SMALL AMPLITUDE OSCILLATORY SHEAR STUDIES ON MOZZARELLA CHEESE PART I. REGION OF LINEAR VISCOELASTICITY

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ABSTRACT

Changes in texture of a low-moisture, part-skim and a low-fat, part-skim Mozzarella cheese during heating were examined by measuring their rheological properties using small amplitude oscillatory shear (SAOS) tests after 1, 4 and 12 weeks of refrigerated storage. In general, the linear viscoelastic range decreases with increasing temperature and age because cheese behaves more like a viscoelastic solid at lower temperature and shorter ripening time. The dynamic rheological properties (η, G' and G") were constant within a range of 0.05% shear strain. The dynamic rheological properties of low-fat, part-skim Mozzarella were found to be higher than that of low-moisture, part-skim Mozzarella within the linear viscoelastic range.*

INTRODUCTION

Texture is an important characteristic of cheese in determining the consumer acceptability and quality (McEwan *et al.* 1989), and textural characteristics affect cheese eating quality, image and handling (Walstra and Peleg 1991; Visser 1991). Cheese is viscoelastic in nature, i.e., it exhibits both elastic (Hookean solid) and viscous (Newtonian fluid) behavior, and in most cases shows no notable yield stress. Cheese consists of a dispersed phase of fat globules embedded in a continous matrix of protein phase. Composition and structural characteristics of cheese affect its rheological properties and they undergo notable changes dur-

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ing maturation. These variations involve all major cheese components (Christiansen *et al.* 1991) and reflect the effects of chemical and physical changes during maturation, proteolysis being the most important (Fox 1989).

The process of mastication and ingestion involves subjecting food materials to large amplitude or nonlinear deformations and flows in order to break down the structure into forms suitable for swallowing and predigestion. To better understand the relationships between structural and rheological characteristics, the food material is subjected to a small amplitude or linear deformation in order to prevent any structural damage. Within this linear range, viscoelastic characteristics are independent of magnitude and rate of deformation or force (Ferry 1980).

Dynamic testing is one of the most important and fundamental methods for determining rheological properties of viscoelastic materials, and it has been used extensively to probe the structure of foodstuffs such as cheese (Steffe 1992; Rao and Steffe 1992). These measurements are normally made by imposing a sinusoidally varying strain (or stress) and measuring the resulting stress (or strain) in the sample.

There have been many research publications on dynamic mechanical properties of cheese despite the fact that determining their rheological properties are complicated by structural nonhomogeneity (Walstra and van Vliet 1982). Nolan *et al.* (1989) used dynamic rheological properties to distinguish between imitation and natural low-moisture, part-skim Mozzarella by measuring the viscoelastic moduli and dynamic viscosities. They also considered problems related to specimen slippage during dynamic rheological analysis. Taneya *et al.* (1979) investigated the effects of maturation on the softening properties of heated natural (Gouda and Cheddar) and process cheese by measuring dynamic viscoelastic properties. Tunick *et al.* (1990) used viscoelastic properties as a means to distinguish the textural differences between Cheddar and Cheshire cheeses. They suggested this method could be used in identification of the two cheeses to prevent mislabeling. Nolan *et al.* (1990) compared rheological behavior of Cheddar and pasteurized process American cheeses by studying the dynamic rheological properties. Ustunol *et al.* (1994) used the dynamic complex modulus of Cheddar cheese with varying fat content as an index of meltability and they report a good correlation with meltability obtained from Arnott's test. A good review of earlier work on dynamic mechanical measurements of cheeses has been given by Konstance and Holsinger (1992).

The objective of this study was to investigate the effect of heating on linear dynamic rheological properties of a low-moisture, part-skim and a low-fat, part-skim Mozzarella cheese. Studies so far have not done comprehensive measurements on the variation of linear viscoelastic range of cheese with temperature and age. It is well known that, at any age, cheese behaves less like a viscoelastic solid as the temperature increases. This has an effect on the region of linear viscoelasticity. Therefore, establishing a region of linear viscoelastic range for a wide temperature range and age is critical. In this paper we report the effect of temperature and age on the linear viscoelastic range of cheese so that the highest value of shear strain for which all measurements fall within the linear viscoelastic can be selected for subsequent frequency sweep measurements. Data obtained in the linear viscoelastic range are readily comparable to study the effects of other experimental variables such as temperature, composition, age, etc.

MATERIALS AND METHOD

Cheese Manufacture

Low-moisture, part-skim and low-fat, part-skim Mozzarella cheeses were made in the Department of Food Science dairy plant at the University of Wisconsin-Madison. Cheese blocks were vacuum-packaged in plastic bags and ripened at 6–8C for rheological measurements after 1, 4 and 12 weeks. The chemical composition data for the cheeses obtained from standardized methods (Bradley *et al.* 1992) are listed in Table 1.

TABLE 1.
CHEMICAL COMPOSITION OF MOZZARELLA CHEESES

Maturation (wk)	Moisture (%)	pH	Fat (%)
A. Low-fat, part-skim (LFPS) Mozzarella			
1	54.5	5.28	8.45
4	53.6	5.21	-
12	53.4	5.21	-
B. Low-moisture, part-skim (LMPS) Mozzarella			
1	47.0	5.17	22.3
4	47.1	5.19	-
12	47.1	5.20	-

Dynamic Rheological Measurements

Disk-shaped cheese samples (mean thickness of 3.5 mm and diameter of 30 mm) were cut from refrigerated blocks using a borer and a cutter, and placed into plastic bags to prevent dehydration. A Bohlin control-strain rheometer (VOR) with a 89.526 g-cm torsion bar and 30-mm diameter parallel plates measuring system was used. Coarse sand paper was glued to the upper plate to prevent slippage. The temperature of the lower plate of the measuring system was maintained by circulating water from a water bath. The sample was placed on the lower plate and then the upper plate was brought in contact with the sample. The sample was held for 3 min to attain temperature equilibrium. All rheological measurements were made at temperatures ranging from 10 to 70C and the rheometer was housed in an environmental chamber.

The dynamic rheological data obtained included the two components of the complex shear modulus (G*): the storage modulus component (G′) and the loss modulus component (G″). The complex viscosity (η^*) and the frequency (ω) were also measured. These parameters are related as follows:

$$|G^*|^2 = (G')^2 + (G'')^2$$

$$\text{and} \quad |\eta^*| = |G^*|/\omega$$

With ω set, values of G*, G′, G″ and η^* were obtained at various shear strains, resulting in a strain sweep to determine the linear viscoelastic region. The strain sweep measurements were made at frequencies of 9.43 and 62.83 rad/s.

RESULTS AND DISCUSSION

The dynamic viscoelastic properties of low-fat, part-skim and low-moisture, part skim Mozzarella cheese are presented in Fig. 1 to 3 and Fig. 4 to 6, respectively. For both types of Mozzarella cheese, the region of linear viscoelasticity decreased with increasing temperature and age. The lowest value of about 0.05% strain was obtained for the linear region after 12 weeks of ripening and at a temperature of 70C. Ak and Gunasekaran (1995) observed that the dynamic mechanical properties of low-moisture, part-skim Mozzarella cheese remained constant up to about 0.5% strain at a temperature of 10C after one week of aging. This was in good agreement with the data of Nolan *et al.* (1989). Tunick *et al.* (1990) studied the strain sweep behavior of Cheddar and Cheshire cheese with age and they observed a quasilinear range (an essentially constant G) up to a strain of 2.5% in each of the samples. Rosenberg *et al.* (1995) studied viscoelastic property changes in Cheddar during ripening using a controlled-stress rheometer and the results of their torque sweep experiments suggested that,

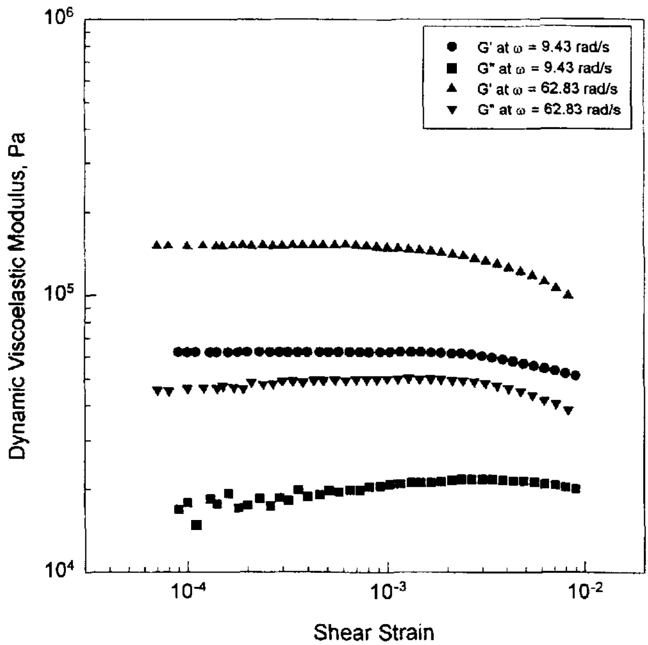

FIG. 1. STRAIN SWEEP OF 1-WEEK OLD LOW-FAT, PART-SKIM MOZZARELLA CHEESE AT 40C

regardless of chemical and structural changes during ripening, no deviation from linear viscoelasticity was noted for torques of 1000 μN-m or less.

All linear viscoelastic parameters decreased with increasing temperature and age, indicating that the cheeses became softer with age. This is due to proteolysis during ripening and thermal softening, resulting in decreased viscosity and elasticity (Creamer *et al.* 1982). It has been observed that elasticity and firmness increases with reduction in fat and cheeses become softer with increase in moisture content (Luyten 1988). Water in cheese is either free or bound to the protein since fat, the other major constituent, is hydrophobic (Prentice 1972). Reduction in moisture alters the casein matrix in cheese and results in a firmer structure. Water acts as a lubricant or a plasticizer between different proteins and therefore, lowering moisture increases hardness and other textural properties of cheese but making it less meltable.

The combined effect of fat and moisture on the textural characteristics of cheese are very significant. The fat content changes the rheological properties more than moisture content, with a synergistic effect causing the differences to become pronounced as both fat and moisture decrease. This is in agreement with results obtained in this study where part-skim Mozzarella (8.45% fat and 53.5% moisture) had higher values of dynamic mechanical properties (η^*, G′ and G″) than low-moisture, part-skim Mozzarella (22.3% fat and 47% moisture).

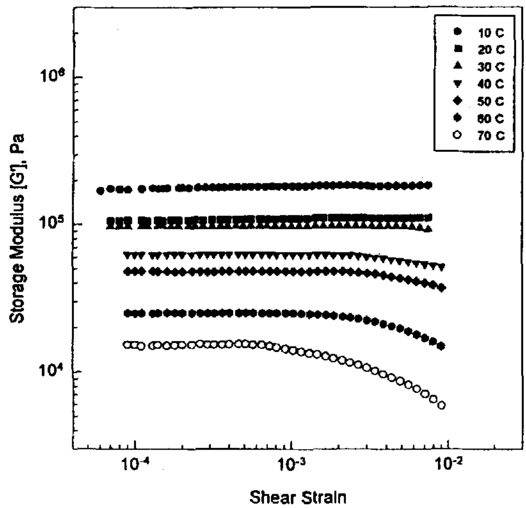

FIG. 2. SHEAR STRAIN DISPERSION OF STORAGE MODULUS AT DIFFERENT TEMPERATURES FOR 1-WEEK OLD LOW-FAT, PART-SKIM MOZZARELLA CHEESE AT ω = 9.43 rad/s

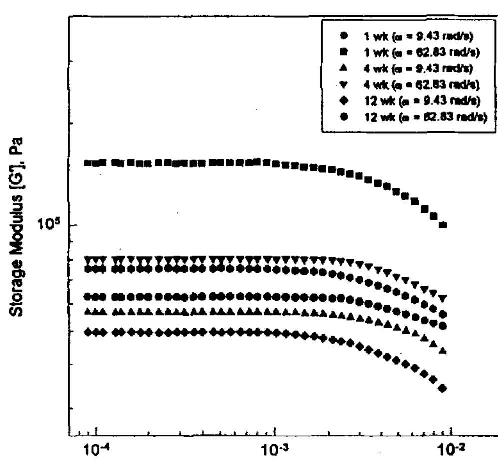

FIG. 3. SHEAR STRAIN DISPERSION OF STORAGE MODULUS WITH MATURATION FOR LOW-FAT, PART-SKIM MOZZARELLA CHEESE AT 40C

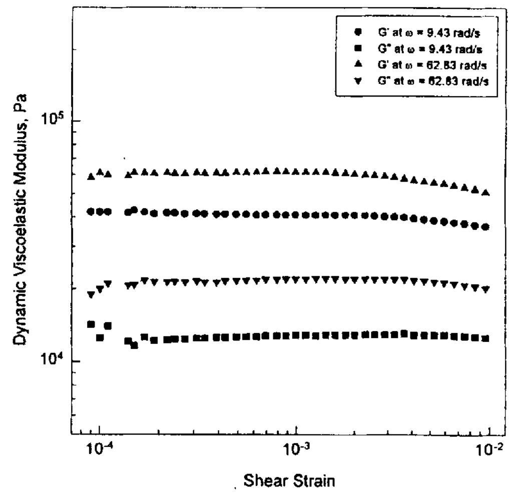

FIG. 4. STRAIN SWEEP OF 1-WEEK OLD LOW-MOISTURE, PART-SKIM MOZZARELLA CHEESE AT 40C

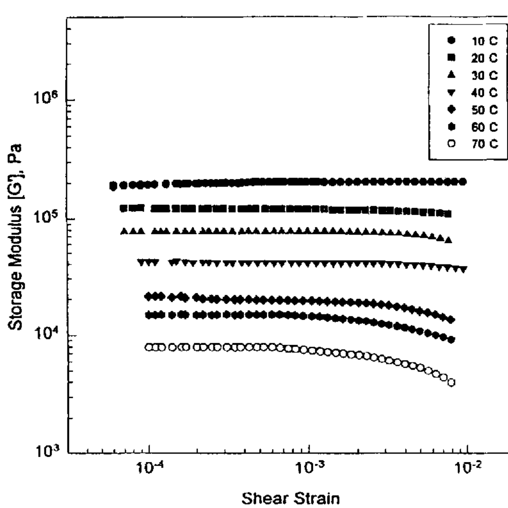

FIG. 5. SHEAR STRAIN DISPERSION OF STORAGE MODULUS AT DIFFERENT TEMPERATURES FOR 1-WEEK OLD LOW-MOISTURE, PART-SKIM MOZZARELLA CHEESE AT ω = 9.43 rad/s

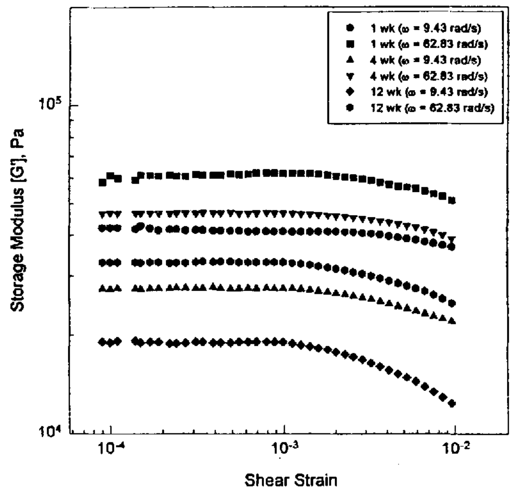

FIG. 6. SHEAR STRAIN DISPERSION OF STORAGE MODULUS WITH MATURATION FOR LOW-MOISTURE, PART-SKIM MOZZARELLA CHEESE AT 40C

CONCLUSIONS

Dynamic oscillatory experiments were useful to study the effects of heating and age on the linear viscoelastic range of cheese. The shear strain limit for linear viscoelastic behavior of Mozzarella cheese decreased with increasing temperature and age. Within the limits of the experimental variables studied, the smallest range of linear viscoelasticity was determined to be about 0.05% shear strain at 70C and 12 weeks of aging. The proteolysis upon ripening led to the softening of cheese as evidenced by decreases in measured viscosity and elasticity. Within the linear viscoelastic range, the dynamic mechanical properties of low-fat, part-skim Mozzarella cheese were higher than that of low-moisture, part-skim Mozzarella cheese.

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