

Application of the vane method in textural characterization of
soy-based yogurt

by

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GENERAL INTRODUCTION

SOY FOODS

Due to remarkable nutritional value and functional properties of soybeans, their utilization for human consumption remains a popular subject of investigation by many food scientists and engineers all over the world. With a growing population, soybeans may be used to address the problem of protein deficiency, an issue in many developing countries, because a soy bean contains 33 - 40% protein. Furthermore, soybeans have a potential not just to "feed the world" but also to make it healthier. Numerous studies have shown health benefits associated with the consumption of soybeans. Incorporated in foods, they reduce the risk of cancer and of heart diseases, prevent osteoporosis and high cholesterol levels in blood (Barnes 1998; Govindji 1999; Riaz 1999). In addition, soy protein based foods may serve as a milk product substitute for dairy intolerable consumers (Johnson 1975; Egbert 1999) and meat product replacement for vegetarians.

It is believed that soybeans have been used in Asia for more than four thousand years, while to North Americans they were introduced only in the middle of 18th century (Wilson 1999). Although this crop is still viewed in the United States mainly as a source of vegetable oil and animal feed, soy products are gradually filling American food markets in the form of traditional Asian

products as well as novel snack foods, desserts, infant formulas and nutritional beverages (Table 1).

SOY PROTEIN AND GELATION

Proteins are polymers composed of different amino acids, which are linked together by peptide bonds (primary structure). The amino acid composition and character of the polypeptide molecule side chains determine secondary, tertiary and quaternary structures of proteins, which, in turn, affect their functional and processing properties. Soy proteins are globulins with a complex quaternary structure. Due to their heterogeneous nature, these proteins were originally separated by their sedimentation properties into four fractions: 2S, 7S, 11S and

Table 1. Soy food products.

<i>Category</i>	<i>Product</i>
Nonfermented	Soybeans
	Soymilk
	Soynuts
	Soynut Butter
	Soybean Sprouts
	Tofu and Tofu Products
	Soy-Based Whipped Toppings
	Yuba
Fermented	Soy Sauce (Tamari, Shoyu, Teriyaki)
	Soy Yogurt
	Tempeh
	Miso
	Natto

15S (Wolf 1972). The composition and content percentage of these fractions are given in Table 2. Two major fractions are 7S (conglycinin) and 11S (glycinin) with molecular weights of 186,000 - 210,000 daltons and 350,000 daltons (Schmidt and Morris 1984) and denaturation temperatures of 74°C and 90°C, respectively (Renkema et al. 2000).

Table 2. Fractions of soy proteins (modified after Wolf 1972)

<i>Protein Fraction</i>	<i>Percentage of total</i>	<i>Components</i>
2S	22	Trypsin inhibitors Cytochrome c 2.3S and 2.8S globulins allantoinase
7S	37	β -amylase hemagglutinins lipoxygenases 7S globulin (conglycinin)
11S	31	11S globulin (glycinin)
15S	11	-

Gelation is an important functional property of proteins used in preparation of many fermented and nonfermented food products, such as cheese, yogurt and tofu. Protein gels, complex three-dimensional networks of polypeptides that exhibit both fluid (viscous) and solid (elastic) behaviors, are formed by denaturation and interactions including dissociation-association, and aggregation (Hermansson 1986). The mechanism of soy protein gelation is not

fully understood; however, it is well established that heat treatment and pH level are important factors in its formation (Hermansson 1986; Puppo and Anon 1998a, 1998b, 2000). Heating allows globular proteins to denature, and expose their reactive groups, which subsequently form inter- and intramolecular links. The four main types of attractive forces involved in the formation of protein network are covalent interactions (200 - 400 kJ mol⁻¹), electrostatic forces (25 - 80 kJ mol⁻¹), hydrogen bonds (10 - 40 kJ mol⁻¹) and hydrophobic bonds (5 - 10 kJ mol⁻¹) (Dickinson 1997). These forces contribute differently to the final gel strength depending on the gel formation conditions, such as protein concentration level, level of protein denaturation, heating/cooling, presence of salts, and pH level (Chronakis 1996; Puppo and Anon 2000; Renkema *et al.* 2000). Addition of coagulants, such as calcium sulfate (CaSO₄), magnesium chloride (MgCl₂), calcium chloride (CaCl₂), glucono- δ -lactone (GDL) or lactic acid yogurt cultures also alters gelation rate and affects breaking strength of the resulting soy protein gel.

CONVENTIONAL METHODS OF GEL TEXTURE ANALYSIS

Texture is among the most important characteristics of food products, which along with flavor, determines its level of consumer acceptance. The texture of a food material is governed by its physical and physicochemical properties on microstructural and macrostructural levels. Depending on testing methodology, textural properties of gels may be described by a wide variety of

subjective (qualitative) and objective (quantitative) parameters. Instrumental methods may be grouped by the type of deformation to which material is subjected: compression, extension and shearing. Techniques used for texture analysis of food gels that will be reviewed in this section are texture profiling using compression instruments, and rheological characterization methods in shear.

Compression methods

Two representatives of a group of instruments that utilize compression deformation are TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, New York) and Instron Universal Testing Machine (Instron Corporation, Canton, Massachusetts). During texture profile analysis, a sample is usually compressed between two surfaces, with one of them being stationary, and the resultant force is measured in a time domain. By applying compression in two cycles, this technique simulates human's first and second bites, which are believed to be the most important in human texture perception. A generalized texture profile curve is shown in Fig. 1. Some texture parameters of gel-like foods that can be quantified with this curve include hardness (or breaking strength), fracturability, cohesiveness ($= \text{Area}_2/\text{Area}_1$), springiness ($= \text{Length}_2/\text{Length}_1$), and gumminess ($= \text{hardness} * \text{cohesiveness}$).

In addition to texture profiling, compression instruments can be used for creep and stress relaxation tests (Tang *et al.* 1998; Karim *et al.* 2000). Unlike

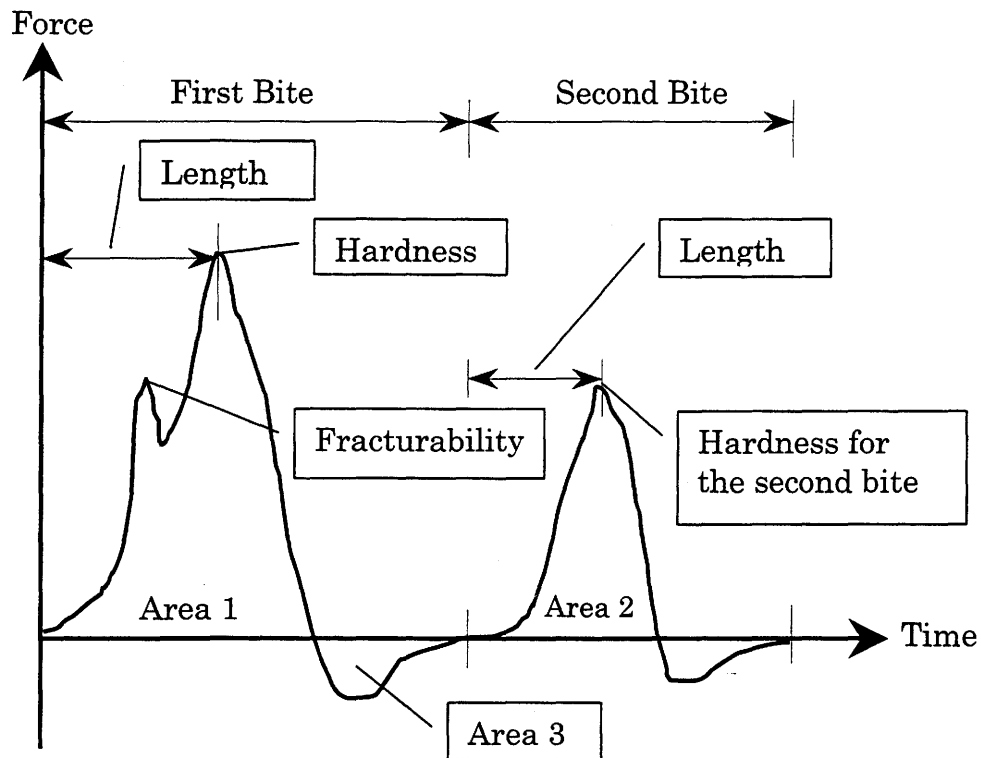


Figure 1. Generalized texture profile curve obtained in compression deformation test.

texture profile analysis, these tests do not involve large deformations and do not destroy gel structure. In a creep experiment, a constant stress is applied to a sample and corresponding strain or displacement is measured as a function of time. In a stress relaxation test, a sample is subjected to a constant strain and the stress required to maintain this strain is measured against time (Karim *et al.* 2000). Typical stress relaxation curves for ideal elastic, viscoelastic and ideal viscous materials are illustrated in Fig. 2.

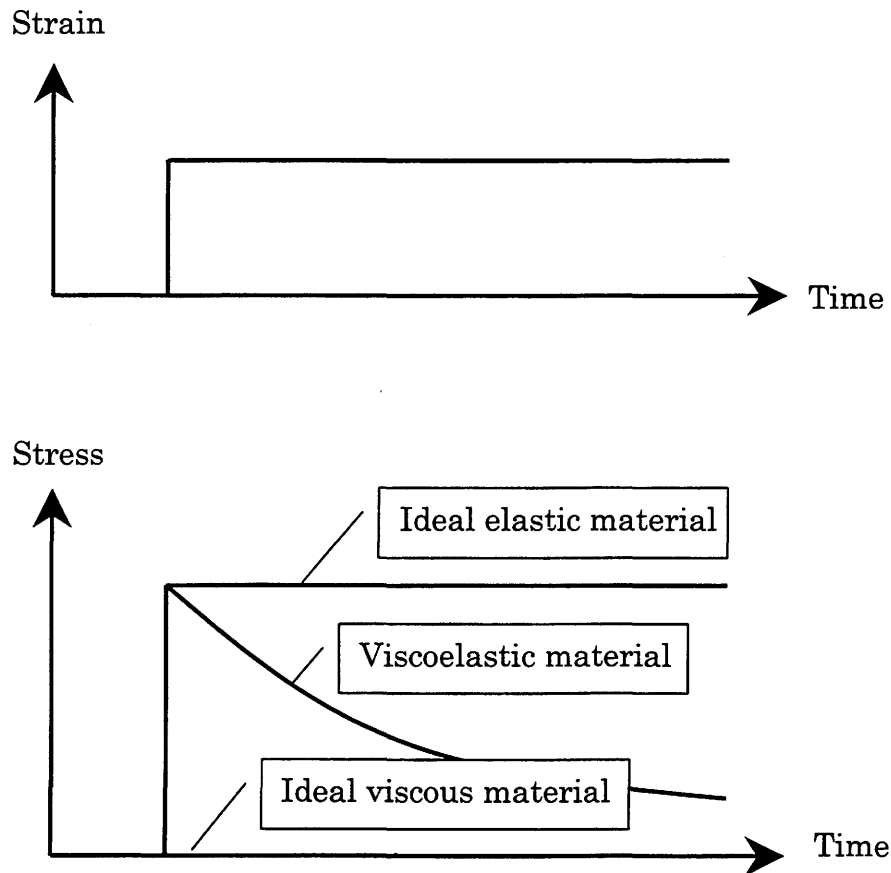


Figure 2. Typical stress relaxation curves
(Source: Steffe, 1996).

Shearing methods

Shearing methods, similarly to those that involve compression, are divided by the level of deformation to which the sample is subjected into two categories small and large deformation. Small deformation methods can be grouped into transient and oscillatory (Steffe 1996). The two most widely used transient shearing experiments are stress relaxation and creep. This methodology is similar to compression stress relaxation and creep tests covered in the previous subsection except they are performed in shear. In oscillatory experiments, a

sample is subjected to a small amplitude sinusoidal stress or strain at fixed frequency and the response signal (strain or stress), different in amplitude and phase, is measured (Fig 3). Parameters of viscoelasticity, such as phase lag (δ , degrees), complex shear modulus ($G^* = \sigma_o/\gamma_o$, Pa), storage modulus ($G' = G^* \cos \delta$, Pa), loss modulus ($G'' = G^* \sin \delta$, Pa) are obtained in this experiment (Steffe 1996).

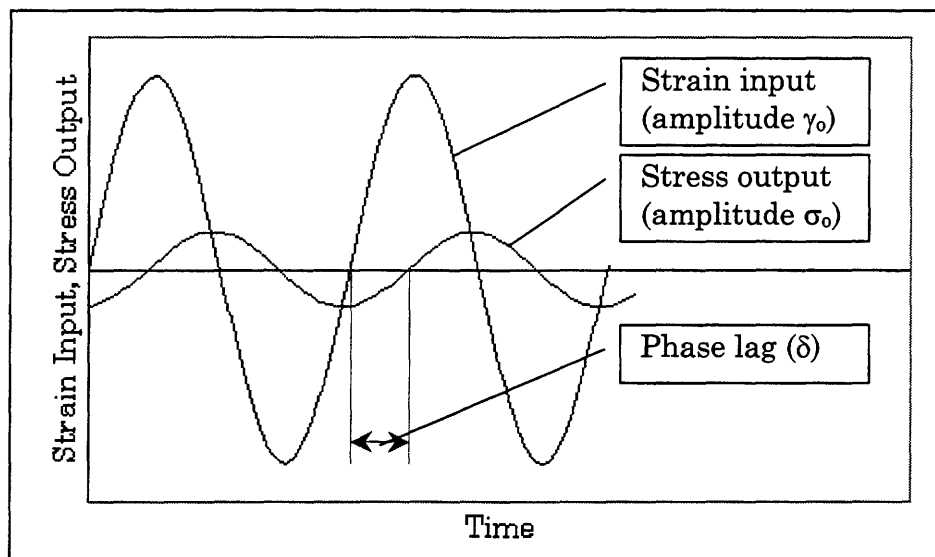


Figure 3. Typical oscillatory test input and output for a viscoelastic sample.

Being non-destructive, the small deformation tests are very useful for a dynamic observation of sample properties during the gelation process. On the other hand, large deformation tests are used to characterize fully developed gel systems, in particular, their failure conditions. A gel sample is prepared in situ, that is between two surfaces of the instrument's sensor system, and deformed in

stress or strain controlled mode until its structure fails. Yield stress (σ_0 , Pa) and yield strain (γ_0 , dimensionless), two fundamental rheological characteristics of materials are obtained in this experiment. Yield stress may be defined as a minimum force per unit area needed to initiate flow of material; yield strain is a level of deformation at yielding point. These parameters are significant for numerous food products and applications. They determine how well the product will flow from the container or how well the applied coating is going to hold on the surface. Furthermore, yield stress and strain correlate well with human perception of food texture (Jankowski and Rha 1986; Keetels *et al.* 1996), because the process of masticating and swallowing of food involves large deformations.

VANE METHOD IN TEXTURE CHARACTERIZATION OF GELS

Vane method is a comparatively new technique in texture characterization of foods. It has been adapted from soil mechanics, and is being used for measurement of yield stress and yield strain of various food materials (Missaire *et al.* 1990; Briggs *et al.* 1995; Yoo *et al.* 1995; Daubert *et al.* 1998). In this method, usually a four-bladed vane (Fig. 4a) is immersed in a sample and rotated at constant rate. The torque, required to maintain this fixed rotation rate, is recorded as a function of time (Fig. 4b). The characteristics of torque-time curve are functions of the viscoelasticity of the tested material. With food gels, sample "stores" energy, behaving as elastic material on the rising interval

of the curve. Then, at torque peak value (M_{\max} , N m), the bonds that formed its three-dimensional network are disrupted and gel structure fractures.

Yield stress value can be calculated from a relationship between the vane dimensions and M_{\max} (Dzuy and Boger 1985):

$$M_{\max} = \frac{\pi D^3}{2} \left(\frac{H}{D} + \frac{1}{m+3} \right) \sigma_o, \quad [1]$$

where H and D are height and diameter of the vane immersed in material (m), respectively, and m is a coefficient which describes the radial distribution function of shear stress on the top and bottom surfaces of the vane. Generally, the assumption $m = 0$ is a valid approximation, particularly for the experiments

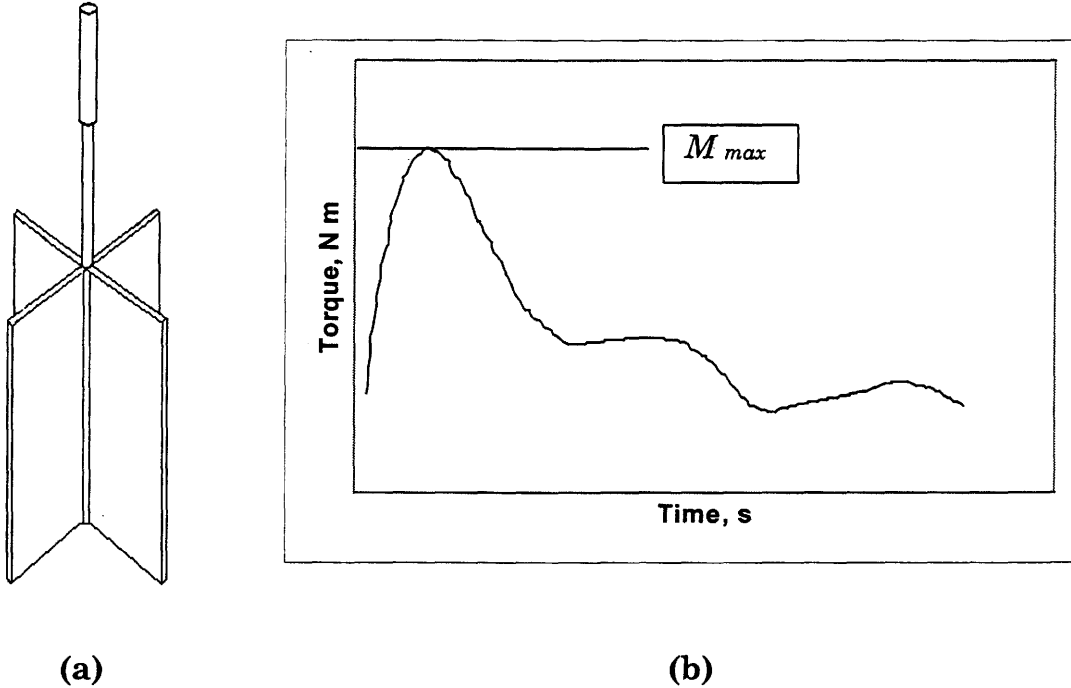


Figure 4. (a) Four-bladed vane. (b) Typical torque-time curve observed in the vane method.

comparing product quality (Steffe 1996). The error associated with this assumption may be partially eliminated by placing the top surface of the vane even with the sample surface (Steffe 1996). Solving for σ_o , and assuming $m = 0$, Eq. [1] becomes

$$\sigma_o = \frac{6M_{\max}}{\pi D^2 (3H + D)} \quad , \quad [2]$$

Two methods of gel yield strain calculation have been described in the literature. Alderman *et al.* (1991) used equation of Hooken elastic solid:

$$\gamma_o = \frac{\sigma_o}{G} \quad [3]$$

Here, G (Pa) is elastic modulus, which can be obtained as follows:

$$G = \frac{1}{4\pi\omega} \left(\frac{dT}{dt} \right) \left(\frac{1}{R^2} - \frac{1}{R_c^2} \right), \quad [4]$$

where $R = (D/2)$ is radius of the vane (m), R_c is radius of the sample container (m), ω (rad/s) is the angular velocity of the vane at radius R , and t is time (s).

The other method was described by Truong and Daubert (2000). It takes into account the diameter of fracture zone edges observed on the gel surface during testing and angular deformation:

$$\gamma_o = \frac{\Omega t}{(D_f/D) - 1}, \quad [5]$$

where (Ωt) is angular deformation (rad), $\Omega = 2\pi(\text{rpm})/60$ is the angular velocity (rad/s), D_f is the diameter of fracture zone (m), t is time at yield (s).

THESIS OBJECTIVES

The objectives of the present study were (1) to analyze the applicability of the vane method for textural characterization of soy yogurts prepared from five varieties of soybeans, (2) to characterize physical properties of soy yogurts as a function of protein content and composition.

THESIS ORGANIZATION

This thesis, "Application of the Vane Method in Textural Characterization of Soy-based Yogurt", is written in the alternate thesis format. The paper contained within this thesis is written in the format required for Journal of Texture Studies. General conclusions and recommendations for future research follow the paper.

Jenni L. Briggs, major professor, guided, analyzed, and reviewed this research and the paper.

REFERENCES

- ALDERMAN, N.J., MEETEN, G.H., SHERWOOD, J.D. 1991. Vane rheometry of bentonite gels. *J. Non-Newton. Fluid.* 39(4), 291-310.
- BARNES, S. 1998. Evolution of the health benefits of soy isoflavones. *Proc. Soc. Exp. Biol. Med.* 217(3), 386-392.

- BRIGGS, J.L., STEFFE, J.F., USTUNOL, Z. 1995. Vane method to evaluate the yield stress of frozen ice cream. *J. Dairy Sci.* 79, 527-531.
- CHRONAKIS, I. 1996. Network formation and viscoelastic properties of commercial soy protein dispersions: effect of heat treatment, pH and calcium ions. *Food Res. Int.* 29(2), 123-134.
- DAUBERT, C.R., TKACHUK, J.A., TRUONG, V.D. 1998. Quantitative measurement of food spreadability using the vane method. *J. Texture Studies* 29, 427-435.
- DICKINSON, E. 1997. Enzymic crosslinking as a tool for food colloid rheology control and interfacial stabilization. *Trends Food Sci. Tech.* 8, 334-339.
- DZUY, N.Q., BOGER, D.V. 1985. Direct yield stress measurement with the vane method. *J. Rheol.* 29(3), 335-347.
- EGBERT, R. 1999. Soy protein in the food processing industry. *Proceedings of World Soybean Research Conference VI*, Chicago, Illinois; August 1999.
- GOVINDJI, A. 1999. The soya bean: so small yet so mighty. *Nutrition Food Sci.* 99(3), 144-148.
- HERMANSSON, A.M. 1986. Soy protein gelation. *J. Am. Oil Chem. Soc.* 63(5), 658-666.
- JANKOWSKI, T., RHA, C.K. 1986. Retrogradation of starch in cooked wheat. *Starch/Stärke* 38(1), 6-9.
- JOHNSON, D. 1975. Use of soy products in dairy product replacement. *J. Am. Oil Chem. Soc.* 52(4), 270A-271A.

- KARIM, A.A., NORZIAH M.H., SEOW C.C. 2000. Methods for the study of starch retrogradation. *Food Chem.* 71, 9-36.
- KEETELS, C.J.A.M., VAN VLIET, T., JURGENS, A., WALSTRA, P. 1996. Effects of lipid surfactants on the structure and mechanics of concentrated starch gels and starch bread. *J. Cereal Sci.* 24(1), 33-45.
- MISSAIRE, F., QIU, C-G., RAO, M.A. 1990. Yield stress of structured and unstructured food suspensions. *J. Texture Studies* 21, 479-490.
- PUPPO, M.C., ANON M.C. 1998a. Effect of pH and protein concentration on rheological behavior of acidic soybean protein gels. *J. Agr. Food Chem.* 46, 3039-3046.
- PUPPO, M.C., ANON M.C. 1998b. Structural properties of heat-induced soy protein gels as affected by ionic strength and pH. *J. Agr. Food Chem.* 46, 3583-3589.
- PUPPO, M.C., ANON M.C. 2000. Gelation of soybean proteins at acidic pH. In *Trends in Food Engineering*, ed. Lozano, J. E., Anon, C., Parada-Arias, E., Barbosa-Canovas, G. V. Technomic Publishing Co., Inc., Lancaster, Pa, 327-340.
- RENKEMA, J.M.S., LAKEMON, C.M.M., DE JONGH, H.H.J., GRUPPEN, H., VAN VLIET, T. 2000. The effect of pH on heat denaturation and gel forming properties of soy proteins. *J. Biotechn.* 79, 223-230.
- RIAZ, M.N.1999. Soybeans as functional foods. *Cereal Food World*, 44(2), 88-92.

- SCHMIDT, R.H., MORRIS, H.A. 1984. Gelation properties of milk proteins, soy proteins, and blended protein systems. *Food Technol.-Chicago* 38(5), 85-88, 90, 92-94, 96.
- STEFFE, J.S. 1996. *Rheological methods in food process engineering* (2nd edition). Freeman Press, East Lansing, Michigan.
- TANG, J., TUNG, M.A., ZENG, Y. 1998. Characterization of gellan gels using stress relaxation. *J. Food Eng.* 38, 279-295.
- TRUONG, V.D., DAUBERT, C.R. 2000. Comparative study of large strain methods for assessing failure characteristics of selected food gels. *J. Texture Studies* 31, 335-353.
- WILSON, L. 1999. Current developments in soyfood processing in North America. *Proceedings of World Soybean Research Conference VI*, August 1999, Chicago, Illinois, USA.
- WOLF, W.J. 1972. What is soy protein? *Food Technol.-Chicago* 26(5), 44-45, 48, 50, 52-54.
- YOO, B., RAO, M.A., STEFFE, J.F. 1995. Yield stress of food dispersions with the vane method at controlled shear rate and shear stress. *J. Texture Studies* 26, 1-10.

APPLICATION OF THE VANE METHOD IN TEXTURAL CHARACTERIZATION OF SOY-BASED YOGURT

A paper to be submitted for publication in the Journal of Texture Studies

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ABSTRACT

Vane method was applied to measure failure characteristics of soy-based yogurts prepared from five soybean varieties: Vinton 81, Asgrow 2401, HP204, IA2056, and IA2025. Yield stress, yield strain, water-holding capacity, and subunit composition of 7S and 11S protein fractions of gel samples were compared. The experiment showed that the vane method may be effectively used as a rapid and inexpensive technique for textural characterization of soy protein-based yogurts. Yield stress (strength), unlike yield strain (elasticity), of tested soy yogurt samples was dependent on protein content and soybean variety. Water-holding capacity was variety dependent, although this dependence was less pronounced at higher protein concentrations. No evidence of correlation between 11S/7S ratio and yield stress of tested samples was found. Analysis suggested that yield stress of soy-based yogurt may be affected by content of acidic subunit AI of 11S fraction.

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INTRODUCTION

An interest in soy-based products has been stimulated by the remarkable nutritional value and significant health benefits of soy components. Incorporated in foods, they have been shown to reduce the risk of cancer and of heart diseases, and to prevent osteoporosis and high cholesterol level in blood (Barnes 1998; Govindji 1999; Riaz 1999). Soy-based yogurt is one product that is gaining popularity. In addition to containing beneficial soy components, the presence of live probiotic bacteria in non-pasteurized yogurt, which are known to enhance natural bacterial environment in the gut, is furthering the physiological value of this product (Jay 1996).

A number of studies has been dedicated to the development of soy yogurt and improvement of its flavor and physical properties (Cheng *et al.* 1990; Lee *et al.* 1990, Shirai *et al.* 1992a, 1992b). The attempts to mask or eliminate undesirable beany flavor in this product have been made by fortification of soymilk with fructose, evaporated milk, and nonfat dry milk (Buono *et al.* 1990). Karleskind *et al.* (1991) investigated the possibility of enhancing acid production or "yogurt flavor" by addition of cheese whey proteins and mineral salts. The effect of calcium fortification (Yazici *et al.* 1997) and addition of gelatin and lactose (Cheng *et al.* 1990) on texture of soy yogurt have also been studied.

Texture is among the most important characteristics of food products, which along with flavor, determines their level of consumer acceptance. Depending on testing methodology (sensory or instrumental), textural properties

of gels may be described by a wide variety of subjective (qualitative) and objective (quantitative) parameters. Rheological instrumental techniques of texture characterization are divided by the level of deformation, small or large, to which the sample is subjected. Being non-destructive, the small deformation tests are very useful for a dynamic observation of sample properties during gelation process (Ross-Murphy 1995; Puppo and Anon 2000). The dynamic low-amplitude oscillatory test has been one of the most widely used small deformation techniques employed for rheological characterization of gelation properties of dairy milk (Hess *et al.* 1997; Lucey *et al.* 1998) and soymilk (Yoshida *et al.* 1992). Large deformation tests, on the other hand, are used to characterize fully developed gel systems, in particular, their failure conditions (Lee *et al.* 1983; Hou *et al.* 1997; Truong and Daubert 2000). The data obtained in this type of tests correlate well with human perception of food texture (Jankowski and Rha 1986; Keetels *et al.* 1996) because the process of masticating and swallowing of food involves large deformations. Two large deformation methods that have been traditionally utilized to measure textural properties of yogurts (dairy and soy) and tofu include uniaxial compression with cylindrical (Hassan *et al.* 1996a; Hou *et al.* 1997; Yazici *et al.* 1997) and conical probe (Dave and Shah 1998); and rotational shearing with concentric cylinders (Skriver *et al.* 1993; Hassan *et al.* 1996b), which has been mainly applied for measurement of yield stress and flow properties of stirred yogurts.

An emerging large deformation technique in texture characterization of foods is the vane method. It has been adapted from soil mechanics, and is being used for measurement of yield stress (σ_0) and yield strain (γ_0) of various viscoelastic food materials (Missaire *et al.* 1990; Briggs *et al.* 1995; Yoo *et al.* 1995; Daubert *et al.* 1998). A detailed description of this method and its procedure may be found in Dzuy and Boger (1985), Liddell and Boger (1996), and Steffe (1996). Yield stress is defined as a minimum force per unit area needed to initiate flow of the material; yield strain is a level of deformation at the yielding point. These parameters are significant for numerous food products and applications. Aside from being employed for textural characterization, they are used to determine how well the product will flow from the container or how well the applied coating is going to hold on the surface.

The vane method has been successfully applied by Briggs *et al.* (1995) for measurement of yield stress of frozen ice cream. Yoo *et al.* (1995) confirmed that this technique is effective for measurement of yield stress of commercial food dispersions, and moreover, does not require expensive rheological instrumentation. Daubert *et al.* (1998) used the vane method for quantitative description of spreadability of selected commercial foods by mapping measured yield stress against yield strain. Truong and Daubert (2000) compared the vane method with traditional uniaxial compression and torsion by exploring failure characteristics of gellan gum gels and commercial tofu samples. The compiled knowledge demonstrates that the vane method is a viable tool for

characterization of foods; although, more research is needed for its standardization on food gels.

The objectives of the present study were (1) to analyze the applicability of the vane method for textural characterization of soy yogurts prepared from five varieties of soybeans, (2) to characterize physical properties of soy yogurts as a function of protein content and composition.

MATERIALS AND METHODS

Raw materials

Soybeans

Five varieties of soybeans grown in Iowa during 1999 and 2000 were used: Vinton 81 (provided by Fairview Farms Inc.), Asgrow 2401 (provided by Grain Quality Laboratory, Iowa State University), HP204, IA2056, and IA2025 (provided by Committee for Agricultural Development, Iowa State University). All varieties are food grade soybeans except for Asgrow 2401, which is a commodity variety. Soybeans were stored in sealed plastic bags at 5°C until needed for sample preparation.

Starter culture

Yogurt culture YC-180 (mixture of *Streptococcus thermophilus* and *Lactobacillus bulgaricus*) was provided by Chr. Hansen, Inc. (Milwaukee, WI). Starter culture solution for soymilk inoculation was prepared by mixing 2.6 g of

frozen YC-180 bacteria into 100 g of distilled water. The solution was allowed to sit under room temperature for 1 h before it was used for inoculation.

Preparation of soy yogurt samples

Five batches of soymilk were prepared from five soybean varieties using cold-grind method described by Kwok *et al.* (2000) with some modifications. Whole soybeans were soaked in tap water at a beans to water ratio of 1/10 (w/w) for 13 h at room temperature. The hydrated beans were then drained and ground for 45 sec with tap water at a ratio of 1/2 (w/w) using a Waring Commercial Blender (Dynamics Corporation of America, New Hartford, CT). The resulting slurry was heated to 95°C, and held for 15 min. Soymilk was separated from insoluble residue by filtering it through a nylon 100-mesh filter sack (Kawanishi Shoko Co. LTD, Los Angeles, CA). The solids content of the filtrate was adjusted to 6, 8 and 10°Brix (Benchtop Refractometer, Bausch & Lomb, Rochester, NY) by addition of boiled tap water. Flasks with soymilk were covered and left on the lab counter for about 2 - 3 h until the temperature of soymilk reached 43°C. Soymilk samples were inoculated with 2% (w/w) of starter culture solution and incubated at 43°C. Incubation was terminated at pH 4.6. Samples were stored at 5°C for 15 h before testing.

Analyses

Solids, protein and crude fat of soymilk

Total solids of soymilk were determined by drying the samples in the laboratory oven (Precision Scientific Inc., Chicago, IL) for 24 h at 105°C.

Soy milk samples were analyzed for protein content using FP-2000

Nitrogen/Protein Determinator (Leco Corporation, St. Joseph, MI). Soymilk crude fat content was determined by acid hydrolysis method (AOAC 954.02).

Rheological measurements

Shear yield stress (σ_o , Pa) and strain (γ_o , dimensionless) measurements by the vane method were performed on a Haake Viscotester[®] VT550 (Thermo Haake, Karlsruhe, Germany). Soy yogurt samples prepared from five soybean varieties at solids levels of 6, 8 and 10°Brix were tested at 5°C in triplicate. A four-bladed vane (Fig. 1a) was immersed in the sample (Fig. 1b) and rotated at 0.5 rpm for 60 sec. The measured torque required to maintain a fixed rotation rate was recorded as a function of time. Yield stress was calculated from its relationship with maximum torque (M_{\max} , N m) and vane dimensions (Dzuy and Boger 1985):

$$M_{\max} = \frac{\pi D^3}{2} \left(\frac{H}{D} + \frac{1}{m+3} \right) \sigma_o, \quad [1]$$

where H and D are height and diameter (m) of the vane immersed in material, respectively, and m is a coefficient which describes the radial distribution

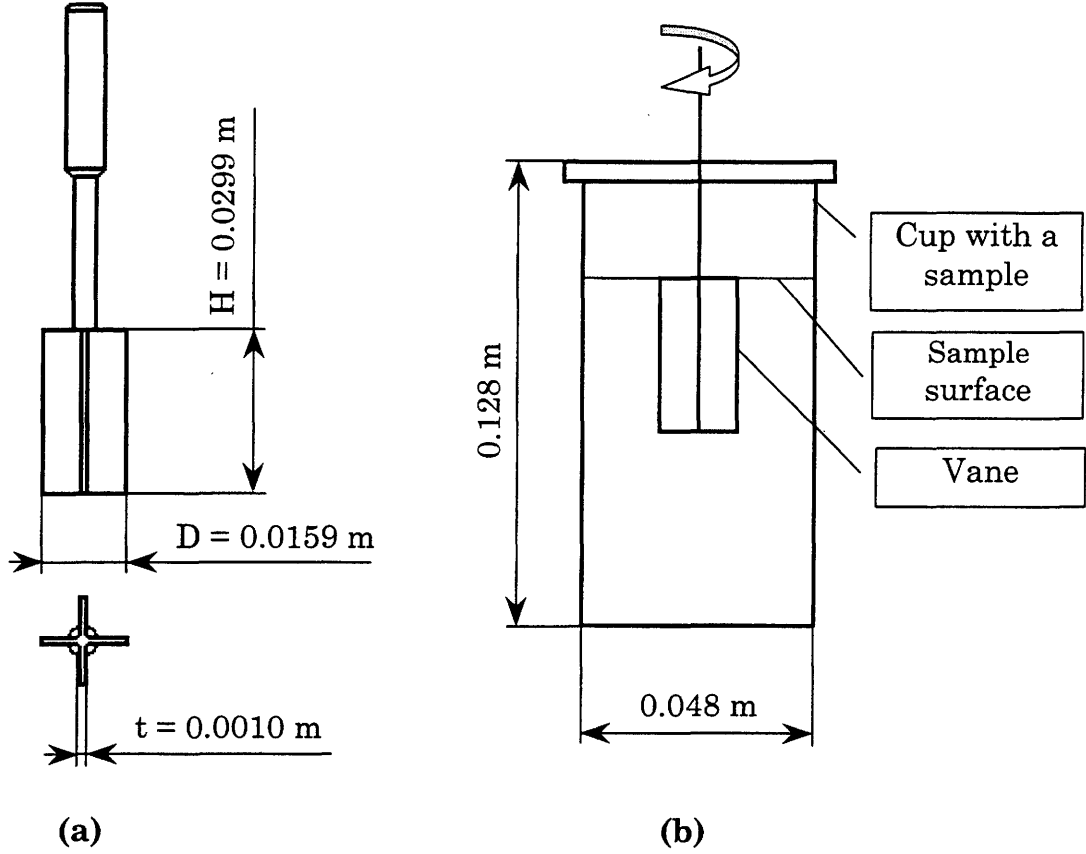


Figure 1. (a) Vane. (b) Vane immersed in the sample.

function of shear stress on the top and bottom surfaces of the vane. Generally, the assumption $m = 0$ is a valid approximation, particularly for the experiments comparing product quality (Steffe 1996). The error associated with this assumption was partially eliminated by placing the top surface of the vane even with the sample surface (Steffe 1996). Solved for σ_o , and assuming $m = 0$, Eq. [1] becomes

$$\sigma_o = \frac{6M_{\max}}{\pi D^2 (3H + D)} \quad [2]$$

Shear yield strain was calculated by the method used by Truong and Daubert (2000). It takes into account the diameter of fracture zone edges observed on the gel surface during testing and angular deformation:

$$\gamma_o = \frac{\Omega t}{(D_f/D) - 1}, \quad [3]$$

where (Ωt) is angular deformation (rad), $\Omega = 2\pi(\text{rpm})/60$ is the angular velocity (rad/s), D_f is the diameter of fracture zone (m), t is time (s) at peak torque.

Commercial plain lowfat sweetened yogurt (Hy-Vee Food Stores, Inc., Des Moines, Iowa) was also tested to provide a point of reference of rheological data.

Water-holding capacity (WHC)

WHC (%) was determined for soy yogurts in triplicate. Soy yogurt samples were prepared as described above in 50-ml centrifuge tubes. Samples (≈ 30 g) were centrifuged in a Beckman J2-21 Centrifuge (Beckman Coulter, Inc., Fullerton, CA) at $1,329 \times g$ for 5 min at room temperature. Supernatant fluid was drained for 1 min and water-holding capacity was calculated as

$$\text{WHC} = \left(\frac{W_{\text{original}} - W_{\text{supernatant}}}{W_{\text{original}}} \right) \times 100, \quad [4]$$

where W_{original} is the mass of non-centrifuged sample (g), and $W_{\text{supernatant}}$ is the mass of the drained supernatant (g).

Protein extraction and 7S and 11S subunit analysis

Soy protein was extracted using procedure described by Wu *et al.* (1999) with modifications: 25 g of finely ground soybeans was stirred in 250 ml of distilled water, and pH of the solution was adjusted to 8.6 with 6M NaOH. After overnight storage in a cold room, 25 ml of the solution was centrifuged for 20 min at 15000 x g and 20°C. 50 µl of collected supernatant was added to 50 µl of extraction buffer solution (50 mM THAM, pH 8.0; 5.0 M Urea; 0.2% SDS; 2% 2-mercaptoethanol), incubated for 2 h at 20°C, and mixed with 100 µl of 2X sample buffer solution (125 mM THAM, pH 6.8; 5.0 M Urea; 0.2% SDS; 2% 2-mercaptoethanol; 20% glycerol; 0.01% bromophenol blue). Samples were heated at 100°C for 10 min and allowed to cool before testing.

Sodium dodecyl sulfate-urea polyacrylamide gel electrophoresis (SDS-urea PAGE) modified after Laemmli (1970) and Cai and Chang (1999) was used for 11S and 7S protein subunit analysis. Electrophoresis was performed at 180 V for 45 min and 12.5%-acrylamide gel was used. Gels were stained with 0.1% Coomassie Blue solution in methanol/acetic acid/water (25:10:65). Gels were scanned on Amersham Pharmacia Biotech Image Scanner (Amersham Pharmacia Biotech AB, Uppsala, Sweden), and analyzed with Kodak ID Image Analysis software (Eastman Kodak Company, Rochester, NY).

Statistical analysis

Statistical analysis was performed by JMP v. 4.0.2 software (SAS Institute Inc., Cary, NC). One-way analysis of variance was performed and differences between mean values were analyzed using Tukey-Kramer HSD Test at α level of 0.05 on soybean variety factor. Correlations between measured parameters were determined by bivariate polynomial and linear regressions.

RESULTS AND DISCUSSION

Soymilks

Solids, protein and crude fat contents of soymilks on an "as is" moisture basis are given in Table 1.

Table 1. Mean concentrations of solids, protein and fat of soymilks.

<i>Soybean variety</i>	<i>Solids, Brix</i>	<i>Total solids, %</i>	<i>Protein, %</i>	<i>Crude fat, %</i>
Vinton 81	6	5.34	2.02	1.62
Vinton 81	8	7.02	2.65	2.13
Vinton 81	10	8.64	3.27	2.62
Asgrow 2401	6	5.34	2.47	1.49
Asgrow 2401	8	6.70	3.10	1.87
Asgrow 2401	10	8.68	4.01	2.42
HP204	6	5.05	2.64	1.34
HP204	8	6.56	3.43	1.74
HP204	10	8.53	4.46	2.26
IA2056	6	5.56	2.68	1.57
IA2056	8	7.75	3.74	2.19
IA2056	10	9.36	4.51	2.65
IA2025	6	4.89	2.38	1.04
IA2025	8	6.74	3.28	1.44
IA2025	10	8.59	4.17	1.83

Rheological measurements

A typical torque-time curve of a soy yogurt sample tested by the vane method is illustrated in Fig. 2. On the rising interval of the curve, the sample "stores" energy, behaving as elastic material. Then, at M_{\max} , the physicochemical bonds that are responsible for its three-dimensional network are disrupted and the gel structure fractures. Fig. 3 and Table A.1 in the Appendix show that the yield stress of tested samples was dependent on both protein content and soybean variety. Second-order polynomial regression was applied to fit the data for each variety (Table 2). This provided well-correlated equations ($R^2 > 0.99$) that were used to interpolate and extrapolate yield stress values for each soybean variety at 2.5 and 4% protein content (Table 3). These protein levels were chosen to avoid excessive extrapolation, which would have occurred if the data were compared at a protein concentration of less than 2.5%. Yield stress

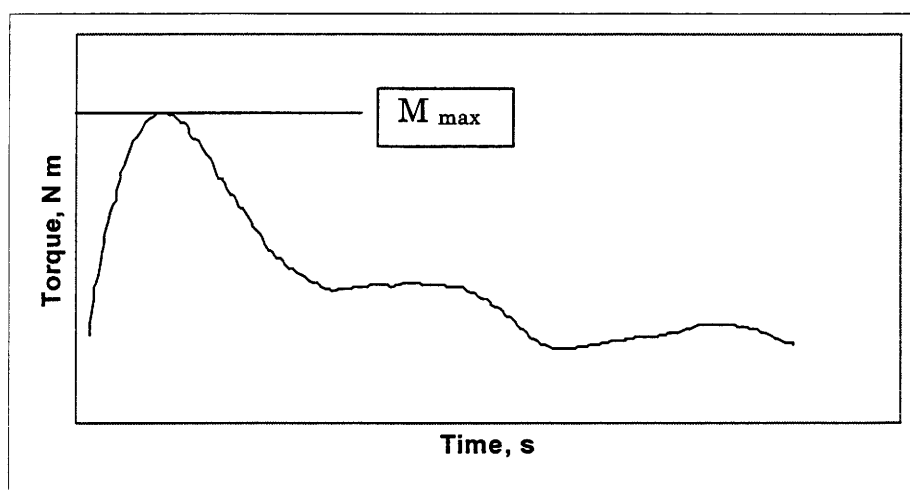


Figure 2. Typical torque-time curve of soy yogurt sample tested by the vane method.

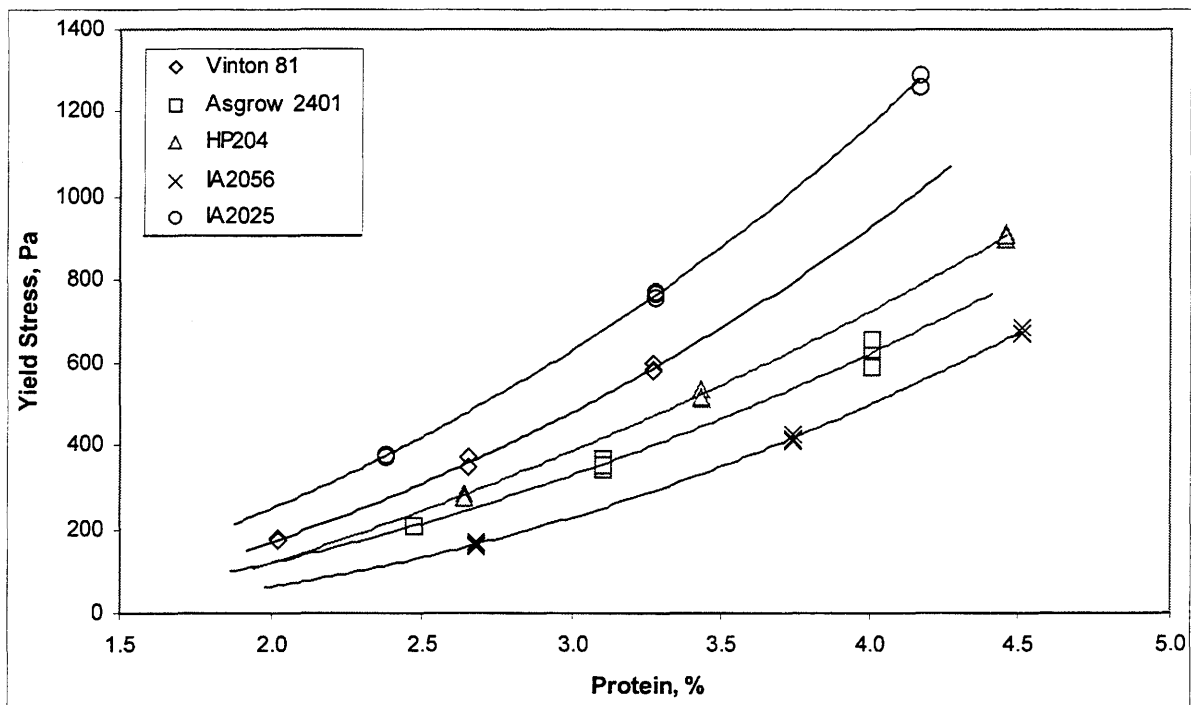


Figure 3. Yield stress of soy yogurt samples prepared from different soybean varieties as a function of protein concentration.

Table 2. Regression equations of yield stress (Y, Pa) of soy yogurts as a function of protein concentration (P, %).

<i>Soybean variety</i>	<i>Regression equation</i>
Vinton 81	$Y = -764.002 + 413.074 P + 68.774 (P - 3.254)^2$
Asgrow 2401	$Y = -492.245 + 272.667 P + 42.666 (P - 3.254)^2$
HP204	$Y = -579.645 + 321.073 P + 36.456 (P - 3.254)^2$
IA2056	$Y = -506.417 + 243.682 P + 52.558 (P - 3.254)^2$
IA2025	$Y = -879.966 + 501.782 P + 79.495 (P - 3.254)^2$

Table 3. Mean yield stress of soy yogurt samples at protein concentrations of 2.5% and 4%.

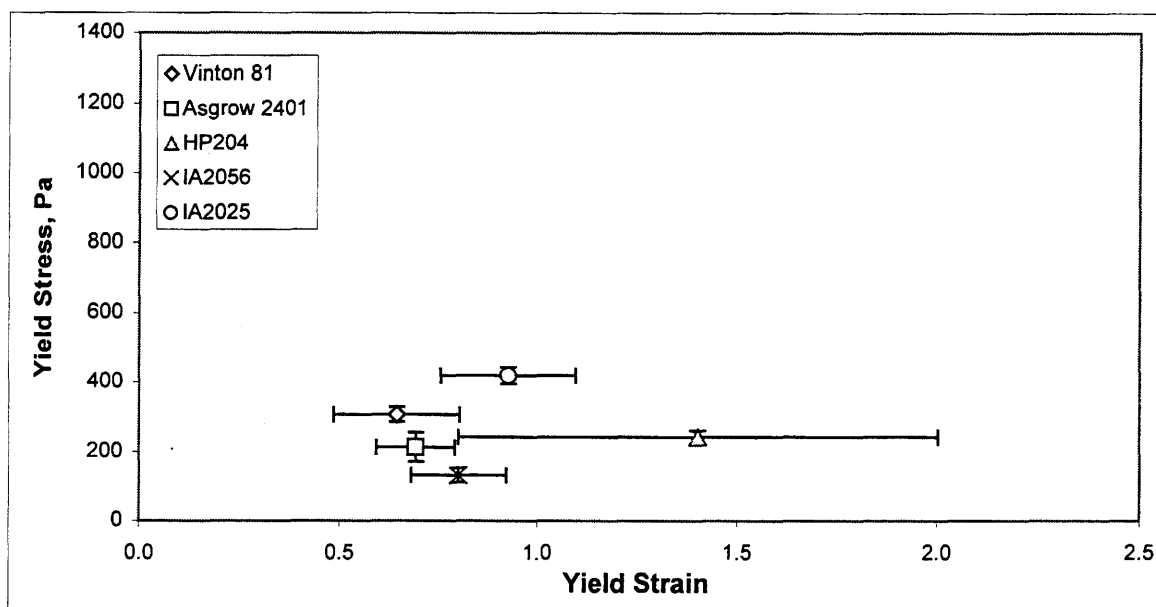
<i>Soybean variety</i>	<i>Mean yield stress at 2.5% protein, Pa</i>	<i>Mean yield stress at 4% protein, Pa</i>	<i>Increase in yield stress, %</i>
Vinton 81	308	927	201
Asgrow 2401	214	622	191
HP204	244	725	197
IA2056	133	498	275
IA2025	420	1171	179

measurement of a commercial plain set-style dairy yogurt sample (protein 4.4%, fat 1.1%, total solids 24.9%) resulted in mean σ_0 value of 215 Pa, and provided a point of reference for data comparison.

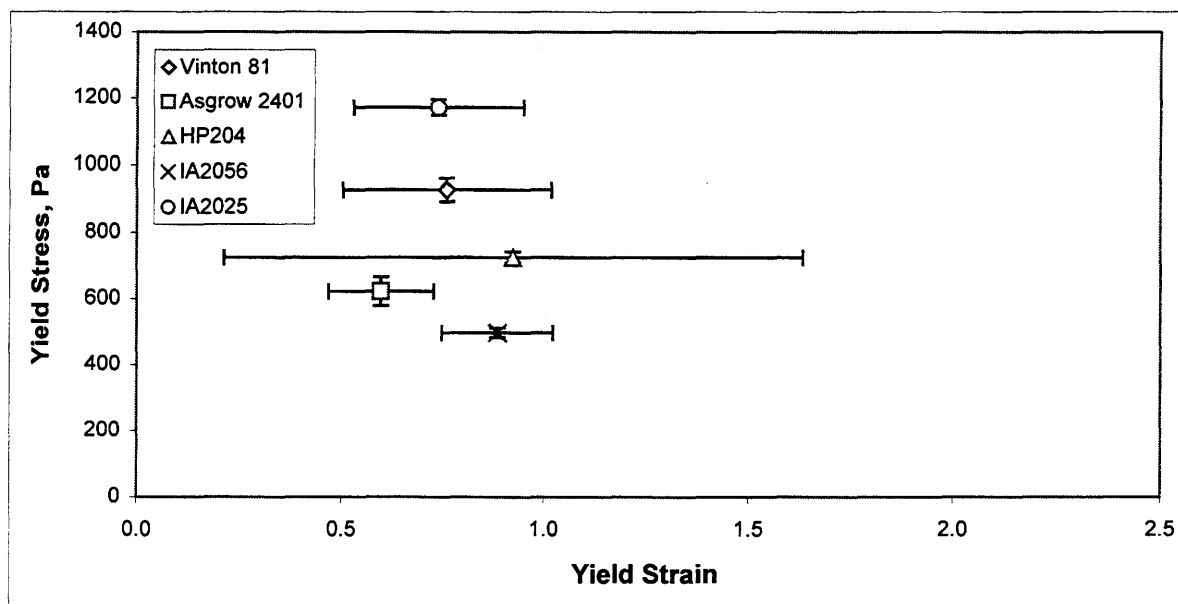
Samples prepared from IA2056 demonstrated 275% increase in mean yield stress from 133 to 498 Pa with an increase of protein concentration from 2.5% to 4%, while the same parameter for gels from IA2025 was only 179%. At the same time the spread of yield stress values between gels prepared from different soybean varieties were 287 and 674 Pa at protein levels of 2.5 and 4% respectively. This indicates that the difference in gel strength of soy yogurts is affected more by soybean variety at higher protein concentrations. It has been previously reported that hardness of soy protein gel is not only dependent on protein concentration (Kang et al. 1991; Puppo and Anon 1998), but is also a function of soybean variety or, in other words, variations in the composition of protein subunits (Nakamura *et al.* 1984; Yoshida *et al.* 1992).

Yield strain value of gel determines how much deformation a sample can withstand before its structure is broken, and may be considered as a measure of its elasticity. Methods of shear strain calculation have been well defined for traditional rheometry sensor systems such as plate and plate, cone and plate, and concentric cylinders (bob and cup) (Steffe 1996). In failure tests that employ concentric cylinders fixture, which is geometrically the closest to vane system, shear yield strain is determined as a function of angular deformation at failure point and the geometry of the sensor system. In our vane tests, shear yield strain of soy yogurt gels was calculated as a function of angular deformation at yielding point and D_f/D ratio (Eq. [3]). D_f/D ratio accounts for the fact that yielding of gel does not occur along the cylindrical surface of sensor's diameter, but along the surface with diameter D_f , which may be as large as two to three times vane's diameter (Keentok et al. 1985; Truong and Daubert 2000). Soy yogurts in this work resulted in D_f/D ratio of 1.32 - 1.82 and angular deformation (Ωt) at yield time of 0.34 - 0.60 rad for all gel samples.

Yield strain values were calculated and linear regression was performed to assess the relationship between yield strain and protein concentration of gel samples for each soybean variety. Although this did not show strong correlations (R^2 from 0.24 to 0.62), the resulting equations were used to interpolate and extrapolate yield strain values for each soybean variety at 2.5 and 4% protein content to construct yield stress - strain maps (Fig. 4). The maps illustrate that unlike yield stress (strength), yield strain (elasticity) did not change significantly



(a)



(b)

Figure 4. Yield stress-yield strain maps of soy yogurt samples at protein concentrations of (a) 2.5% and (b) 4%. (Bars represent 90% prediction intervals).

with an increase of protein concentration from 2.5 to 4%. This observation may be explained as follows: the number of physicochemical bonds, which is directly related to gel strength, became larger with an increase of protein concentration, while the nature of molecular interactions and their proportions, related to elasticity, remained the same. Stress - strain maps indicated that elasticity of tested soy yogurts was independent on soybean variety at both protein concentrations.

It is also worth mentioning that similar observations and conclusions regarding elasticity of the tested samples could be made by comparing values of angular deformation (Ωt) at yielding point. This suggests that angular deformation may well be used as a measure of elasticity when quick evaluation of quality is required, because this calculation avoids the need to measure D_f .

For the purpose of data comparison, yield stress and strain of commercial dairy plain set-style yogurt (protein 4.4%, fat 1.1%, total solids 24.9%) were measured. Commercial dairy gel had softer, but more elastic body ($\sigma_0 = 215 \pm 38.1$ Pa, $\gamma_0 = 2.70 \pm 0.43$) than soy yogurts at corresponding protein level.

Vane method showed to be an effective and rapid technique in determination of engineering properties of soy protein gels at failure conditions. In addition, the important advantages of this method over traditional rotational rheometry were: (1) it did not require expensive controlled stress instrument, (2) the gel sample did not have to be prepared within the instrument's sensor

system, and (3), in the case of commercial products, the sample could be tested in its original container.

Water-holding capacity

WHC of a protein gel is a critical parameter in yogurt manufacturing since it is related to syneresis, which is undesirable in this product. To our best knowledge, no information has been reported regarding this property of yogurts prepared from soymilk. Fig. 5 and Table A.2 of Appendix show that WHC of tested gels increased with protein concentration. This implies that soy protein gels with higher number of physicochemical bonds (or more developed structure) have a better ability to entrap water within its three-dimensional network.

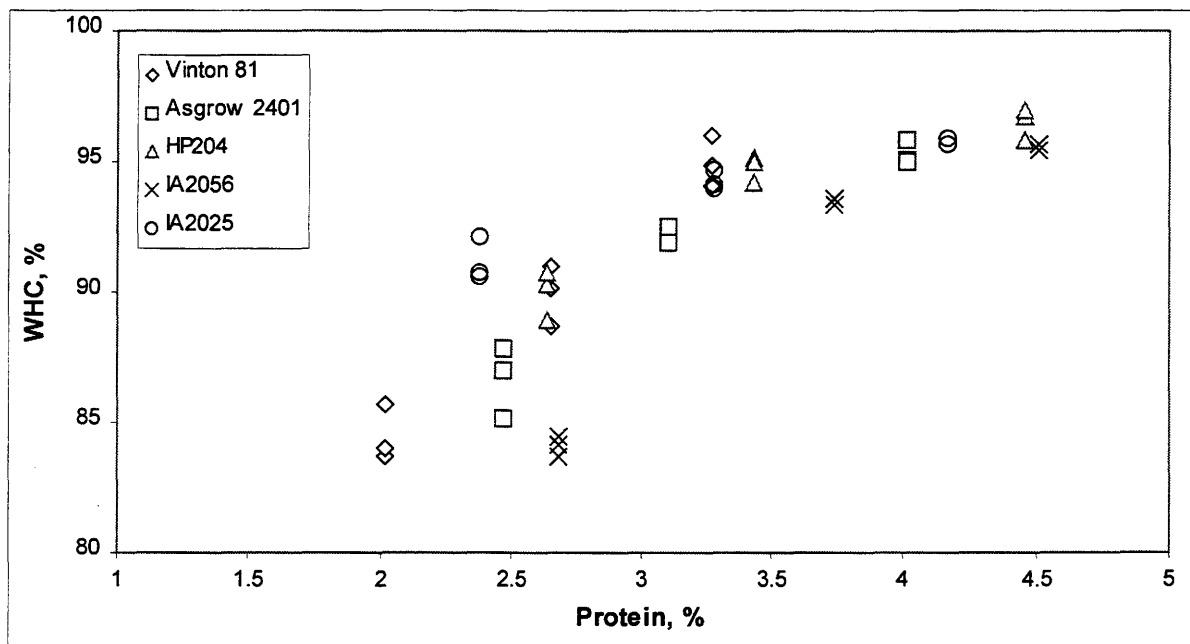


Figure 5. Dependency of water-holding capacity of soy yogurt samples on protein concentration.

WHC was variety dependent, but this dependence became less pronounced at higher protein concentrations. WHC of all samples ranged from 84.1 to 96.5%. Shirai *et al.* (1992a) experimented with yogurts prepared from mixture of soymilk, oat flour and dried cheese whey and reported syneresis value of 10.4% (centrifuged at 1535 x g for 20 min at 20°C), which in terms of WHC is 89.6%.

The relationship between WHC and yield stress of soy yogurts is shown in Fig. 6. It illustrates that when the σ_0 was below 600 Pa, the WHC increased linearly from 84 to 95%. However, at $\sigma_0 > 600$ Pa WHC remained relatively constant. This suggests that WHC of tested samples had reached its maximum value, and in terms of protein concentration this value corresponds to 3.5%.

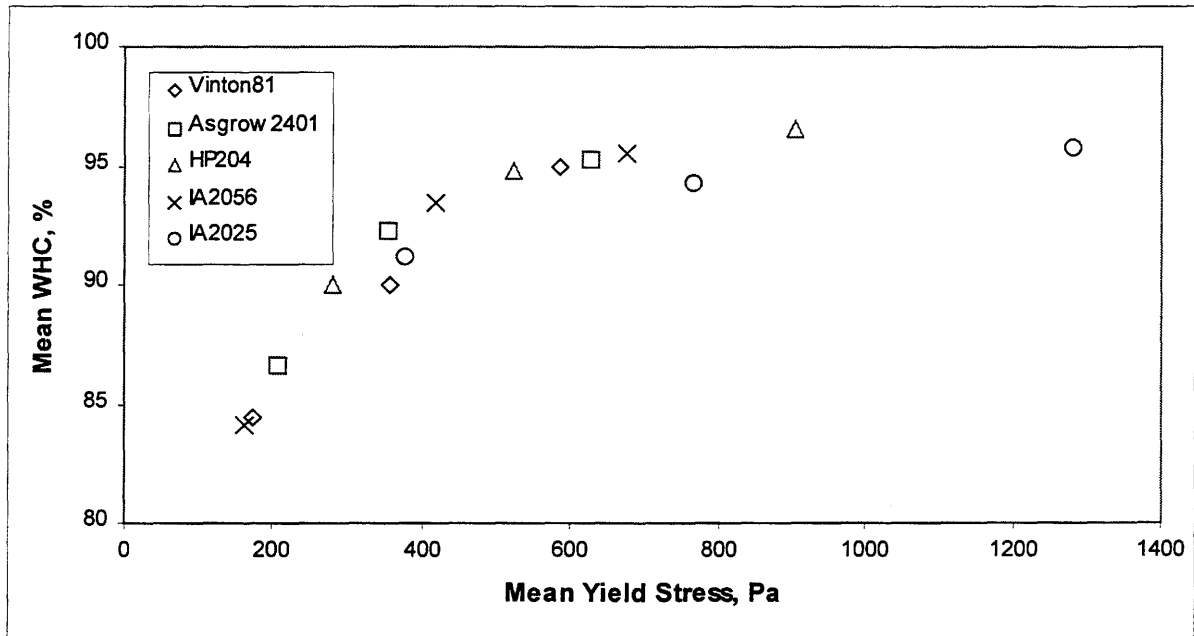


Figure 6. Relationship between water-holding capacity and yield stress of soy yogurt samples.

7S and 11S analysis

7S (conglycinin) and 11S (glycinin) fractions are two major components of soy protein, of which 11S is known to form heat-induced gels with higher hardness (Saio and Watanabe 1978). The results of 7S and 11S SDS-PAGE analysis of tested soybean varieties are given in Fig 7 and Table 4. The effect of 11S/7S ratio on quality of tofu from selected soybean varieties was reported by Ji *et al.* (1999). Therefore, the attempt to explain the difference in yield stress values between tested soy yogurts with the same protein concentration was made by performing linear regressions of yield stress on 11S/7S ratio at protein levels of 2.5 and 4%. The analysis did not give an evidence of correlation between these two parameters (R^2 0.0003 and 0.0016).

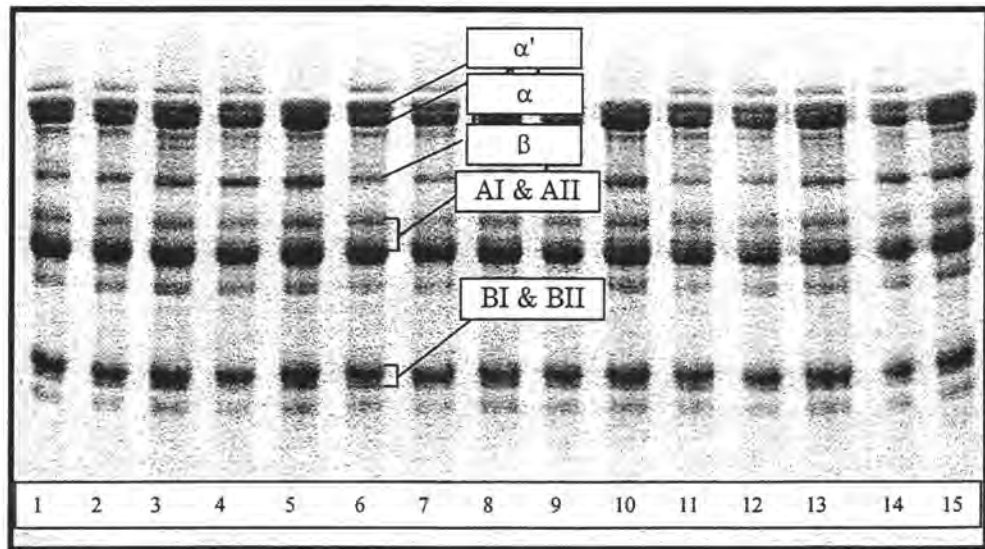


Figure 7. SDS-PAGE patterns of proteins extracted from Vinton 81 (lanes 1, 6, 11), Asgrow 2401 (lanes 2, 7, 12), HP204 (lanes 3, 8, 13), IA2056 (lanes 4, 9, 14), IA2025 (lanes 5, 10, 15).

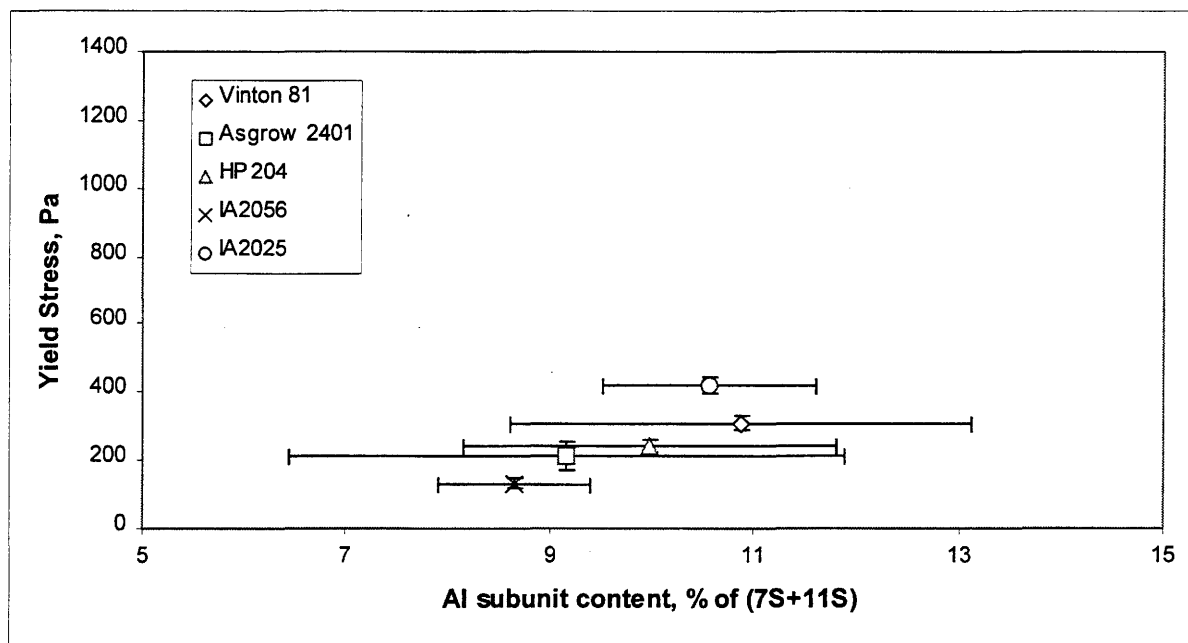
Table 4. Subunit composition of 7S and 11S fractions of soy protein extracted from five soybean varieties.

			<i>MW,</i> <i>kDa</i>	<i>Vinton 81</i>		<i>Asgrow2401</i>		<i>HP204</i>		<i>IA2056</i>		<i>IA2025</i>	
				mean % of (7S+11S)	st. dev.	mean % of (7S+11S)	st. dev.	mean % of (7S+11S)	st. dev.	mean % of (7S+11S)	st. dev.	mean % of (7S+11S)	st. dev.
7S	α	≈ 68		13.09	0.37	12.94	0.24	13.47	0.52	12.34	0.52	12.88	0.25
	α'	≈ 68		14.51	0.78	15.56	0.72	15.67	1.57	16.04	0.95	15.88	1.31
	β	42		9.33	0.15	9.34	0.76	11.26	0.87	12.50	0.13	12.05	0.46
	Total			36.92	0.46	37.84	1.27	40.41	1.90	40.88	0.86	40.81	1.17
11S	AI	32		10.87	1.34	9.15	1.61	9.98	1.09	8.66	0.44	10.56	0.62
	AII	30		27.64	1.02	27.90	2.04	27.36	1.62	27.00	0.98	25.60	0.29
	BI	≈ 17		14.08	1.87	15.08	0.49	14.63	0.63	13.67	0.29	14.52	1.63
	BII	≈ 17		10.48	0.59	10.03	1.75	7.62	2.69	9.78	0.29	8.51	1.54
	Total			63.08	0.46	62.16	1.27	59.59	1.90	59.12	0.86	59.19	1.17
11S/7S				1.709		1.643		1.475		1.446		1.450	

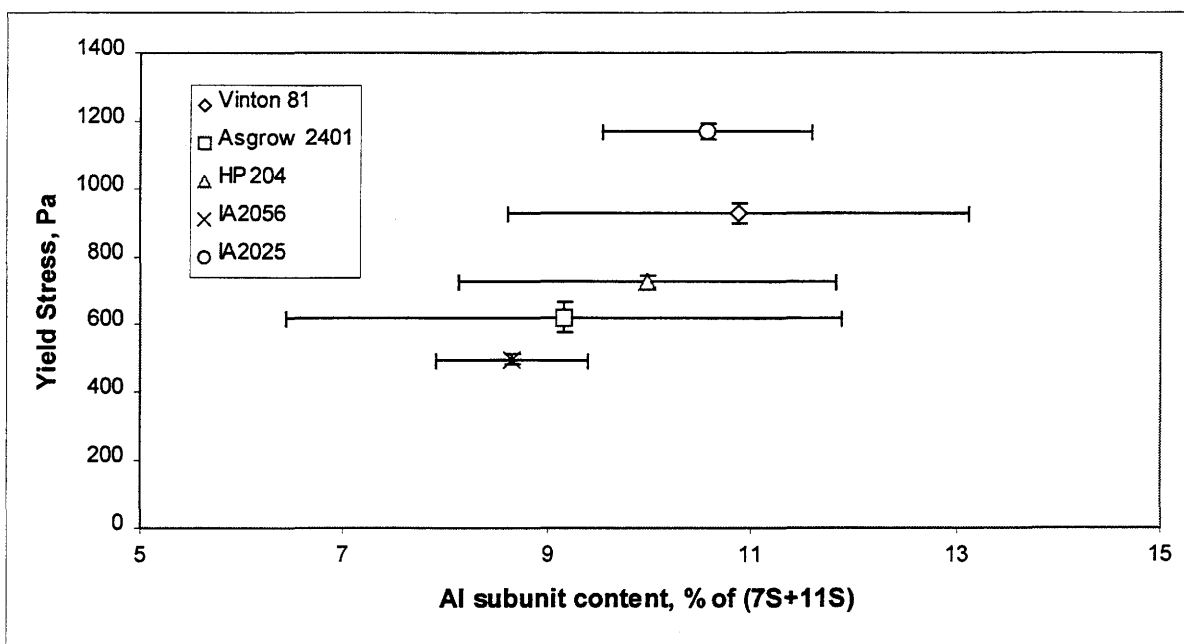
The relationship between hardness of heat-induced gels prepared from glycinins of several soybean varieties and one of their acidic subunits has been reported by Nakamura *et al.* (1984). Fig. 8 shows the yield stress of tested in our experiment yogurt samples as a function of content of acidic subunit AI of 11S at protein levels 2.5 and 4%. Even though statistical analysis indicated that concentrations of AI subunit of different soybean varieties were not significantly different, a trend of yield stress increase with an increase of mean concentration of AI subunit could be observed. More research is needed to confirm this relationship.

CONCLUSIONS

1. The vane method may be effectively used as a rapid and inexpensive technique for textural characterization of soy protein- based yogurts.
2. Yield stress, unlike yield strain, of tested samples was dependent on protein content and soybean variety.
3. Compared to commercial dairy yogurt, soy yogurts had a higher yield stress, but lower yield strain.
4. Water-holding capacity of soy yogurt gels was variety dependent; however, this dependence was less pronounced at higher protein concentrations.
5. No evidence of correlation between 11S/7S ratio and yield stress of tested samples was found.



(a)



(b)

Figure 8. Yield stress dependence on acidic subunit AI of 11S protein fraction of soy yogurt samples at protein concentrations of (a) 2.5% and (b) 4%. (Bars represent 90% prediction intervals for yield stress and 90% confidence intervals for AI subunit content).

REFERENCES

- BARNES, S. 1998. Evolution of the health benefits of soy isoflavones. *Proc. Soc. Exp. Biol. Med.* *217*(3), 386-392.
- BRIGGS, J.L., STEFFE, J.F., USTUNOL, Z. 1995. Vane method to evaluate the yield stress of frozen ice cream. *J. Dairy Sci.* *79*, 527-531.
- BUONO, M.A., SETSER, C., ERICKSON, L.E., FUNG, D.Y.C. 1990. Soymilk yogurt: sensory evaluation and chemical measurement. *J. Food Sci.* *55*(2), 528-531.
- CAI, T., CHANG, K.-C. 1999. Processing effect on soybean storage proteins and their relationship with tofu quality. *J. Agric. Food Chem.* *47*, 720-727.
- CHENG, Y.J., THOMPSON, L.D., BRITTIN, H.C. 1990. Sogurt, a yogurt-like soybean product: development and properties. *J. Food Sci.* *55*(4), 1178-1179.
- DAUBERT, C.R., TKACHUK, J.A., TRUONG, V.D. 1998. Quantitative measurement of food spreadability using the vane method. *J. Texture Studies* *29*, 427-435.
- DAVE, R.I., SHAH, N.P. 1998. The influence of ingredient supplementation on the textural characteristics of yogurt. *Aust. J. Dairy Technol.* *53*, 180-184.
- DZUY, N.Q., BOGER, D.V. 1985. Direct yield stress measurement with the vane method. *J. Rheol.* *29*(3), 335-347.
- GOVINDJI, A. 1999. The soya bean: so small yet so mighty. *Nutrition Food Sci.* *99*(3), 144-148.

- HASSAN, A.N., FRANK, J.F., SCHMIDT, K.A., SHALABI, S.I. 1996a. Textural properties of yogurt made with encapsulated nonropy lactic cultures. *J. Dairy Sci.* **79**, 2098-2103.
- HASSAN, A.N., FRANK, J.F., SCHMIDT, K.A., SHALABI, S.I. 1996b. Rheological properties of yogurt made with encapsulated nonropy lactic cultures. *J. Dairy Sci.* **79**, 2091-2097.
- HESS, S.J., ROBERTS, R.F., ZIEGLER, G.R. 1997. Rheological properties of nonfat yogurt stabilized using *Lactobacillus delbrueckii* ssp. *bulgaricus* producing exopolysaccharide or using commercial stabilizer systems. *J. Dairy Sci.* **80**, 252-263.
- HOU, H.J., CHANG, K.C., SHIH, M.C. 1997. Yield and texture properties of soft tofu as affected by coagulation method. *J. Food Sci.* **62**(4), 824-827.
- JANKOWSKI, T., RHA, C.K. 1986. Retrogradation of starch in cooked wheat. *Starch-Stärke* **38**(1), 6-9.
- JAY, J.M. 1996. *Modern food microbiology* (5th edition). Chapman & Hall, New York.
- JI, M.P., CAI, T.D., CHANG, K.C. 1999. Tofu yield and textural properties from three soybean cultivars as affected by ratios of 7S and 11S proteins. *J. Food Sci.* **64**(5), 763-767.
- KANG, I.J., MATSUMURA, Y., MORI, T. 1991. Characterization of texture and mechanical properties of heat-induced soy protein gels. *J. Am. Oil Chem. Soc.* **68**(5), 339-345.

- KARLESKIND, D., LAYE, I., HALPIN, E., MORR, C.V. 1991. Improving acid production in soy-based yogurt by adding cheese whey proteins and mineral salts. *J. Food Sci.* *56*(4), 999-1001.
- KEENTOK, M., MILTHORPE, J.F., O'DONOVAN, E. 1985. On the shearing zone around rotating vanes in plastic liquids: theory and experiment. *J. Non-Newton. Fluid* *17*, 23-35.
- KEETELS, C.J.A.M., VAN VLIET, T., JURGENS, A., WALSTRA, P. 1996. Effects of lipid surfactants on the structure and mechanics of concentrated starch gels and starch bread. *J. Cereal Sci.* *24*(1), 33-45.
- KWOK, K.-C., BASKER, D., NIRANJAN, K. 2000. Kinetics of sensory quality changes in soymilk during thermal processing, by parametric and non-parametric data analyses. *J. Sci. Food Agr.* *80*, 595-600.
- LAEMMLI, U.K. 1970. Cleavage of structural proteins during assembly of the head of bacteriophage T4. *Nature* *227*, 680-686.
- LEE, S.-Y., MORR, C.V., SEO, A. 1990. Comparison of milk-based and soy-milk based yogurt. *J. Food Sci.* *55*(2), 532-536.
- LEE, Y.C., ROSENAU, J.R., PELEG, M. 1983. Rheological characterization of tofu. *J. Texture Studies* *14*, 143-154.
- LIDDELL, P.V., BOGER, D.V. 1996. Yield stress measurement with the vane method. *J. Non-Newton. Fluid* *63*, 235-261.

- LUCEY, J.A., MUNRO, P.A., SINGH, H. 1998. Rheological properties and microstructure of acid milk gels as affected by fat content and heat treatment. *J. Food Sci.* 63(4), 660-664.
- MISSAIRE, F., QIU, C-G., RAO, M.A. 1990. Yield stress of structured and unstructured food suspensions. *J. Texture Studies* 21, 479-490.
- NAKAMURA, T., UTSUMI, S., KITAMURA, K., HARADA, K., MORI, T. 1984. Cultivar differences in gelling characteristics of soybean glycinin. *J. Agr. Food Chem.* 32, 647-651.
- PUPPO, M.C., ANON M.C. 1998. Effect of pH and protein concentration on rheological behavior of acidic soybean protein gels. *J. Agr. Food Chem.* 46, 3039-3046.
- PUPPO, M.C., ANON M.C. 2000. Gelation of soybean proteins at acidic pH. In *Trends in Food Engineering*, ed. J. E. Lozano, C. Anon, E. Parada-Arias, G. V. Barbosa-Canovas. Technomic Publishing Co., Inc., Lancaster, Pa; 327-340.
- RIAZ, M.N. 1999. Soybeans as functional foods. *Cereal Food World*; 44(2), 88-92.
- ROSS-MURPHY, S.B. 1995. Rheological characterization of gels. *J. Texture Studies* 26, 391-400.
- SAIO, K., WATANABE, T. 1978. Differences in functional properties of 7S and 11S soybean proteins. *J. Texture Studies* 9, 135-157.

SHIRAI, K., GUTIERREZ-DURAN, M., MARSHALL, V.M.E., REVAH-

MOISEEV, S., GARCIA-GARIBAY, M. 1992a. Production of a yogurt-like product from plant foodstuffs and whey. Sensory evaluation and physical attributes. *J. Sci. Food Agr.* *59*, 205-210.

SHIRAI, K., PEDRAZA, G., GUTIERREZ-DURAN, M., MARSHALL, V.M.E.,

REVAH-MOISEEV, S., GARCIA-GARIBAY, M. 1992b. Production of a yogurt-like product from plant foodstuffs and whey. Substrate preparation and fermentation. *J. Sci. Food Agr.* *59*, 199-204.

SKRIVER, A., ROEMER, H., QVIST, K.B. 1993. Rheological characterization of stirred yoghurt: viscometry. *J. Texture Studies* *24*, 185-198.

STEFFE, J.S. 1996. *Rheological methods in food process engineering* (2nd edition). Freeman Press, East Lansing, Michigan.

TRUONG, V.D., DAUBERT, C.R. 2000. Comparative study of large strain methods for assessing failure characteristics of selected food gels. *J. Texture Studies* *31*, 335-353.

WU, S., MURPHY, P.A., JOHNSON, L.A., FRATZKE, A.R., REUBER, M.A.

1999. Pilot-plant fractionation of soybean glycinin and β -conglycinin. *J. Am. Oil Chem. Soc.* *76*(3), 285-293.

YAZICI, F., ALVAREZ, V.B., HANSEN, P.M.T. 1997. Fermentation and

properties of calcium-fortified soy milk yogurt. *J. Food Sci.* *62*(3), 457-461.

- YOO, B., RAO, M.A., STEFFE, J.F. 1995. Yield stress of food dispersions with the vane method at controlled shear rate and shear stress. *J. Texture Studies* 26, 1-10.
- YOSHIDA, M., KOHYAMA, K., NISHINARI, K. 1992. Gelation properties of soymilk and soybean 11S globulin from Japanese-grown soybeans. *Biosci. Biotech. Bioch.* 56(5), 725-728.

GENERAL CONCLUSIONS

The vane method may be effectively used as rapid and inexpensive technique for textural characterization of soy protein-based yogurts. Yield stress, unlike yield strain, of tested samples was dependent on protein content and soybean variety. Compared to commercial dairy yogurt, soy yogurts had a higher yield stress, but lower yield strain. Water-holding capacity of soy yogurt gels was variety dependent; however this dependence was less pronounced at higher protein concentrations. No evidence of correlation between 11S/7S ratio and yield stress of tested samples was found. Analysis suggested that yield stress of soy-based yogurt may be affected by content of acidic subunit AI of 11S fraction.

Some recommendations on future research regarding application of the vane method are:

1. Confirm the hypothesis that yield stress of soy-based yogurt is affected by content of acidic subunit AI of 11S fraction.
2. Correlate yield stress with WHC of soy protein gels and investigate the possibility of using vane test data for quick evaluation of WHC of the product.
3. Investigate the effect of storage conditions on yield stress and yield strain of soy yogurt.
4. Correlate results of the vane test with sensory characteristics of food gels.
5. Evaluate effect of various cultures on failure properties of soy yogurts.

APPENDIX

Table A.1. Rheological data.

<i>Soybean variety</i>	<i>Sample #</i>	<i>Soymilk solids, °Brix</i>	<i>Protein content, %</i>	<i>Fat content, %</i>	<i>Torque, N m</i>	<i>Yield Stress, Pa</i>	<i>Fracture zone diameter, m</i>	<i>Yield time, s</i>	<i>Angular velocity, rad/s</i>	<i>Yield Strain, Pa</i>
Vinton 81	1	6	2.02	1.62	0.00249	177.7	0.0275	8.952	0.0524	0.645
Vinton 81	2	6	2.02	1.62	0.00243	173.5	0.0260	8.983	0.0524	0.743
Vinton 81	3	6	2.02	1.62	0.00244	174.2	0.0290	8.272	0.0524	0.528
Vinton 81	4	8	2.65	2.13	0.00521	371.9	0.0285	8.593	0.0524	0.570
Vinton 81	5	8	2.65	2.13	0.00485	346.2	0.0280	8.272	0.0524	0.571
Vinton 81	6	8	2.65	2.13	0.00489	349.1	0.0270	8.642	0.0524	0.651
Vinton 81	7	10	3.27	2.62	0.00840	599.6	0.0255	8.552	0.0524	0.745
Vinton 81	8	10	3.27	2.62	0.00817	583.2	0.0250	7.982	0.0524	0.733
Vinton 81	9	10	3.27	2.62	0.00809	577.5	0.0250	7.912	0.0524	0.727
Asgrow 2401	1	6	2.47	1.49	0.00291	207.7	0.0275	9.314	0.0524	0.671
Asgrow 2401	2	6	2.47	1.49	0.00291	207.7	0.0280	10.786	0.0524	0.745
Asgrow 2401	3	6	2.47	1.49	0.00290	207.0	0.0280	10.035	0.0524	0.693
Asgrow 2401	4	8	3.10	1.87	0.00515	367.6	0.0290	8.913	0.0524	0.568
Asgrow 2401	5	8	3.10	1.87	0.00478	341.2	0.0280	9.374	0.0524	0.647
Asgrow 2401	6	8	3.10	1.87	0.00495	353.3	0.0280	10.375	0.0524	0.716
Asgrow 2401	7	10	4.01	2.42	0.00884	631.0	0.0270	8.242	0.0524	0.621
Asgrow 2401	8	10	4.01	2.42	0.00828	591.0	0.0275	7.871	0.0524	0.567
Asgrow 2401	9	10	4.01	2.42	0.00917	654.6	0.0270	8.212	0.0524	0.618

Table A.1. (Continued).

<i>Soybean variety</i>	<i>Sample #</i>	<i>Soy milk solids, °Brix</i>	<i>Protein content, %</i>	<i>Fat content, %</i>	<i>Torque, N m</i>	<i>Yield Stress, Pa</i>	<i>Fracture zone diameter, m</i>	<i>Yield time, s</i>	<i>Angular velocity, rad/s</i>	<i>Yield Strain, Pa</i>
HP204	1	6	2.64	1.34	0.00402	287.0	0.0215	10.445	0.0524	1.562
HP204	2	6	2.64	1.34	0.00396	282.7	0.0210	11.106	0.0524	1.824
HP204	3	6	2.64	1.34	0.00386	275.5	0.0250	11.446	0.0524	1.052
HP204	4	8	3.43	1.74	0.00751	536.1	0.0260	10.445	0.0524	0.864
HP204	5	8	3.43	1.74	0.00720	514.0	0.0240	9.604	0.0524	0.992
HP204	6	8	3.43	1.74	0.00726	518.2	0.0265	10.365	0.0524	0.817
HP204	7	10	4.46	2.26	0.01260	899.4	0.0260	9.664	0.0524	0.800
HP204	8	10	4.46	2.26	0.01275	910.1	0.0250	9.613	0.0524	0.883
HP204	9	10	4.46	2.26	0.01270	906.6	0.0250	10.054	0.0524	0.924
IA2056	1	6	2.68	1.57	0.00237	169.2	0.0220	6.519	0.0524	0.894
IA2056	2	6	2.68	1.57	0.00229	163.5	0.0235	6.860	0.0524	0.755
IA2056	3	6	2.68	1.57	0.00223	159.2	0.0230	6.489	0.0524	0.765
IA2056	4	8	3.74	2.19	0.00573	409.0	0.0230	7.260	0.0524	0.855
IA2056	5	8	3.74	2.19	0.00597	426.2	0.0220	6.860	0.0524	0.941
IA2056	6	8	3.74	2.19	0.00584	416.9	0.0225	6.879	0.0524	0.872
IA2056	7	10	4.51	2.65	0.00940	671.0	0.0230	7.922	0.0524	0.933
IA2056	8	10	4.51	2.65	0.00958	683.8	0.0225	7.260	0.0524	0.920
IA2056	9	10	4.51	2.65	0.00941	671.7	0.0230	7.291	0.0524	0.859

Table A.1. (Continued).

<i>Soybean variety</i>	<i>Sample #</i>	<i>Soymilk solids, °Brix</i>	<i>Protein content, %</i>	<i>Fat content, %</i>	<i>Torque, N m</i>	<i>Yield Stress, Pa</i>	<i>Fracture zone diameter, m</i>	<i>Yield time, s</i>	<i>Angular velocity, rad/s</i>	<i>Yield Strain, Pa</i>
IA2025	1	6	2.38	1.04	0.00525	374.8	0.0240	10.735	0.0524	1.108
IA2025	2	6	2.38	1.04	0.00530	378.3	0.0250	10.064	0.0524	0.925
IA2025	3	6	2.38	1.04	0.00521	371.9	0.0255	9.724	0.0524	0.847
IA2025	4	8	3.28	1.44	0.01078	769.5	0.0270	11.106	0.0524	0.836
IA2025	5	8	3.28	1.44	0.01082	772.4	0.0270	10.465	0.0524	0.788
IA2025	6	8	3.28	1.44	0.01059	755.9	0.0270	10.024	0.0524	0.755
IA2025	7	10	4.17	1.83	0.01764	1259.2	0.0275	10.395	0.0524	0.749
IA2025	8	10	4.17	1.83	0.01809	1291.3	0.0280	10.355	0.0524	0.715
IA2025	9	10	4.17	1.83	0.01803	1287.0	0.0280	10.755	0.0524	0.743

Table A.2. Water-holding capacity data.

<i>Soybean variety</i>	<i>Sample #</i>	<i>Soymilk solids, °Brix</i>	<i>Protein content, %</i>	<i>Tare wt, g</i>	<i>Original gross wt, g</i>	<i>Original net wt, g</i>	<i>Pellet gross wt, g</i>	<i>Pellet net wt, g</i>	<i>WHC, %</i>
Vinton 81	1	6	2.02	10.9070	42.2580	31.3510	37.1416	26.2346	83.68
Vinton 81	2	6	2.02	11.0108	42.5283	31.5175	37.4893	26.4785	84.01
Vinton 81	3	6	2.02	10.4597	40.3706	29.9109	36.0880	25.6283	85.68
Vinton 81	4	8	2.65	11.3653	42.9200	31.5547	39.3551	27.9898	88.70
Vinton 81	5	8	2.65	10.3247	41.7876	31.4629	38.9592	28.6345	91.01
Vinton 81	6	8	2.65	11.0094	42.6102	31.6008	39.5031	28.4937	90.17
Vinton 81	7	10	3.27	11.1361	41.0628	29.9267	39.2854	28.1493	94.06
Vinton 81	8	10	3.27	10.3220	41.5764	31.2544	40.3170	29.9950	95.97
Vinton 81	9	10	3.27	10.9580	42.3753	31.4173	40.7544	29.7964	94.84
Asgrow 2401	1	6	2.47	10.9070	41.4157	30.5087	36.8880	25.9810	85.16
Asgrow 2401	2	6	2.47	11.0108	42.6783	31.6675	38.5677	27.5569	87.02
Asgrow 2401	3	6	2.47	10.4597	44.2915	33.8318	40.1684	29.7087	87.81
Asgrow 2401	4	8	3.10	11.3653	42.5884	31.2231	40.1542	28.7889	92.20
Asgrow 2401	5	8	3.10	10.3247	42.8169	32.4922	40.3868	30.0621	92.52
Asgrow 2401	6	8	3.10	11.0094	42.3644	31.3550	39.8437	28.8343	91.96
Asgrow 2401	7	10	4.01	11.1361	41.4268	30.2907	40.1618	29.0257	95.82
Asgrow 2401	8	10	4.01	10.3220	42.0777	31.7557	40.5141	30.1921	95.08
Asgrow 2401	9	10	4.01	10.9580	43.3848	32.4268	41.7667	30.8087	95.01

Table A.2. (Continued).

<i>Soybean variety</i>	<i>Sample #</i>	<i>Soymilk solids, °Brix</i>	<i>Protein content, %</i>	<i>Tare wt, g</i>	<i>Original gross wt, g</i>	<i>Original net wt, g</i>	<i>Pellet gross wt, g</i>	<i>Pellet net wt, g</i>	<i>WHC, %</i>
HP204	1	6	2.64	10.9070	41.4982	30.5912	38.1198	27.2128	88.96
HP204	2	6	2.64	11.0108	42.0112	31.0004	39.0070	27.9962	90.31
HP204	3	6	2.64	10.4597	41.7333	31.2736	38.8363	28.3766	90.74
HP204	4	8	3.43	11.3653	42.2654	30.9001	40.4918	29.1265	94.26
HP204	5	8	3.43	10.3247	42.8179	32.4932	41.2458	30.9211	95.16
HP204	6	8	3.43	11.0094	42.2932	31.2838	40.7182	29.7088	94.97
HP204	7	10	4.46	11.1361	42.4071	31.2710	41.3931	30.2570	96.76
HP204	8	10	4.46	10.3220	42.4378	32.1158	41.1104	30.7884	95.87
HP204	9	10	4.46	10.9580	42.4037	31.4457	41.4677	30.5097	97.02
IA2056	1	6	2.68	10.9070	41.3923	30.4853	36.4142	25.5072	83.67
IA2056	2	6	2.68	11.0108	42.7413	31.7305	37.8089	26.7981	84.46
IA2056	3	6	2.68	10.4597	41.2635	30.8038	36.3732	25.9135	84.12
IA2056	4	8	3.74	11.3653	41.5475	30.1822	39.5451	28.1798	93.37
IA2056	5	8	3.74	10.3247	40.4543	30.1296	38.4664	28.1417	93.40
IA2056	6	8	3.74	11.0094	42.2759	31.2665	40.2798	29.2704	93.62
IA2056	7	10	4.51	11.1361	41.0866	29.9505	39.7283	28.5922	95.46
IA2056	8	10	4.51	10.3220	40.4681	30.1461	39.1029	28.7809	95.47
IA2056	9	10	4.51	10.9580	41.9625	31.0045	40.6259	29.6679	95.69

Table A.2. (Continued).

<i>Soybean variety</i>	<i>Sample #</i>	<i>Soymilk solids, °Brix</i>	<i>Protein content, %</i>	<i>Tare wt, g</i>	<i>Original gross wt, g</i>	<i>Original net wt, g</i>	<i>Pellet gross wt, g</i>	<i>Pellet net wt, g</i>	<i>WHC, %</i>
IA2025	1	6	2.38	10.9070	41.6012	30.6942	38.7115	27.8045	90.59
IA2025	2	6	2.38	11.0108	42.3300	31.3192	39.8715	28.8607	92.15
IA2025	3	6	2.38	10.4597	41.2969	30.8372	38.4549	27.9952	90.78
IA2025	4	8	3.28	11.3653	41.6811	30.3158	39.9053	28.5400	94.14
IA2025	5	8	3.28	10.3247	42.0208	31.6961	40.3284	30.0037	94.66
IA2025	6	8	3.28	11.0094	41.6417	30.6323	39.7964	28.7870	93.98
IA2025	7	10	4.17	11.1361	42.9667	31.8306	41.6050	30.4689	95.72
IA2025	8	10	4.17	10.3220	44.0019	33.6799	42.6321	32.3101	95.93
IA2025	9	10	4.17	10.9580	42.8579	31.8999	41.4915	30.5335	95.72