration has the more significant impact; however, the effects of each factor could be separated for a clearer picture.
2. The sensory parameters used in this work did not correlate with the instrumental measurements. Additional sensory parameters should be explored in the form of both oral and non-oral judgments.

6. Summary

Three wheat-based hot cereals (2 ½ Minute Cream of Wheat, Instant Original Cream of Wheat, and Malt-o-Meal) and two oat-based hot cereals (Regular Oatmeal and Instant Oatmeal) were evaluated using the vane method in an attempt to characterize the flow behavior of the cereals. The vane method was chosen as a simple, objective method of measurement to determine apparent yield stress values.

The hot cereals were also presented to a semi-trained descriptive analysis panel for sensory characterization. The panelists were asked to evaluate the cereals against a defined reference sample in four categories: thickness (stirrability), stickiness to spoon, stickiness to self, and viscosity. These parameters were suggested and defined by the panelists as a group. The test method used was a 15cm line scale with a reference sample at 7.5cm.

Results from the rheological tests were evaluated to determine the change in apparent yield stress over time (hydration and cooling) and also to compare the difference in apparent yield stress between the cereals in each category (i.e., wheat-based and oat-based). The results indicate that apparent yield stress is an effective parameter to characterize the flow behavior of the cereals. Each cereal had a characteristic value at any particular hold time relative to the other cereals in the category.

The sensory scores were analyzed by ANOVA to determine if panelists could distinguish between the different types of cereal. Panelists were able to tell the difference between at least two of the three wheat-based cereals for all four sensory parameters. Conversely, the panelists were only able to distinguish between the oat-based cereals for the parameter of viscosity.

Sensory scores for each parameter and the instrumentally determined apparent yield stress values were compared to determine if a particular sensory score could be predicted by the instrumental measurement. Regression analysis indicates that there is poor correlation between apparent yield stress and all hot cereal sensory parameters considered in this study.

The results from this work, although lacking correlation between sensory and instrumental parameters, are valuable. Data from the rheological measurements can be used to characterize the differences between each cereal. By choosing one hold time by which to compare the cereals, a quality control test can be designed for evaluation between batches of cereal as it is processed. Also, it is possible to use these apparent yield stress values to aid in product development through evaluation of alternative ingredients in a traditional product.

7. Appendix

7.1. Apparent Yield Stress Measurements for Wheat Based Cereals

Table 7.1. Measurements for apparent yield stress for each hold time for 2 1/2 Minute Cream of Wheat.

	min	5min	8min	10min	12min	14min	15min	18min	20min
	26.0	26.0	26.8	28.3	55.5	46.8	42.1	35.0	47.1
	21.3	30.2	38.7	29.6	37.7	41.5	43.7	58.6	47.3
	20.8	30.2	28.4	32.7	35.3	42.5	50.3	48.4	54.0
	20.3	34.7	27.3	37.0	36.1	40.4	42.9	47.7	49.9
	19.9	25.1	31.6	30.0	36.5	37.7	45.4	45.3	48.0
		29.8	29.8	28.1		38.6	46.3	50.9	50.6
		27.8	28.8			34.8	36.1	46.5	46.4
		36.0	32.0			40.6	39.8	47.8	51.8
		32.5				40.3	34.5	45.1	48.6
						37.5			43.4
						40.9			
Average	21.7	30.3	30.4	30.9	40.2	40.2	42.3	47.2	48.7
STDev	2.5	3.7	3.8	3.4	8.6	3.1	5.0	6.1	3.0
Var	6.2	13.5	14.6	11.7	73.6	9.7	24.7	37.6	8.9

Table 7.2. Measurements for apparent yield stress for each hold time for Instant Cream of Wheat.

	3min	5min	8min	10min	12min	14min	15min	18min	20min
	45.1	64.5	64.8	72.0	60.5	48.7	53.1	80.1	52.7
	41.2	45.1	69.7	62.6	69.1	75.8	60.6	67.1	68.9
	50.8	58.6	49.1	53.7	62.9	61.8	67.5	74.4	90.1
	55.4	57.4	61.9	44.4	54.5	77.6	55.3	59.8	62.2
	61.5	61.5	51.5	65.6	62.1	67.7	80.5	68.3	60.9
	52.6	43.6	52.5	65.9	49.9	59.2	69.7	70.0	70.3
		46.6	50.2	52.7	72.9	75.6	65.5	44.7	66.7
		45.6		54.8	63.0	38.6	63.3	45.1	72.8
Average	51.1	52.9	57.1	59.0	61.9	63.1	64.4	63.7	68.1
STDev	7.3	8.5	8.2	9.0	7.3	14.0	8.7	13.0	10.9
Var	52.7	71.5	67.6	81.4	53.6	196.1	75.0	168.5	119.5

Table 7.3. Measurements for apparent yield stress for each hold time for Malt-o-Meal.

	3min	5min	8min	10min	12min	14min	15min	18min	20min
	19.5	21.2	23.4	24.0	31.5	37.3	35.7	36.2	37.5
	19.6	20.1	22.1	26.9	29.0	32.6	28.2	35.2	40.9
	18.0	19.5	22.7	25.9	28.7	33.6	27.6	33.6	40.8
	18.0	18.6	24.8	24.5	29.5	30.1	28.6	36.6	34.7
	17.8	20.8	22.1	23.8	31.9	29.4	31.8	37.4	40.0
	20.0	23.4	23.6	22.6					
	21.2	21.4	22.4	24.4					
	19.8	18.4	22.5	26.3					
	19.3	20.5	23.6	22.1					
	20.5	20.8	23.1	21.4					
Average	19.4	20.5	23.0	24.2	30.1	32.6	30.4	35.8	38.8
STDev	1.1	1.4	0.8	1.8	1.5	3.2	3.4	1.5	2.6
Var	1.2	2.1	0.7	3.3	2.1	10.0	11.5	2.2	6.9

7.2. Apparent Yield Stress Measurements for Oat Based Cereals

Table 7.4. Measurements for apparent yield stress for each hold time for One Minute Oatmeal.

	3min	12min	14min	15min	18min	20min
	110.4	554.4	569.3	480.0	639.0	749.2
	133.7	527.8	524.8	431.8	670.1	570.1
	83.2	491.9	483.8	756.8	580.2	799.4
	100.9	456.2	553.7	462.2	506.1	656.0
	106.1	513.2	439.5	463.4	618.1	627.7
	115.5	539.6			705.1	550.0
	100.8					716.3
						638.6
Average	107.2	513.9	514.2	518.8	619.8	658.7
STDev	15.5	35.5	52.9	134.2	70.2	98.6
Var	239.8	1261.4	2802.3	17999.3	4931.3	9719.3

Table 7.5. Measurements for apparent yield stress for each hold time for Instant Regular Oatmeal.

	3min	5min	8min	10min	12min	14min	15min	18min	20min
	573.0	742.1	537.7	641.8	679.7	1048.7	780.1	846.0	984.4
	410.7	644.8	774.3	880.3	737.5	702.2	748.7	1079.0	709.4
	518.5	443.9	828.7	746.0	874.4	987.8	866.1	788.1	1004.6
	488.8	559.5	795.2	543.3	780.0	809.5	826.8	945.9	862.5
	461.8	791.0	604.8	736.0	808.8	871.6	823.9	1222.4	1207.8
	404.2	473.1	743.1	770.3					1135.4
		639.1		878.1					
Average	476.2	613.3	714.0	742.2	776.1	883.9	809.1	976.3	984.0
STDev	64.8	129.8	116.0	121.1	73.4	138.4	45.5	176.4	180.9
Var	4201.3	16848.9	13447.5	14673.6	5382.1	19166.6	2068.0	31101.5	32719.1

7.3. Sensory Scores Based on 15cm Line Scale for Wheat-Based Cereals

Table 7.6. Sensory scores for thickness (stirrability) for wheat-based cereals.

		COW	ICOW	MOM
Panelist	1	8.53	8.29	11.29
	2	8.29	4.78	11.88
	3	6.59	11.52	8.09
	4	7.97	4.23	8.45
	5	10.62	10.97	13.38
	6	8.72	12.91	13.42
	7	6.75	12.43	12.59
	8	6.43	8.21	10.18
	9	6.63	9.87	10.22
	10	6.24	10.38	11.88
	11	8.72	9.28	9.71
	12	8.33	8.8	9.83
	1	7.3	7.18	10.74
	2	7.62	8.8	9.99
	3	7.66	8.09	12.31
	4	7.3	7.86	9.47
	5	8.21	12.2	14.37
	6	8.17	11.45	14.52
	7	7.62	13.06	13.97
	8	7.46	8.96	13.22
	9	6.87	6.79	13.58
	10	6.67	10.93	11.21
	11	7.46	9.47	14.64
	12	7.03	8.6	10.81
	1	6.51	6.59	12.59
	2	6.16	7.86	10.22
	3	7.58	8.33	12.39
	4	6.99	6.99	12.43
	5	5.01	12.31	14.33
	6	6.99	8.13	9.43
	7	6.3	10.93	10.97
	8	4.5	10.58	13.62
	9	5.09	4.66	9.08
	10	6.51	5.61	8.57
	11	3.71	11.76	13.97
	12	6.47	10.62	11.56
Average		7.08	9.15	11.64
STDev		1.29	2.38	1.92
Var		1.67	5.66	3.69

Table 7.7. Sensory scores for stickiness to spoon for wheat-based cereals.

		COW	ICOW	MOM
Panelist	1	7.82	4.78	10.58
	2	10.93	3.87	12.63
	3	6.47	10.74	6.75
	4	8.17	4.11	12.16
	5	10.3	6.87	12.31
	6	8.29	14.44	13.66
	7	4.34	8.68	13.5
	8	6.75	6.63	10.03
	9	6.16	9.79	9.04
	10	6.32	9.71	11.09
	11	9.95	8.64	11.13
	12	6.83	7.9	11.13
	1	9.24	7.11	10.1
	2	8.13	9.08	10.14
	3	7.26	8.09	10.42
	4	5.84	6.59	9.28
	5	4.97	12.98	13.81
	6	5.88	11.68	15
	7	4.82	8.76	13.3
	8	7.58	8.25	13.38
	9	7.22	5.45	11.92
	10	5.29	6.91	11.01
	11	6.04	7.18	12.59
	12	6.99	8.49	10.66
	1	6.2	6.51	12.47
	2	6.4	6.95	9.51
	3	6.51	9.55	12.31
	4	7.5	7.93	11.09
	5	4.66	11.49	14.25
	6	8.09	5.84	10.66
	7	6.25	8.29	11.17
	8	4.26	8.68	13.38
	9	4.34	0.52	8.96
	10	7.11	5.21	7.86
	11	3.51	10.54	13.38
	12	6.28	8.21	11.68
Average		6.74	7.96	11.45
STDev		1.72	2.65	1.86
Var		2.94	7.04	3.44

7.8. Sensory scores for stickiness to self for wheat-based cereals.

		COW	ICOW	MOM
Panelist	1	7.7	5.61	9.47
	2	9.75	8.13	10.06
	3	6.28	13.26	7.11
	4	10.93	2.84	8.76
	5	8.72	12.35	12.51
	6	6.59	13.81	13.46
	7	7.54	13.38	12.12
	8	7.5	9.39	9.91
	9	6.87	10.74	9.28
	10	7.38	10.97	12.23
	11	7.54	5.92	12.16
	12	6.83	9.75	10.38
	1	8.13	7.89	10.18
	2	10.06	1.7	4.54
	3	7.22	8.8	9.99
	4	9.47	5.84	12
	5	4.97	11.52	12.43
	6	2.69	12.63	15
	7	2.65	13.1	13.38
	8	6.36	8.25	10.7
	9	7.38	7.89	13.3
	10	3.79	11.72	10.14
	11	4.07	11.29	13.38
	12	6.71	10.5	11.09
	1	5.13	6.83	12.16
	2	5.68	8.41	9.91
	3	8.57	4.3	10.42
	4	7.46	8.57	13.18
	5	6.55	13.18	12.75
	6	6.71	11.21	10.18
	7	5.95	11.76	11.96
	8	4.23	10.77	13.54
	9	2.96	7.14	6.36
	10	7.11	6.43	7.42
	11	4.11	12.08	13.93
	12	7.93	5.49	3.99
Average		6.65	9.26	10.82
STDev		2.03	3.15	2.56
Var		4.12	9.90	6.57

Table 7.9. Sensory scores for viscosity for wheat-based cereals.

		COW	ICOW	MOM
Panelist	1	8.01	7.7	11.6
	2	10.5	10.7	12.12
	3	6.55	13.34	6.43
	4	8.88	2.13	8.6
	5	7.42	11.37	11.8
	6	8.92	13.02	11.76
	7	5.21	13.81	9.75
	8	6.36	10.54	9.04
	9	6.63	9.43	11.72
	10	6.79	11.56	12.98
	11	9.16	10.38	9.39
	12	6.47	9.28	9.67
	1	7.89	7.86	9.75
	2	4.97	12.04	5.41
	3	6.04	8.21	7.7
	4	6.59	8.37	9.99
	5	5.21	14.4	10.42
	6	5.05	14.33	14.48
	7	3.48	13.46	11.72
	8	6.08	8.49	11.92
	9	7.14	7.93	13.46
	10	5.25	8.09	7.18
	11	3.71	11.68	12.23
	12	7.07	8.76	10.62
	1	4.94	8.41	11.96
	2	5.76	9.51	10.89
	3	6	9.71	4.42
	4	8.29	9.04	11.8
	5	7.26	13.66	9.63
	6	6.71	7.9	9.16
	7	6.35	9.32	8.64
	8	10.58	10.03	13.93
	9	2.65	11.21	7.26
	10	5.96	6.32	7.42
	11	3.99	11.96	10.03
	12	6.24	10.89	10.97
Average		6.50	10.13	10.16
STDev		1.79	2.55	2.34
Var		3.21	6.53	5.47

7.4. Sensory Scores Based on 15cm Line Scale for Oat-Based Cereals

Table 7.10. Sensory scores for thickness (stirrability) for oat-based cereals.

		1MIN	IOAT
Panelist	1	10.77	8.53
	2	10.81	8.29
	3	6.67	6.59
	4	4.7	7.97
	5	7.38	10.62
	6	6.83	8.72
	7	7.5	6.75
	8	5.41	6.43
	9	7.07	6.63
	10	8.84	6.24
	11	7.22	8.72
	12	7.42	8.33
	1	1.62	4.78
	2	4.3	3.91
	3	2.17	7.74
	4	8.76	6.63
	5	7.86	12.31
	6	8.41	10.03
	7	4.15	10.85
	8	8.17	6.59
	9	2.73	6.4
	10	6.2	9.75
	11	6.67	8.01
	12	7.7	7.26
	1	10.66	12.51
	2	7.54	7.89
	3	8.37	2.57
	4	6.47	8.84
	5	8.13	10.58
	6	6.63	6.99
	7	8.01	7.86
	8	7.42	8.72
	9	8.17	9.95
	10	7.07	7.54
	11	7.82	1.82
	12	6.71	10.46
Average		7.01	7.88
STDev		2.11	2.35
Var		4.45	5.54

Table 7.11. Sensory scores for stickiness to spoon for oat-based cereals.

		1MIN	IOAT
Panelist	1	8.25	6.75
	2	8.37	6.99
	3	6.16	4.66
	4	0.4	0.56
	5	7.38	6.28
	6	6.95	8.33
	7	7.5	8.8
	8	6.95	8.17
	9	7.22	8.17
	10	7.26	7.93
	11	6.91	8.53
	12	7.5	7.82
	1	4.58	7.18
	2	7.54	0.4
	3	5.21	7.5
	4	7.62	8.41
	5	7.66	7.7
	6	7.62	7.82
	7	6.75	7.9
	8	7.46	7.58
	9	2.17	6.67
	10	7.38	8.53
	11	6.95	7.89
	12	7.5	7.5
	1	9.67	9.04
	2	7.42	7.38
	3	7.46	7.62
	4	6.95	6.99
	5	7.42	8.88
	6	6.71	7.82
	7	7.5	7.58
	8	7.3	7.78
	9	7.5	8.88
	10	7.3	7.42
	11	7.82	7.5
	12	7.11	10.62
Average		6.93	7.38
STDev		1.62	1.95
Var		2.63	3.79

Table 7.12. Sensory scores for stickiness to self for oat-based cereals.

		1MIN	IOAT
Panelist	1	9	5.76
	2	8.6	2.57
	3	6.99	6.43
	4	2.49	2.49
	5	6.59	4.9
	6	7.54	10.14
	7	7.5	9.59
	8	6.87	7.97
	9	7.38	8.84
	10	7.54	9.16
	11	5.88	7.78
	12	7.5	7.5
	1	6.47	6.2
	2	8.72	9
	3	6.12	7.38
	4	8.57	9.12
	5	8.57	11.6
	6	7.5	9.12
	7	6.04	8.8
	8	8.8	6.4
	9	2.41	5.76
	10	7.42	6
	11	6.24	7.97
	12	7.5	7.03
	1	9.83	9.16
	2	7.46	4.38
	3	9.55	8.09
	4	5.25	2.13
	5	7.5	10.85
	6	7.5	3.12
	7	7.62	5.57
	8	7.54	6.47
	9	6.87	6.24
	10	7.18	7.42
	11	8.68	3.75
	12	7.03	9.51
Average		7.23	7.06
STDev		1.56	2.40
Var		2.43	5.74

Table 7.13. Sensory scores for viscosity for oat-based cereals.

		1MIN	IOAT
Panelist	1	9.59	5.61
	2	10.26	1.94
	3	6.39	3.36
	4	6.63	4.66
	5	7.07	3.67
	6	7.14	6.36
	7	7.5	0.83
	8	6.75	5.45
	9	7.42	7.93
	10	8.17	6.2
	11	7.34	5.88
	12	6.91	9.12
	1	3.04	2.88
	2	4.86	3.16
	3	4.19	6.79
	4	10.1	6
	5	7.5	8.72
	6	7.11	9.35
	7	5.05	7.58
	8	8.45	4.03
	9	4.82	7.14
	10	8.45	8.49
	11	6.91	6.63
	12	7.93	6.4
	1	8.72	7.89
	2	7.42	4.42
	3	8.84	2.21
	4	6.51	3.63
	5	7.5	10.7
	6	7.5	6.24
	7	9.43	2.02
	8	7.54	5.57
	9	7.22	5.17
	10	7.46	6.83
	11	7.97	1.62
	12	6.87	6.99
Average		7.29	5.60
STDev		1.54	2.41
Var		2.37	5.80

7.5. ANOVA Results for Descriptive Analysis for Wheat-Based Cereals

Table 7.14. ANOVA table for wheat cereals for the sensory parameter "thickness."

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	13	479.26	36.87	12.34	<.0001
Error	94	280.89	2.99		
Corrected total	107	760.15			

Table 7.15. Effect of subject on variation between wheat cereals for the sensory parameter "thickness."

Source	Degrees of freedom	Type III SS	Mean Square	F Value	Pr>F
Subject	11	105.11	9.56	3.20	0.0010
Treatment	2	374.15	187.08	62.61	<.0001

Table 7.16. Least Squares Means for effect of treatment for wheat cereals and the sensory parameter "thickness."

	1	2	3
1		<.0001	<.0001
2	<.0001		<.0001
3	<.0001	<.0001	

Table 7.17. ANOVA table for wheat cereals for the sensory parameter “stickiness to spoon.”

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	13	515.34	39.64	9.66	<.0001
Error	94	385.64	4.10		
Corrected total	107	900.99			

Table 7.18. Effect of subject on variation between wheat cereals for the sensory parameter “stickiness to spoon.”

Source	Degrees of freedom	Type III SS	Mean Square	F Value	Pr>F
Subject	11	84.42	7.67	1.87	0.0531
Treatment	2	430.93	215.46	52.52	<.0001

Table 7.19. Least Squares Means for effect of treatment for wheat cereals and the sensory parameter “stickiness to spoon.”

	1	2	3
1		0.0125	<.0001
2	0.0125		<.0001
3	<.0001	<.0001	

Table 7.20. ANOVA table for wheat cereals for the sensory parameter "stickiness to self."

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	13	414.77	31.91	4.80	<.0001
Error	94	624.39	6.64		
Corrected total	107	1039.16			

Table 7.21. Effect of subject on variation between wheat cereals for the sensory parameter "stickiness to self."

Source	Degrees of freedom	Type III SS	Mean Square	F Value	Pr>F
Subject	11	96.17	8.74	1.32	.2277
Treatment	2	318.60	159.30	23.98	<.0001

Table 7.22. Least Squares Means for effect of treatment for wheat cereals and the sensory parameter "stickiness to self."

	1	2	3
1		<.0001	<.0001
2	<.0001		.0121
3	<.0001	.0121	

Table 7.23. ANOVA table for wheat cereals for the sensory parameter "viscosity."

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	13	382.15	29.40	5.89	<.0001
Error	94	468.84	4.99		
Corrected total	107	850.99			

Table 7.24. Effect of subject on variation between wheat cereals for the sensory parameter "viscosity."

Source	Degrees of freedom	Type III SS	Mean Square	F Value	Pr>F
Subject	11	63.20	5.74	1.15	.3313
Treatment	2	318.95	159.48	31.97	<.0001

Table 7.25. Least Squares Means for effect of treatment for wheat cereals and the sensory parameter "thickness."

	1	2	3
1		<.0001	<.0001
2	<.0001		.9576
3	<.0001	.9576	

7.6. ANOVA Results for Descriptive Analysis for Oat-Based Cereals

Table 7.26. ANOVA table for oat cereals for the sensory parameter "thickness (stirrability)."

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	12	70.530	5.877	1.18	0.3153
Error	59	292.749	4.962		
Corrected total	71	363.278			

Table 7.27. ANOVA table for oat cereals for the sensory parameter "stickiness to spoon."

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	12	47.874	3.989	1.31	0.2400
Error	59	180.310	3.056		
Corrected total	71	228.183			

Table 7.28. ANOVA table for oat cereals for the sensory parameter "stickiness to self."

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	12	49.697	4.141	1.03	0.4319
Error	59	236.537	4.010		
Corrected total	71	286.234			

Table 7.29. ANOVA table for oat cereals for the sensory parameter "viscosity."

Source	Degrees of freedom	Sum of squares	Mean square	F value	Pr>F
Model	12	99.500	8.292	2.05	0.0348
Error	59	238.307	4.039		
Corrected total	71	337.807			

Table 7.30. Effect of subject on variation between oat cereals for the sensory parameter "viscosity."

Source	Degrees of freedom	Type III SS	Mean Square	F Value	Pr>F
Subject	11	47.667	4.333	1.07	0.3982
Treatment	1	51.833	51.833	12.83	0.0007

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