Viscoelastic and Textural Properties of Cheddar Cheese under Various Temperature Conditions

Ziad Abu-Waar [1], Mohammed Saleh [2] and Young S. Lee [3]

[1] Department of Physics, Faculty of Science, The University of Jordan, Amman-Jordan
[2] Department Nutrition and Food Technology, Faculty of Agriculture, The University of Jordan, Amman-Jordan,
[3] Department of Food Science and Nutrition, Dankook University, South Korea
misaleh@ju.edu.jo

Abstract: The impact of temperature on the viscoelastic properties of cheddar cheese was examined. Cylindrical samples of 20 mm diameter and 30 mm height (diameter-to-height ratio of 0.67) were prepared. Uniaxial compression tests were performed under three different temperatures (4, 15 and 25°C) using a TA–XT2 plus texture analyzer. Stress relaxation tests were conducted with a constant applied strain of 70% using a crosshead speed of 0.833 mm/sec. Regardless of the types of cheese, hardness decreased as test temperature decreased, supporting that textural properties of cheddar cheese are temperature dependent. Hardness-Temperature Coefficient of cheddar cheese (-4.0) was smaller compared to that of fruits or vegetables (-1.0), implying that more careful test temperature should be controlled during a textural test for cheddar cheese. Stress relaxation data were best fitted by the Generalized Maxwell and Peleg models (R^2 >0.99). Furthermore, models parameters were observed to be deformation rate dependent.

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1. Introduction

Food texture, especially cheese has been a subject of research for decades (Xiong *et al*., 2002; Meullenet and Breuil 2001; Meullenet and Gross 1999; Bourne 1982 and Szczesniak 1963). Cheese texture properties are of considerable importance to consumers as will as to manufacturer, packager, distributor and retailer (Fox *et al*., 2000) and are often expressed in sensory terms to reflect on consumer's perception of quality.

Several rheological techniques have been developed and used to predict foods sensory texture attributes as a replacement to the expensive, time consuming and sample restriction of the sensory evaluation methods (Xiong *et al*., 2002; Culioli and Sherman 1976 and Drake *et al*., 1999). For example, uniaxial compression testing is used in several food applications, including cheese, to provide information regarding materials during large-scale mechanical deformation (Wium *et al*., 1997 and Thybo *et al*., 2000). More specifically, uniaxial compression was employed to provide rheological and textural properties of cheese that are related to the fracture and flow during testing (Ak and Gunasekaran 1992 and Peleg and Nonnand 1982). Stress relaxation testing is also used to evaluate viscoelastic behaviors of cheese during the initial elastic and viscous stress decay (Peleg and Nonnand 1982 and Diefes 1993).

Mechanical properties of foods depend upon the amount and rate at which deformation usually occurs (Xiong *et al*., 2002). For example, during force compression testing (i.e., dynamic rheological behavior measurement of food as strain increased over time); low compression testing (i.e., less than 50% of the original material height), measurements were correlated with material hardness while at high compression testing (i.e., more than 70% of the original material height), measurements were correlated with the chewing behavior of material (Fox *et al*., 2000). For this, instrumental testing conditions are usually designed to simulate the conditions to which food materials are subjected to during mastication and size reduction processes (Gunasekaran and Ak 2003). Other factors that affects instrumental condition includes sample dimensions, deformation rate, friction at contact surfaces between testing samples and the instrument as well as cheese variety; all reported to have significant impacts on cheese texture measurement (Ak and Gunasekaran 1992; Culioli and Sherman 1976 and Goh and Sherman 1987).

Because of their relation to sensory texture, conditions of the fracture properties of foods are crucial in developing products with desired textural characteristics. For instance, increasing Gouda cheese temperature resulted in a decrease of the fracture stress and compression force (Gunasekaran and Ak 2003). Ak and Gunasekaran (1995) on the same manner related the decreasing in cheese compression force to the thermal softening of the casein network in the cheese influenced by testing conditions.

Although several instrumental testing are in use to predict the sensory characteristics of foods, almost exclusively testing are conducted under ambient temperature (20-25°C). Little research has been conducted to study the effect of cheese temperature on the uniaxial compression and or fracture properties. Therefore the objective of this study is to investigate the impact of temperature during stress relaxation test on cheese viscoelastic and textural properties.

2. Material and Methods

2.1 Testing cheese samples:

Five Mild, Sharp and Medium cheddar cheese blocks were purchased from a local market for preparing the measured cheese samples. Cylindrical cheese samples of 2.0 cm in diameter and 3.0 cm height (diameter-to-height ratio of 0.67) were prepared from each cheese blocks using a cork borer. Samples were stored at 4°C until used. Cheese samples were allowed to attain the required testing temperature (4, 15 or 25 °C) for two hours before performing the each rheological measurement. A digital thermometer was inserted into a dummy sample before testing to guarantee that samples achieved the desired testing temperature before testing.

2.2 Uniaxial compression test:

The effect of storage temperatures (7, 15 and 25°C) on the textural properties of cheddar cheese were evaluated using a uniaxial compression test by a TA–XT2 plus texture analyzer. A load cell of 50-kg was used to eliminate noise during measurement. Samples top and bottom surfaces were lubricated immediately before measurements with a mineral oil in order to reduce the friction at the contact surfaces between cheese samples and the TA–XT2 plus texture analyzer plate. Six deformation rates were selected (0.50, 3.0, 5.5 and 8.0 mm/sec). Cheese samples were compressed to 70% of original height and five replicates at each test condition were performed.

2.3 Stress relaxation test:

Stress relaxation tests were conducted with constant applied strain of 20% using a crosshead speed of 0.833 mm/sec. Stress relaxation forces were recorded after holding for two minutes (Figure 1). Force time data were used to calculate compressive stress (σ). Generalized Maxwell [1] and Peleg and Normand [2] models were fitted using force and stress data using the following formula.

$$F(t) = F_1 \exp\left(-\frac{t}{\lambda_1}\right) + F_2 \exp\left(-\frac{t}{\lambda_2}\right) + \cdots + F_n \exp\left(-\frac{t}{\lambda_n}\right) \quad [1]$$

$$\frac{\sigma_0 t}{\sigma_0 - \sigma} = k_1 + k_2 t \quad [2]$$

Where λ_1 and λ_n are the relaxation times, F_1 to F_n are the decay forces, and $F_{(t)}$ is the instantaneous force in a stress relaxation test, σ_0 is the initial stress, σ is the decreasing stress at time t, and K_1 and K_2 are constants.

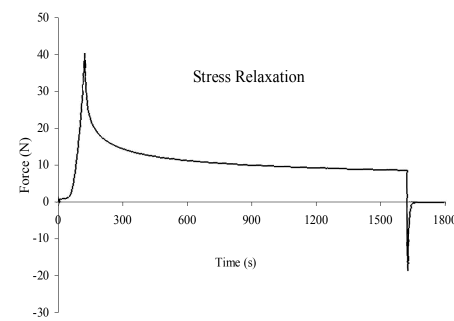

Figure 1: Typical stress-relaxation curve

3. Results and Discussion:

Texture properties of cheddar cheese stored and measured at various temperatures are presented in table 1. Cheese hardness, first and second compression areas, springiness and cohesiveness were measured using a uniaxial compression Texture Profile Analysis (TPA) test. TPA at deformation 70% and at deformation rate of 0.833mm/s was used to compare the effect of temperature on cheese textural properties as suggested by Xiong *et al*., (2002). Xiong *et al*., (2002) indicated the low deformation rate (1.0 mm/s) and deformation between 70 and 90% best correlate with sensory measurements of cheese. Masi (1987) also suggested that if the cheese does not show rupture or yield, then the stress and the work per unit of volume should correspond to 80% deformation. However, deformation rate effect on cheese textural properties was also evaluated in this study and is presented in figure 2 (i.e., for sharp cheddar cheese). Results indicated that temperature significantly ($P<0.05$) impacted cheddar cheese textural properties. For instance, hardness of mild cheddar cheese measured at 25°C increased from 20.9N to 86.8 N when measured at 7°C. Similarly, hardness changed from 22.8N to 118 N for sharp cheddar when measured at 25°C and 7°C, respectively. Medium cheddar cheese had the highest hardness value ranging from 27.3N at 25°C to 118.2N at 7°C. Similar trends were reported for first and second compression where the higher the temperature the lower the area under curve. The decrease in hardness, area under TPA curves of cheese with the increase in temperature is in agreement with Gunasekaran and Ak (2003) who reported a sample temperature of Gouda cheese resulted in a decrease of the fracture stress and compression force. The decrease in the deformations was further related to the thermal softening of casein network with the increase in temperatures (Ak MM, Gunasekaran 1995).

Table 1: Effect of temperature on the textural properties of Mild, Sharp and Medium cheddar cheese stored at 7, 15 and 25^{o}C compressed at a constant deformation rate of 0.833 mm/s.

Textural Properties	Temperature (^{o}C) during Compression	Cheese Type Mild	Sharp	Medium
Hardness (N)	7	86.8 [a]	103.8 [a]	118.2 [a]
	15	66.8 [a]	71.4 [b]	76.5 [b]
	25	21.9 [b]	22.8 [c]	27.3 [c]
First Compression Area (N.s)	7	387.2 [a]	525.7 [a]	572.9 [a]
	15	260.9 [ab]	339.7 [a]	262.3 [ab]
	25	94.5 [b]	150.6 [a]	93.7 [b]
Second Compression Area (N.s)	7	70.9 [a]	92.3 [a]	102.5 [a]
	15	45.5 [ab]	51.9 [ab]	54.0 [ab]
	25	18.4 [b]	23.6 [b]	20.7 [b]
Springiness	7	0.29 [a]	0.24 [a]	0.27 [b]
	15	0.26 [a]	0.19 [a]	0.28 [b]
	25	0.31 [a]	0.45 [b]	0.38 [a]
Cohesiveness	7	0.20 [a]	0.20 [a]	0.19 [b]
	15	0.19 [a]	0.16 [b]	0.20 [ab]
	25	0.22 [a]	0.18 [ab]	0.22 [a]

[1] For the same cheese type, value of hardness, compression area, springiness and cohesiveness at various temperatures having different letter are significantly different ($P<0.05$) according to LSD.

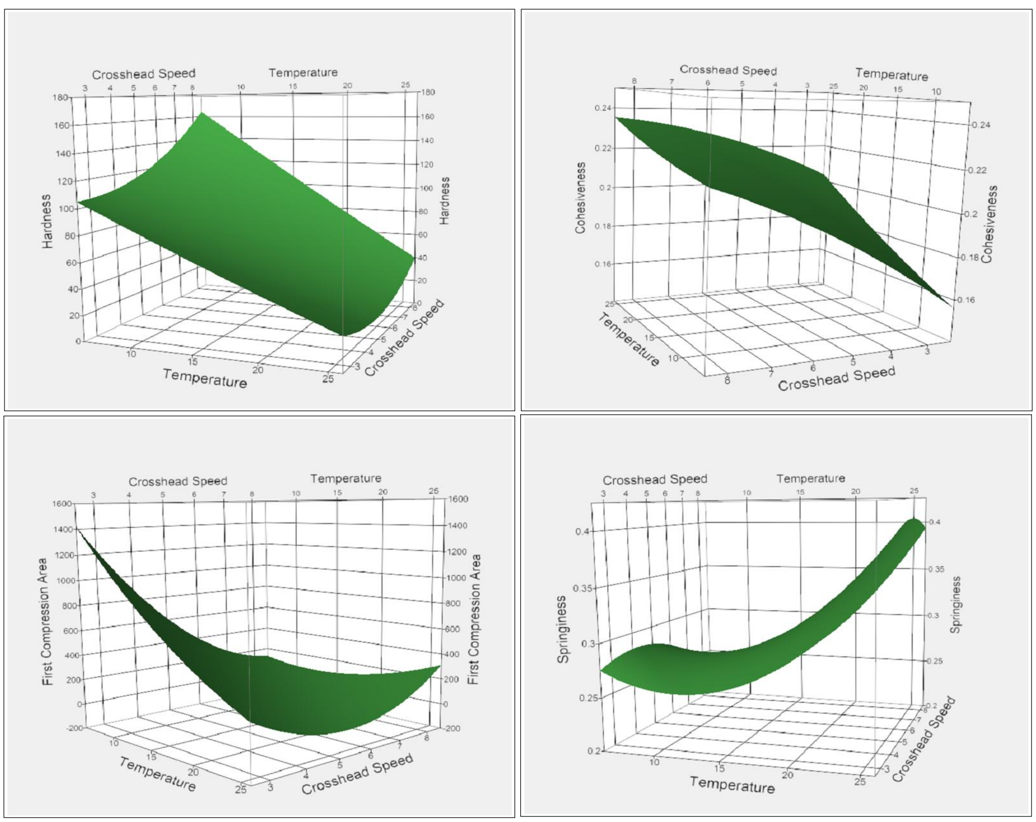

Figure 2: Response surface plots of the effect of temperature and deformation rate on the texture properties of sharp cheddar cheese.

Table 2: Hardness-Temperature Coefficients (HTC) of the three cheddar cheeses types based on different loading test speeds.

Crosshead Speed (mm/s)	Mild	Medium	Sharp
0.5	-4.14[1]	-4.48	-4.41
3.0	-4.28	-4.26	-4.26
5.5	-4.11	-4.26	-4.64
8.0	-4.12	-4.15	-4.31

[1] Where, T1 = lowest (7°C) and T2 = highest (25°C) temperature at which the hardness was measured, respectively

$$\frac{\text{Hardness at } T_2 - \text{ Hardness at } T_1}{\text{Hardness at } T_1 \times (T_2 - T_1)} \times 100\% \text{ per degree}$$

Table 2 shows the Hardness-Temperature Coefficients (HTC) of the three cheddar cheeses types used in this study and were based on different loading test speeds. HTC is known as the percent change in hardness per degree temperature increase over the temperature change (Bourne and Comstock 1986). Similarly, other temperature coefficients including cohesiveness-temperature, springiness-temperature can also be calculated. HTC of cheddar cheese samples were calculated to elucidate the relationship between hardness of cheeses and temperature. The HTC of various cheddar samples ranged from -4.11 to -4.64 indicating that hardness decrease with the increase in temperature irrespective to test compression rate. Results of HTC for cheddar cheese samples tested were lower significantly (P<0.05) lower than that of fruits or vegetables (-1.0) (Bourne and Comstock 1986; Feuge and Guice 1959; Miyada and Tappel 1956; Bourne 1982b; Sarvacos 1970 and Oakenfull and Scott 1985) and meat products (Simon *et al*., 1965 and Capraso *et al*., 1978) suggesting that textural properties of cheese are four times temperature sensitive than fruits of vegetables.

The relationship between fracture and deformation in a uniaxial compression tests is very significant, especially for the solid and semi-solid foods such as cheese. The relationship usually provides information that is typically associated with sensory attributes perceived during mastication (Drake *et al*., 1999). However, stress relaxation measurement will provide information regarding the testing conditions that best fit sensory characteristics prediction.

Figure 3 presents stress relaxation of cheddar cheese measured at various temperatures. Results showed a decrease in relaxation time for various cheddar cheese samples with the increase in temperature regardless of cheese type. In cheddar cheese; fat globules are usually connected and stabilized to the casein network and contributed to the textural properties of cheese (Lucey *et al*., 2003 and O'Mahony *et al*., 2005). The decrease in relaxation time with the increase in temperature indicated that casein network became weak and less elastic accompanied with the increase in fats melting resulting in increased cheese meltability. Cheese meltability is usually characterized by melting and forming a viscous fluid with decreased flow properties upon heating (Gunasekaran and Ak 2003).

Figure 3 also present fitted Peleg and Maxwell models of sharp cheddar cheese stress relaxation at various temperatures. Peleg model fitted with rate of deformation while Maxwell model was fitted with the mount of stress during the relaxation test. Both models were best fit stress relaxation data of cheddar cheese having correlation coefficients of more than 99% at tested temperature used. The increase in temperature resulted in a progressive decrease of Peleg model's coefficient manifested by the decrease in slops. Furthermore, it is evident that at high temperatures, cheese relaxes at faster rate than at low temperatures (figure 3).

General Maxwell model is one of the suitable rheological models for describing the viscoelastic behavior mostly of agricultural materials (Waananen and Okos 1992 and Steffe 1992) and is usually represented by equation 1. The number of elements in the Maxwell models is usually selected on the basis of maximum fit of model on measured stress relaxation data. Del Nobile *et al*., (2007) for instance presented the ability of generalized Maxwell model for describing the stress relaxation behavior of solid-like foods.

4. Significance:

Texture of cheddar cheese is temperature dependent therefore; temperature should be controlled during textural properties measurements to better correlate instrumental with sensory attributes. Textural properties of cheddar cheese are more than four times affected by temperature than meat and vegetables indicating a lower structural stability that was attributed to microstructure network differences.

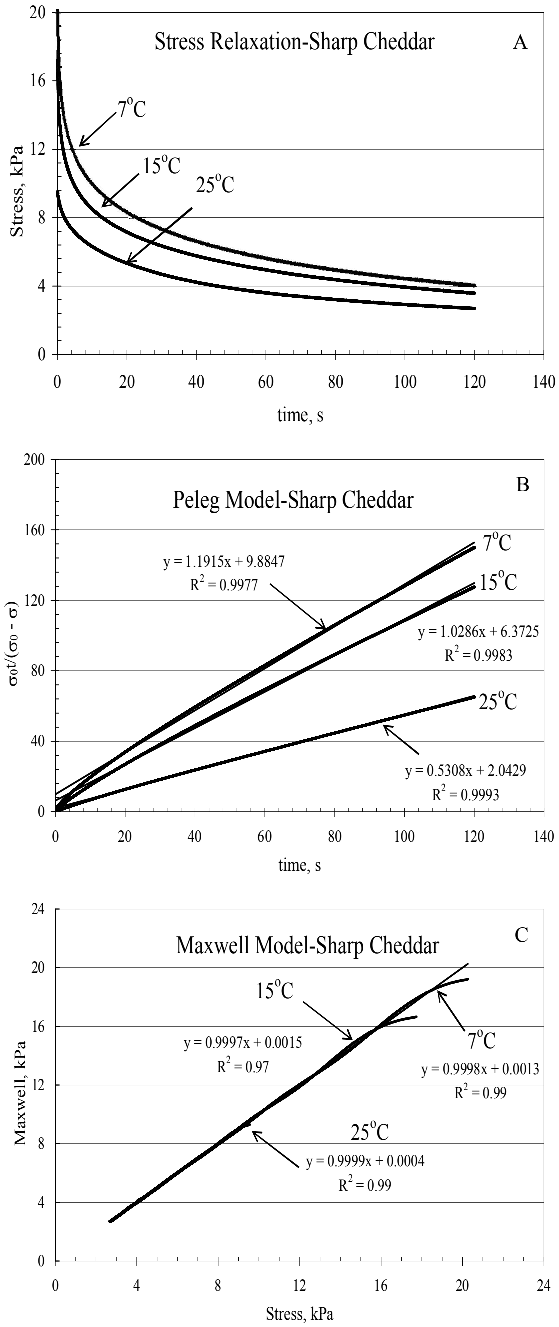

Figure 3: Stress relaxation [A], Peleg model [B] and Generalized Maxwell models [C] of mild, medium and sharp cheddar cheese deformed under deformation rate of 0.833 mm/s for two minutes at 7°C, 15°C and 25°C.

Corresponding Author:
Dr. Mohammed Saleh
Department Nutrition and Food Technology, Faculty of Agriculture, The University of Jordan, Amman-Jordan, misaleh@ju.edu.jo

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