Available online at www.sciencedirect.com

SCIENCE DIRECT®

International Dairy Journal 13 (2003) 585–591

INTERNATIONAL DAIRY JOURNAL

www.elsevier.com/locate/idairyj

Review

Sensory and mechanical aspects of cheese texture

E. Allen Foegeding[a,*], Jennifer Brown[b], MaryAnne Drake[a], Christopher R. Daubert[a]

[a] *Department of Food Science, Southeast Dairy Foods Research Center, North Carolina State University, Box 7624 236 Schaub Hall, Raleigh, NC 27695-7624, USA*

[b] *The Dial Corporation, 15501 N Dial Blvd, Scottsdale, AZ 85254, USA*

Received 6 January 2003; accepted 2 April 2003

Abstract

Producing high quality dairy products requires precise control over factors determining product appearance, flavor and texture. Food texture is analyzed by descriptive sensory analysis. This method uses terms that depict the textural sensations perceived from first bite through mastication and swallowing. One component of sensory texture is mechanical properties, which are determined by empirical or fundamental methods. However, if one wants to understand the molecular basis of texture, then fundamental tests are required. Fundamental rheological properties are linked to network models, such as those for rubber elasticity or filled gels. These models predict how network interactions will alter rheological properties, providing a link from molecular interactions to sensory texture. In general, sensory and rheological terms that relate to the overall firmness and resiliency of cheese are highly correlated. However, sensory terms that describe the breakdown pattern, adhesiveness and cohesiveness of cheese, are weakly, if at all, correlated with rheological properties.

Keywords: Sensory texture; Rheological properties; Fracture properties; Cheese

Contents

1. Understanding food texture . . . 585
2. Determining molecular mechanisms for texture . . . 586
3. Rheological analysis of cheese . . . 586
4. Sensory analysis of cheese texture . . . 588
5. Correlating sensory and rheological tests . . . 589
6. Analysis of cheese texture . . . 589
7. Conclusions . . . 590
Acknowledgements . . . 590
References . . . 590

1. Understanding food texture

Food texture is defined as "all the rheological and structural (geometric and surface) attributes of the product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors" (Lawless & Heymann, 1998, Chapter 11). By this definition, every dairy food has a "texture" that defines the product type and level of quality. Therefore, a dairy food manufacturer must understand the factors controlling texture in order to make products of the highest

---

*Corresponding author. Tel.: +1-919-513-2244; fax: +1-919-515-7124.

E-mail address: allen_foegeding@ncsu.edu (E. Allen Foegeding).

0958-6946/03/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0958-6946(03)00094-3

quality and consistency. The ability to make a broad variety of dairy products has been developed and refined over the centuries; however, many of the factors responsible for product characteristics and quality are not understood at a molecular level. Indeed, the complexity of dairy products makes them very difficult to study at a molecular level, leaving the close observation and repeatability skills of the manufacturer as one means to assure high quality products. Large-scale production of dairy foods and the desire to develop new products has stimulated interest in understanding the science of texture. This manuscript will focus on the mechanical aspects of texture with emphasis on linking terms from descriptive sensory analysis with fundamental rheological properties.

2. Determining molecular mechanisms for texture

Food texture is comprehensively investigated by sensory analysis. Mechanical and tactile elements are often simultaneously investigated by various instruments and then correlations are established between sensory terms and mechanical/tactile properties. The benefit of using fundamental rheological methods to evaluate the mechanical elements of texture is that they are linked to theories that explain molecular mechanisms. An approach to understanding the molecular mechanism(s) of texture is shown in Fig. 1. The first step would be to establish relationships among sensory texture and rheological properties (microstructural properties may also be investigated but this discussion will be restricted to rheological properties). Then the appropriate theories that describe the food (e.g., non-Newtonian fluid, composite material or particle gel) and predict the influence of various elements of the food (e.g., gel network and filler particles) (van Vliet, 1988; Whittle & Dickinson, 1998) are chosen. If the food behaves as predicted, then a molecular mechanism is established and ingredient and processing alternatives can be developed based on the material model. This approach is clearly over-simplified for dairy foods and will not be able to predict all the complex elements of texture; however, it will provide a scientific framework that can be continuously modified to more closely fit the food. One could view this as a start in developing more complex models.

There are benefits and limitations associated with using fundamental rheological properties. Fundamental rheological methods are beneficial because they are linked with microstructural and molecular mechanisms. However, materials must be homogeneous and isotropic, and be in a geometrical shape that stresses and strains can be precisely calculated. This requirement clearly limits the choice of foods that can be evaluated by fundamental rheological methods. In contrast, sensory analysis and empirical mechanical texture methods place little or no limits on the material being analyzed. While this allows for evaluation of a wide range of materials, it does not provide any information concerning microstructural or molecular mechanisms.

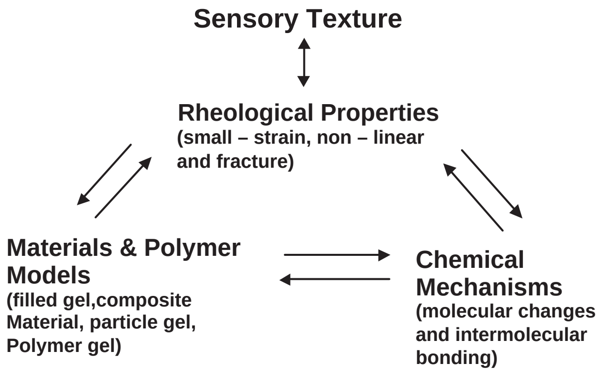

Fig. 1. Determining molecular mechanisms for food texture.

If homogeneous and isotropic are reasonable assumptions, then one must determine if the material is a fluid, semi-solid or solid. An additional classification is as viscous, elastic or viscoelastic. This will determine which rheological methods and properties are appropriate. Fig. 2 shows a range of product consistency and corresponding rheological methods. The discussion that follows will focus on the analysis of cheese texture, with primary emphasis on solid, viscoelastic materials.

3. Rheological analysis of cheese

Food rheology, the material science of foods, investigates the relationships among stress (σ), strain (γ) and time scale of foods to (1) understand the effects of processing on products, (2) probe the system structure, and (3) reveal critical aspects of food texture. Rheological assays may be classified as either empirical or fundamental. Empirical tests are relatively simple procedures that typically measure a force on a sample and the accompanying deflection. These methods rely completely on test parameters, such as sample volume, shape, and testing speed. On the other hand, fundamental tests are more sophisticated in that they account for sample geometry, volume, and testing conditions. These tests transcend instrumentation and permit scientists and engineers to speak a common language regarding material properties. Numerous texts have been written regarding the importance of rheological measurements for foods and should be consulted for a more detailed description (Steffe, 1996; Rao, 1999).

Rheological measurements may be categorized into three regimes for viscoelastic solid foods (Fig. 3). The first region is the linear realm, where the relationship between stress and strain is proportionate, and Hooke's law is obeyed. The next region is one of nonlinearity; the

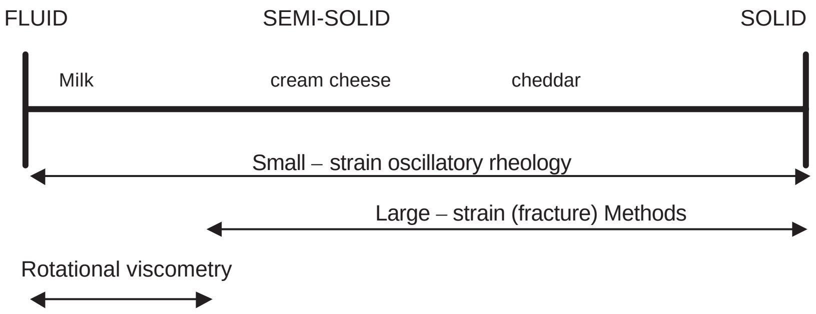

Fig. 2. Rheological continuum of properties and methods.

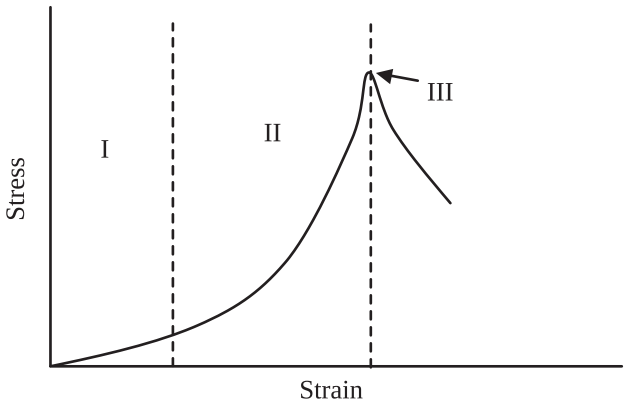

Fig. 3. Rheological regimes for viscoelastic solid foods.

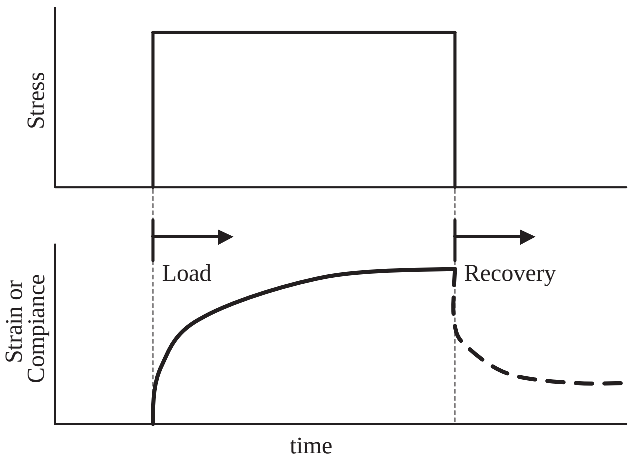

Fig. 4. Creep parameters.

nonlinear regime is as the name implies a more complex relationship between stress and strain. Finally, the last point occurs at sample fracture. Regions I and III have been well characterized for food materials due to the simplicity of gathering and interpreting measurements in these zones. For example, small amplitude oscillatory shear can only measure rheological properties in region I, and testing to failure (point III) can be easily quantified and explained. However, to describe the sensory response during mastication of food products, region II cannot be ignored and may profoundly and significantly contribute to the understanding of texture analysis and sensory description.

When performing rheological tests, should a change of test speeds cause a deviation in the response path through each of the regions, the material may be classified as viscoelastic rather than elastic. A viscoelastic material incorporates aspects of fluid-(viscous) and solid-(elastic) like behaviors, and testing frequency (ω) has a strong impact on which of the behaviors dominates the response. Typically, as the test speed or frequency is slowed, the viscous nature is more prominently revealed. Therefore, viscoelastic property determination incorporates time (t) as a critical variable, and measurements are performed in either a dynamic or transient mode.

During transient tests an instantaneous and constant load or deformation is applied to the material, and the responding behavior is monitored with the lapsing time. For example, a creep test places an instantaneous and constant stress on the material while the strain or compliance (J) is measured with time (Fig. 4). Data from creep tests may determine retardation time constants (λ) of the sample, a characteristic time descriptor for the material. These time constants provide insight as to the ease a material can adapt to an applied load, and the larger the constant, the slower material relaxation. A second component to a creep test is recovery upon load removal. If the sample displays no recovery, maintaining a constant degree of strain or compliance, the sample has a significant viscous component.

Dynamic tests subject the material to sinusoidally varying stresses or strains while recording the material response (Fig. 5). To determine viscoelastic properties with dynamic tests, samples must be measured within the linear viscoelastic region, region I of Fig. 3. During the oscillatory test, the sample either stores energy or dissipates energy in the form of heat. A purely elastic substance will store all energy, while an ideally viscous

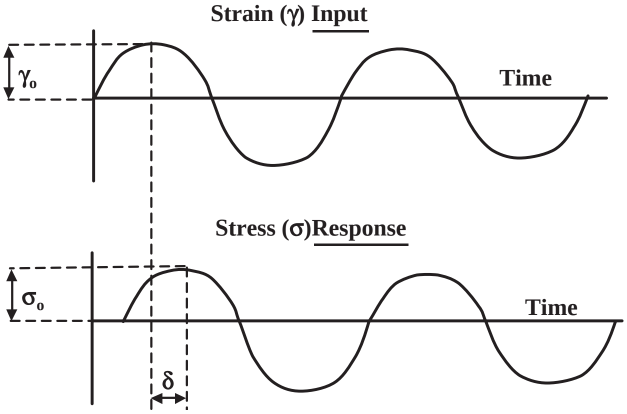

Fig. 5. Dynamic testing parameters.

material will dissipate and lose the energy. The ratio of energy lost to energy stored is an important parameter known as the phase angle (δ) and describes the relative degree of viscoelasticity. For example, a purely elastic material will have a phase angle of 0°. Since Hooke's Law, a proportional region between stress and strain, is obeyed for these tests, the ratio of stress and strain amplitudes (σ_0, γ_0) provides another important viscoelastic property, the complex modulus (G^*). This modulus, in conjunction with the phase angle, can produce the two primary viscoelastic terms of interest, the storage (G') and loss (G'') moduli:

$$G' = G^* \cos(\delta),$$

$$G'' = G^* \sin(\delta).$$

The storage modulus reflects the degree in which a material stores energy (elastic component), while the loss modulus describes the degree of dissipation (viscous component). These two viscoelastic properties are typically measured while the oscillatory frequency is changing to produce the mechanical spectra of the sample, or a rheological fingerprint of the small strain behavior for the material.

When correlating rheological and sensory properties, loading to failure and measuring the stress and strain at fracture is a common procedure. Regions II and III of Fig. 3 are evaluated using large strain methodologies (compression, torsion, or tension), which may be performed empirically (Texture Profile Analysis) or fundamentally. Typically, compression tests are selected due to the simple sample preparation required. During compression, a cylindrical specimen is squeezed between two plates. The force to deform the material to failure is used to compute a fracture stress, while the degree of deformation determines fracture strain. Likewise, a tension test extends the sample until rupture, and similar parameters are calculated. Tensile tests are seldom performed due to complications associated with securing specimens to the instrumentation. Lastly, a torsion test essentially twists the material to fracture. The degree of rotation and magnitude of torque required to break the sample is monitored to calculate the strain and stress at fracture. Torsion places a condition known as pure shear on the material, creating an equivalent distribution of shear and normal stresses throughout the sample. Likewise, each of these fracture approaches can create a combination of shear and normal stress distributions throughout the material, and care must be extended to report the appropriate failure conditions.

In addition to rheological analysis, other material sciences are frequently encountered to explain the connection between material properties and sensory performance. Tribology is a science that investigates the design, friction, wear, and lubrication of interacting surfaces in relative motion. Tribology has been used to study the role of surface properties on sample adhesiveness and lubricity. Tribology plays an important role in the manner in which a food product is detected in the oral cavity, specifically the tooth surface, tongue, and upper palate.

4. Sensory analysis of cheese texture

Sensory texture is complex and both tactile (geometrical properties: mouthfeel, smoothness, grittiness, moisture properties) and kinesthetic (mechanical properties: hardness, cohesiveness, springiness) properties are evaluated in the mouth (Meilgaard, Civille, & Carr, 1999). Many of these properties can also be perceived by manipulation of cheese with the hands (Drake, Gerard, & Civille, 1999a). In many products, such as potato chips, visual and auditory properties of texture can be very important. With cheese, textural aspects perceived in the mouth play the most critical role, although spreadability and slicing properties can be critical texture properties perceived by the eyes and hands with some cheeses.

Sensory texture tests can be divided into two categories: affective and analytical. Affective tests involve consumers and their perceptions of acceptability and texture concepts. Such tests are useful for exploring the role that texture plays in consumer choice and acceptability. Analytical tests involve the use of screened or trained panelists whose responses are treated as instrumental data. Such tests include discriminatory tests and the most powerful tool in the sensory arsenal: descriptive analysis. Descriptive analysis is the tool of choice for qualitatively and quantitatively differentiating cheeses and for exploring and defining the relationships between sensory and instrumental perception of cheese texture.

Descriptive analysis of cheese texture requires a descriptive technique and a texture lexicon or language to describe the texture properties. There are several valid approaches to descriptive analysis (Drake & Civille, 2003). These approaches include, Flavor Profile Method, Quantitative Descriptive Analysis (QDA), the Spectrum technique and other techniques which have taken parts of two or more of the previous methods. A texture language can be identified for the cheese(s) and/or cheese properties of interest using any of these approaches. Alternatively, the texture profile method, unique to texture analysis, was developed by Alina Szczesniak in the early 1960s to specifically address texture properties of foods and their correlations with empirical texture measurements (Szczesniak, Brandt, & Friedman, 1963). The language, scales, and definitions, were later expanded for specific foods, although natural cheese has not been a focus (Civille & Szczesniak, 1973).

Panelist selection, scales and scale usage, and training are critical parts of any descriptive texture analysis approach. These specifics are reviewed elsewhere (Drake & Civille, 2003; Meilgaard et al., 1999). One important issue not to be overlooked is panelist training. Although descriptive analysis does not require expensive instrumentation, time and training are required. The old adage "you reap what you sow" directly applies. A good texture panel will require training by an experienced panel leader. While texture training generally does not require the number of hours that flavor analysis does, a minimum of 10–20 h depending on the number of terms will be required for a panel to perform with the precision necessary to differentiate products and to define sensory/instrumental relationships.

A good texture language or lexicon is also required for descriptive analysis of cheese texture. Properties of a good texture lexicon include clear and precise definitions, standardized procedures (sample presentation, temperature), standard order of term evaluation, references for each term, scale anchors, and non-redundancy of terms. (One example: firmness can be the force required to bite through the sample with the molars or the incisors.) These properties are necessary in order to provide a point of reference for training panelists, facilitate replication and/or comparison of results at other sites, and to establish sound relationships between sensory and instrumental measurements (Drake & Civille, 2003). Fortunately, providing these requirements is straightforward and generally easier for texture than flavor lexicons. A sensory texture language is also not necessarily finite. The language will continue to be refined, particularly as additional cheeses are studied or as additional instrumental studies are conducted.

5. Correlating sensory and rheological tests

There are many complications associated with relating fundamental rheological measurements and sensory data. First, rheological tests are designed to measure physical properties and not mimic the human sensory process. Rheological tests measure only a 'single' event: the forces and deformations associated with 'first' bite during consumption. This represents only 2–10% of the total normal mastication time (Bourne, 1975). Also, human individual oral processes are highly idiosyncratic; instrumental methods cannot mimic each person's particular chewing patterns (Wilkinson, Dijksterhuis, & Minekus, 2000). Clearly, the goal in measuring fundamental rheological properties is not to mimic the sensory process. The goal is to accurately measure physical properties, and determine how these properties relate to the dynamic perception of texture.

6. Analysis of cheese texture

Texture is an important characteristic used to differentiate many cheese varieties (Antoniou, Petridis, Raphaelides, Omar, & Kesteloot, 2000; Wendin, Langton, Caous, & Hall, 2000) and is considered by the consumer as a determinant of overall quality and preference (Lee, Imoto, & Rha, 1978; Adda, Gripon, & Vassal, 1982; McEwan, Moore, & Colwill, 1989; Guinard & Mazzucchelli, 1996). For a discussion of instrumental analysis of cheese texture see International Dairy Federation (1991) bulletin 268.

Descriptive analysis of cheese texture has been conducted on a variety of cheeses with different fat contents and some with fat replacers (Piggot & Mowat, 1991; Drake & Swanson, 1996; Drake, Truong, & Daubert, 1999b; Lobato-Calleros, Robles-Martinez, Caballero-Perez, & Aguirre-Mandujano, 2001; Madsen & Ardö, 2001; Gwartney, Foegeding, & Larick, 2002). In these studies, descriptive sensory analysis was used to differentiate cheeses and/or the impact of various treatments. An equal if not greater number of studies have been conducted to explore the relationships between sensory properties and instrumental measurements of cheese texture (Wium, Gross, & Qvist, 1997; Bachmann, Bütikofer, & Meyer, 1999; Drake, Gerard, Truong, & Daubert, 1999c; Antoniou et al., 2000; Benedito, Gonzalez, Rossello, & Mulet, 2000; Truong, Daubert, Drake, & Baxter, 2002) and to devise instrumental methods to more accurately assess or predict sensory properties of cheese (Sørensen & Jepsen, 1998; Breuil & Meullenet, 2001; Meullenet & Finney, 2002). Instrumental mechanical measurements have correlated well with the mechanical sensory perceptions, such as hardness and springiness, but lack in correlations with other terms (Lee et al., 1978; Chen, Larkin, Clark, & Irwin, 1979; Casiraghi, Lucisano, & Pompei, 1989; Jack, Piggott, & Patterson, 1993). This could be due to a complete lack of correlation or a lack of comprehensiveness in the rheological properties measured.

In a recent investigation, we determined the sensory and rheological properties of mozzarella and pizza cheese (stirred curd manufacturing process) over a 38-day aging period (Brown, 2002). Textural properties were determined by: descriptive sensory analysis, controlled-strain oscillatory testing, controlled-stress creep testing and large-strain torsional testing. These tests covered strain regions I–III (Fig. 3) with actual strain and stress values ranging from 0.001 to ~2.0 and 18 to 40,000 Pa, respectively. The tests were conducted at various strain rates so the viscoelastic nature of cheese was accounted for in testing. The small and large strain moduli were both stain rate dependent, confirming the viscoelastic, time-dependent nature of the cheeses. The correlations among sensory and rheological properties were highly dependent on the level of strain applied to the cheese. Rheological properties determined in the linear viscoelastic region (G^* and G') were only correlated with firmness determined by hand or chewing. Probing slightly beyond the linear viscoelastic region with creep testing resulted in more correlations. In addition to firmness, resiliency (springiness) and chewdown (adhesiveness) sensory properties were also correlated with rheological properties. However, fracture properties proved to be the most highly correlated with sensory texture. The fracture modulus (fracture stress/fracture strain) was correlated with firmness, springiness, degree of breakdown during chewing and adhesiveness. Note that the fracture modulus is a ratio of stress to strain, just like G^* and G'. The difference being the level of strain used to determine the moduli. It appears that as one moves from region I, to II to III in the stress–strain curve (Fig. 3), the rheological properties detected are more associated with those perceived by sensory perception.

7. Conclusions

Sensory texture is a complex property of foods that encompasses physical properties not detected by rheological methods. However, rheological methods which probe beyond the linear region are correlated with elements of sensory firmness, resiliency and, to a lesser extent, chewdown terms. Rheological properties determined by fracture and creep testing show the highest degree of correlation with sensory terms. The chewdown sensory characteristics were the least correlated with rheological properties. This study suggests that fundamental rheological properties can be used to understand certain elements of cheese texture.

Acknowledgements

Paper No. FSR-02-51 of the Journal Series of the Department of Food Science, NCSU, Raleigh, NC 27695-7624. Support from the North Carolina Agricultural Research Service, Dairy Management Inc. and the Southeast Dairy Foods Research Center are gratefully acknowledged. The use of trade names in this publication does not imply endorsements by the North Carolina Agricultural Research Service of the products named nor criticism of similar ones not mentioned.

References

Adda, J., Gripon, J. C., & Vassal, L. (1982). The chemistry of flavour and texture generation in cheese. *Food Chemistry*, *9*, 115–129.

Antoniou, K. D., Petridis, D., Raphaelides, S., Omar, Z. B., & Kesteloot, R. (2000). Texture assessment of French cheeses. *Journal Food Science*, *65*, 168–172.

Bachmann, H. P., Bütikofer, U., & Meyer, J. (1999). Prediction of flavour and texture development in Swiss-type cheeses. *Lebensmittel-Wissenschaft und -Technologie*, *32*, 284–289.

Benedito, J., Gonzalez, R., Rossello, C., & Mulet, A. (2000). Instrumental and expert assessment of Mahon cheese texture. *Journal of Food Science*, *65*, 1170–1174.

Bourne, M. C. (1975). Is rheology enough for food texture measurement? *Journal of Texture Studies*, *6*, 259–262.

Breuil, P., & Meullenet, J. F. (2001). A comparison of three instrumental tests for predicting sensory texture profiles of cheese. *Journal of Texture Studies*, *32*, 41–55.

Brown, J. A. (2002). *Cheese texture*. M.S. Thesis. North Carolina State University.

Casiraghi, E., Lucisano, M., & Pompei, C. (1989). Correlation among instrumental texture, sensory texture and chemical composition of five Italian cheeses. *Italian Journal Food Science*, *1*, 53–63.

Chen, A. H., Larkin, J. W., Clark, C. J., & Irwin, W. E. (1979). Textural analysis of cheese. *Journal of Dairy Science*, *62*, 901–907.

Civille, G. V., & Szczesniak, A. (1973). Guide to training a texture profile panel. *Journal of Texture Studies*, *4*, 204–210.

Drake, M. A., & Civille, G. V. (2003). Flavor Lexicons. *Comprehensive Reviews in Food Science*, *2*, 33–40.

Drake, M. A., Gerard, P. D., & Civille, G. V. (1999a). Ability of hand evaluation versus mouth evaluation to differentiate texture of cheese. *Journal of Texture Studies*, *14*, 425–441.

Drake, M. A., Truong, V. D., & Daubert, C. R. (1999b). Rheological and sensory properties of reduced fat processed cheeses containing lecithin. *Journal of Food Science*, *64*, 744–747.

Drake, M. A., Gerard, P. D., Truong, V. D., & Daubert, C. R. (1999c). Relationship between instrumental and sensory measurements of cheese texture. *Journal of Texture Studies*, *30*, 451–476.

Drake, M. A., & Swanson, B. G. (1996). Fat mimetics in low fat cheeses. *Journal of Food Science*, *61*, 1267–1270.

Guinard, J. X., & Mazzucchelli, R. (1996). The sensory perception of texture and mouthfeel. *Trends in Food Science and Technology*, *7*, 213–219.

Gwartney, E. A., Foegeding, E. A., & Larick, D. K. (2002). The texture of commercial full-fat and reduced fat cheese. *Journal of Food Science*, *67*, 812–816.

International Dairy Federation. (1991). Rheological and fracture properties of cheese. *IDF Bulletin* 268.

Jack, F. R., Piggott, J. R., & Paterson, A. (1993). Relationships between rheology and composition of Cheddar cheeses and texture as perceived by consumers. *International Journal of Food Science and Technology*, *28*, 293–302.

Lawless, H. T., & Heymann, H. (1998). Texture evaluation. In *Sensory evaluation of food*. New York, NY: Chapman & Hall.

Lee, C. H., Imoto, E. M., & Rha, C. (1978). Evaluation of cheese texture. *Journal of Food Science*, *43*, 1600–1605.

Lobato-Calleros, C., Robles-Martinez, J. C., Caballero-Perez, J. F., & Aguirre-Mandujano, E. (2001). Fat replacers in low fat Mexican Manchego cheese. *Journal of Texture Studies*, *32*, 1–14.

Madsen, J. S., & Ardo, Y. (2001). Exploratory study of proteolysis, rheology, and sensory properties of Danbo cheese with different fat contents. *International Dairy Journal*, *11*, 423–431.

McEwan, J. A., Moore, J. D., & Colwill, J. S. (1989). The sensory characteristics of Cheddar cheese and their relationship with acceptability. *Journal of the Society of Dairy Technology*, *42*, 112–117.

Meilgaard, M. M., Civille, G. V., & Carr, T. (1999). Descriptive analysis techniques. In: *Sensory evaluation techniques* (3rd ed). New York, NY: CRC Press.

Meullenet, J. F., & Finney, M. L. (2002). Measurement of biting velocities and predetermined and individual crosshead speed instrumental imitative tests for predicting cheese hardness. *Journal of Texture Studies*, *33*, 45–58.

Piggot, J. R., & Mowat, R. G. (1991). Sensory aspects of maturation of Cheddar cheese by descriptive analysis. *Journal of Sensory Studies*, *6*, 49–62.

Rao, M. A. (1999). *Rheology of fluid and semisolid foods*. Gaithersburg, MD: Aspen Publications.

Sørensen, L. K., & Jepsen, R. (1998). Assessment of sensory properties of cheese by near-infrared spectroscopy. *International Dairy Journal*, *8*, 863–871.

Steffe, J. F. (1996). *Rheological methods in food process engineering*. East Lansing, MI: Freeman Press.

Szczesniak, A., Brandt, M. A., & Friedman, H. H. (1963). Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. *Journal of Food Science*, *28*, 397–403.

Truong, V. D., Daubert, C. R., Drake, M. A., & Baxter, S. R. (2002). Vane rheometry for textural characterization of Cheddar cheese: Correlation with other instrumental and sensory measurements. *Lebensmittel-Wissenschaft und -Technologie*, *35*, 305–314.

van Vliet, T. (1988). Rheological properties of filled gels. Influence of filler matrix interactions. *Colloid & Polymer Science*, *266*, 518–524.

Wendin, K., Langton, M., Caous, L., & Hall, C. (2000). Dynamic analyses of sensory and microstructural properties of cream cheese. *Food Chemistry*, *71*, 363–378.

Whittle, M., & Dickinson, E. (1998). Large deformation rheological behavior of a model particle gel. *Journal of the Chemical Society Faraday Transactions*, *94*, 2453–2462.

Wilkinson, C., Dijksterhuis, G. B., & Minekus, M. (2000). From food structure to texture. *Trends in Food Science and Technology*, *11*, 442–450.

Wium, H., Gross, M., & Qvist, K. B. (1997). Uniaxial compression of UF-Feta cheese related to sensory texture analysis. *Journal of Texture Studies*, *28*, 455–476.