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Research Article

Mechanical and Viscoelastic Properties of Mozzarella Cheese

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Abstract: The aim of this study is to determine the mechanical properties and the viscoelastic characteristics of the mozzarella cheese made from buffalo milk. Mozzarella cheese has a characteristic structure as the curd undergoes a stretching process in hot water that leads to the formation of a fibrous structure. This affects the number, strength and type of bond between the protein molecules that form the basis for the rheological properties exhibited. The mechanical properties and the viscoelastic characteristics of buffalo mozzarella were measured in the present study. Uniaxial compression tests between parallel plates with an extra 5.8 cm compression were carried out in cheese cubes of 2 cm edge in order to estimate Peleg model parameters such as the compressive stress, deformation modulus, degree of elasticity and A and B constants. Cheese cubes were compressed and decompressed at a deformation rate of 20 cm/min up to 40% of their height through a complete compression-decompression cycle. For a compression area of 4.0×10^{-4} m^2 a maximum compressive strength of 28.0±3 N, a compressive stress of 7.0×10^4 Pa and a deformation modulus of E_D = 175.0 kPa were obtained. The degree of elasticity was 73.0±8.5%, which indicates that mozzarella cheese has a very elastic texture. The values for A and B constants of the Peleg model were as follows: A = 0.83 and B = 0.11. Buffalo mozzarella exhibitselastic recovery levels suitable for technological use, as well as viscoelastic solid properties.

Keywords: Deformation modulus, elasticity, peleg model, relaxation, texture, uniaxial compression

INTRODUCTION

Mozzarella cheese has a characteristic structure as the curd undergoes a stretching process in hot water that leads to the formation of a fibrous structure (Lucey *et al*., 2003). This process affects the number, strength and type of bond between the protein molecules (especially casein) that form the basis for the rheological properties exhibited. The structure of the cheese is determined by the spatial arrangement of its components, especially casein, which undergoes a number of modifications during the process therefore obtaining a firm, elastic, spongy texture as well as viscoelastic properties (Bunka *et al*., 2013; Hickey *et al*., 2015). This gives the cheese functional properties that make it suitable for use in the preparation of pizza and other foods made with melted cheese. In this case, the rheological methods can become a very useful tool when it comes to quality control, since these parameters are closely linked to the expected functional properties (Olivares *et al*., 2009).

Important mechanical properties regarding cheese texture such as deformation modulus, compressive stress, degree of elasticity and fracture strain can be evaluated either through a uniaxial compression test or by using rheological and physicochemical methods (Holland *et al*., 2010; Tunick and Van Hekken, 2010). The uniaxial compression test between parallel plates is one of the most commonly used methods for estimating data related to mechanical properties as well as stress-strain curves (Gunasekaran and Mehmet, 2003). Stress relaxation tests are indicated to estimate viscoelastic characteristics (Bertola *et al*., 1991). Parameters such as compressive stress, deformation modulus, fracture strain and others, can be estimated in the first case. In the second case, stress-strain curves vs. relaxation time are obtained and other fundamental parameters can be calculated by adjusting mechanical models. Mechanical models include the Peleg model (1979), which has managed to obtain product characteristic curves through the normalization and linearization of primary data. Data about mechanical properties of cheese allow obtaining information about its structure. Since these data include fundamental rheological data (Chen and Opara, 2013; Pascua *et al*., 2013; Franco *et al*., 2013; Koc *et al*., 2013) and models have also been used to study the effects of texture enhancers in cheese (Albenzio *et al*., 2013; Stieger and Van de Velde, 2013; Cooke *et al*., 2013, Skeie *et al*., 2013; Castro *et al*., 2014; Saint-Eve *et al*., 2015; Verruck *et al*., 2015) they can be a useful tool for comparing similar products. The purpose of this study is to determine the main

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mechanical and viscoelastic properties of buffalo mozzarella.

MATERIALS AND METHODS

Samples: Samples from (5) different batches of buffalo mozzarella were used in the test. The test sample was cut into a 2 cm cube and then compressed at a rate of 20 cm/min to 40% of its total height at a temperature of 10°C. Universidad de Córdoba (Córdoba, Colombia) Vegetable Processing and Agro-industry Research Group.

Mechanical determinations: Three types of uniaxial compression tests were carried outusing an Instron 1140 system, in order to calculate the compressive stress (σ_o), deformation modulus (E_D) and degree of elasticity (E%). A 5.8 cm diameter compression fitting was used to compress the product. The test sample was cut into a 20 mm cube and then compressed at a rate of 20 cm/min to 40% of its total height at a temperature of 10°C. The compression area was $4\times10^{-4}m^2$. The degree of elasticity was measured according to recoverable strain after reversing the orientation of compression under the same experimental conditions previously used (Kaletunc *et al*., 1991). The compression force was calculated as follows:

$$\sigma_o = \frac{F}{A}$$

The Peleg method (1979) was used in order to study stress relaxation and determine the viscoelastic properties of cheese. Parameters A (decrease in stress) and B (initial relaxation rate) which are characteristics of the material were also calculated. Cheese was cut into a 20 mm cube and then allowed to relax for 300 s.

A convenient mathematical procedure has been tested in order to apply these conditions to relaxation curves.

- Relaxation curves have been normalized, i.e., the decline parameter Y(t) was calculated as follows:

  $$Y(t) = \frac{F_o - F(t)}{F_o}$$

  where, F_o y F(t) account for compression forces that occur at the beginning and at a given time, respectively.
- The typical pattern of the function Y(t) versus t suggests the simplified mathematical form of Mickley *et al*. (1957):

  $$Y(t) = \frac{abt}{1+bt}$$

If a = 0 the stress does not relax at all (i.e., in an ideal elastic solid) and if a = 1.0 the stress level eventually reaches zero (e.g., in liquids). In the equation $0 < a < 1$, accounts for the asymptotic residual values of $Y(\infty)$. The constant b is the representative of the "rate" at which the stress relaxes (1/b is the time necessary to reach the level of a/2).

One of the mathematical characteristics of Eq. (4) is that it yields a straight line when plotted as follows:

$$\frac{t}{Y(t)} = \frac{1}{ab} + \frac{1}{a}$$

RESULTS AND DISCUSSION

Deformation modulus: Regarding the uniaxial compression of cheese made from buffalo milk, the average value of the maximum compressive strength was 8.0±3 N, compression area of 4.0×10^{-4} m^2, compressive stress of 7.0×10^4 Pa, deformation modulus of E_D = 175.0 kPa. The results of this parameter are lower than those obtained from 290 kPa for Cheddar cheese (Weaver *et al*., 1978; Hort and Le Grys, 2001), which is classified as hard. Rosenau *et al*. (1978) suggest values of 125 kPa, while Green *et al*. (1985) suggest values of 156 kPa. On the other hand, the results obtained are similar to those of Agrawal *et al*. (1997) for Mozzarella (150 kPa) and Emmentaler cheese (182 kPa) for a period of 4 months (Rohm *et al*., 1992).

Compared to fresh, moist cheese, these results are superior to those obtained by Fritzen-Freire *et al*. (2010) regarding acidified cheese and by Pascua *et al*. (2013) regarding Murcian wine cheese. Typically, high effort values suggest the presence of hardness, resistance and more than one unbreakable surface. Low-moisture, high-protein cheese is more resistant to breakage (Magenis *et al*., 2014) besides the use of technology by manufacturers (Pascua *et al*., 2013). This type of mozzarella cheese is relatively hard although it is in fact a fresher cheese with a higher moisture content than Cheddar cheese. This may be because it is made from buffalo milk (which is higher in protein than cow's milk) and also undergoes a "direct acidification" process, which could account for the mentioned properties.

Degree of elasticity: The degree of elasticity for mozzarella cheese was73.0±8.5%, a value considerably higher than that obtained by Weaver *et al*. (1978) and Bunka *et al*. (2013) for Edam cheese; this therefore indicates that this cheese is rather a type of curd with higher moisture levels, as well as fluffier and more elastic than ripened cheese. That being said, it can be established that said product exhibits a high degree of elastic recovery suitable for the technological use.

Relaxation: As follows:

$$\frac{t}{Y(t)} = 1.197t + 9.232$$

The coefficient of determination is highly significant ($p<0.001$). Values of a = 0.83 and b = 0.11 are obtained. The value of "a" is still on the viscoelastic region, as well as relatively high and close to unity and therefore the viscous component has greater influence.

On the other hand, "b" is closer to 0, which means that the rate at which σ_o decreases in time is very slow and the stress is not completely relaxed, which implies the proximity to the ideal elastic solid (Bunka *et al*., 2013; Morgado *et al*., 2017).

The elastic component has much more influence, as opposed to reports on Minas Frescal cheese (Magenis *et al*., 2014) with B values ranging from 0.4 to 0.3 1/s and A values ranging from 0.5 to 0.9; while Fritzen-Freire *et al*. (2010) report B values ranging from 0.5 to 0.3 1/s and A values ranging from 0.05 to 0.1, which suggests a tendency towards viscosity rather than elasticity. This is corroborated by the high value of the degree of elastic recovery observed in the present study, which indicates that this type of cheese has a very elastic texture.

CONCLUSION

Mozzarella cheese made from buffalo milk has mechanical properties that exhibit a high degree of elasticity and have a deformation modulus of 175 kPa. This type of cheese also has solid viscoelastic properties. The Peleg model can be used to explain the viscoelastic behavior of Mozzarella cheese.

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