*Journal of Food Biosciences and Technology,*
Islamic Azad University, Science and Research Branch, Vol. 11, No. 1, 1-10, 2021

# Influence of Guar Gum on Texture Profile Analysis and Stress Relaxation Characteristics of Carrot Sponge Cake

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Received: 21 September 2017 Accepted: 1 October 2019

ABSTRACT: Stress relaxation has traditionally been employed as one of the principal means for measuring the viscoelastic behavior of foods. The objective of this study was to determine the texture profile analysis and stress relaxation characteristics of carrot sponge cake formulated with four different levels of guar gum (0, 0.25, 0.5 and 0.75 %). Texture profile analysis results showed a decrease in the carrot cake consistency, gumminess and chewiness with increasing the level of gum. The consistency and hardness values decreased from 4773.11 to 2260.60 g.s and 915.45 to 458.54 g with increasing guar gum levels from 0 to 0.75 %, respectively. The results showed that mechanical stress relaxation data of carrot sponge cakes were fitted well by both the Peleg-Normand and four-element Maxwell models. The $F_0$ (initial force) and %SR (percentage stress relaxation) parameter of carrot sponge cakes decreased with increasing gum concentration ($P<0.05$). Although all decay forces ($F_1$, $F_2$ , $F_3$ and $F_4$) of the carrot sponge cakes obviously decreased with increasing guar gum concentration. The elasticity of the carrot sponge cakes was the highest at 0.75% guar gum concentration.

**Keywords**: *Guar Gum, Maxwell Model, Peleg-Normand Model, Sponge Cake, Stress Relaxation.*

## Introduction

Rheology concerns the flow and deformation of a material. Stress relaxation is a transient test of viscoelasticity involving application of small strains, allowing determination of elastic and viscous moduli if appropriate models are fitted to data. The stress relaxation tests have been widely used in rheological studies of food products. Generally, experimental force decay curves have been presented in the form of discrete Maxwell model containing 2 to 4 elements (Chen *et al.*, 2013; Salehi & Kashaninejad, 2018). Peleg and Normand suggested that stress relaxation data can be recalculated to a normalized stress (or force) and next fitted with time. The Peleg-Normand model has fewer constants than the Maxwell model, thus the former is a simple, quick and effective method to handle stress relaxation data. Singh *et al.* (2006) reported that the $k_2$ value in the Peleg-Normand model was suitable for differentiating various food products. Hatcher *et al.* (2008) reported that uniaxial stress relaxation provided a complementary discriminating method for texture measurement of yellow alkali noodle. Sozer *et al.* (2008) found the stress relaxation data of spaghetti enriched with fiber were fitted well by both the three-element Maxwell and Peleg-Normand

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models. Huang *et al.* (1995) found that stress relaxation was significantly and negatively correlated with the overall eating quality of steamed bread. Study on the stress relaxation of steamed bread is very rare so far.

Hydrocolloids or gums are widely used as functional ingredients in the food industry. In addition to the obvious benefits of taste, texture, mouth feel, moisture control, and water mobility, they also improve the overall product quality and stability by withstanding the demands of processing, distribution, storage and final preparation (Salehi *et al.*, 2015; Salehi, 2019a, 2020). Guar gum is a high molecular weight, non-ionic galactomannan obtained from the seed cotyledon of the cluster bean *Cyamopsis tetragonolobus (L)*. Guar is hydrophilic. It hydrates rapidly in cold water to form a colloidal dispersion and it is not digested by intestinal enzymes in man (Dogra *et al.*, 1989). Kang *et al.* (1997) showed that many gum types including hydroxypropylmethylcellulose (HPMC), locust bean gum, guar gum, carrageenan, xanthan gum and agar resulted in acceptable rice breads.

In the bakery products, gums have been used to improve mixing and extension of shelf life of the products through moisture retention and prevention of syneresis in frozen foods and pie fillings. Several studies have been carried out showing the potential use of hydrocolloids in bread making including wheat bread, whole wheat bread, rye bread, protein-fortified starch bread and frozen bread dough (Salehi, 2017, 2019b). Xanthan gum mixed with other gums is the most widely used in bakery products (Kaur *et al.*, 2015). Sharadanant and Khan (2003) reported that gum acacia increased the loaf volume and improved bread characteristics such as texture, cell wall structure and softness.

Stress relaxation behaviour of high acyl gellan gels was investigated by Chen *et al.* (2013), and data were fitted successfully by a seven elements empirical model and a four term modified Maxwell model with three fixed relaxation times. Relaxation appeared to be associated with the shifting of cross-links in the gel matrix. Stress relaxation of date at different temperature and moisture content was studied by Zare *et al.* (2012). A texture analyzer was used to apply uniaxial compression tests. Individual date fruit was uniaxially compressed at speed of 1 mm/s. It was found that Generalized Maxwell and Nussinovitch models appropriately describe viscoelastic characteristics of date fruits as compared to Peleg model. Dough from strong wheat cultivar exhibited slower rates of stress relaxation and higher storage modulus as compared to moderate, weak, and very weak cultivars (Rao *et al.*, 2001).

The aim of this study was to investigate the stress relaxation and textural parameters of fiber-enriched carrot sponge cake formulated with four different levels (0, 0.25, 0.5 and 0.75 %) of guar gum.

## Materials and Methods

- *Infrared –Hot air drying of carrot*

Slices of carrot (*Dacus carota*) with 5 mm thickness were prepared with the aid of a steel cutter and were immediately placed into the dryer. Infrared-hot air method, when properly applied, can be used for achieving a high-quality product. The carrot slices were dried in an infrared–hot air dryer (Infrared radiation lamp (NIR), Philips, Germany) with 250 W power and 60°C with air at a velocity of 1 m/s. The dried samples were milled and passed through a 50 mesh sieve (0.29±0.02 mm diameter). The milled powder was weighed and stored in an air-tight bottle till required the experiments (Salehi *et al.*, 2016a).

- *Carrot sponge cake preparation*

The ingredients used in the formula of carrot sponge cakes were cake flour (90 gr), carrot powder (10 gr), guar gum (at four different levels of 0, 0.25, 0.5 and 0.75 %), fresh eggs (72 gr), sucrose (72 gr), sunflower oil (57 gr, Ladan Co. Iran), whey (4 gr, Pegah Co. Iran), baking powder (2 gr, Mahsa, Tehran, Co. Iran), vanilla (0.5 gr, Shahsavand, Mashahd, Co. Iran), water (30 gr) and nonfat dry milk powder (2 gr, Pegah Co. Iran). Sucrose and sunflower oil were poured into a bowl, and mixed for 4 min. Whole egg was added to the bowl, and then mixed for 2 min. The sifted cake flour, carrot powder, whey, baking powder, vanilla, guar gum, water and nonfat dry milk powder was gradually poured into a bowl, and mixed for 4 min. Water was added to the bowl, and then mixed for 1 min (Salehi *et al.*, 2016a).

For each cake, 30 g of cake batter was poured into a cake pan and baked at 195°C for 20 min in a oven toaster (Noble, Model: KT-45XDRC). The cakes were allowed to cool for 30 min, and then were removed from the pans. The cooled cakes were packed in polypropylene bags at room temperature before physico-chemical and sensory evaluation analyses.

- *Textural properties of cakes*

The texture profile analysis (TPA) of carrot sponge cake samples (2×2×2 cm) from the midsection of the cakes were performed using a texture analyzer (TA-XT Plus, Stable Micro Systems Ltd., Surrey, UK) with a 36 mm diameter cylindrical probe, 50% compressing and a test speed of 1.0 mm $s^{-1}$. The crust of cake samples was removed in cake texture determination. A double cycle was programmed and the texture profile was determined using Texture Expert 1.05 software (Stable Microsystems). Other parameters were defined as: pre-test speed 2.0 mm $s^{-1}$, post-test speed 2.0 mm $s^{-1}$ and trigger force 5 g (Salehi *et al.*, 2016b). The texture parameters recorded were consistency, hardness, cohesiveness, adhesiveness, springiness, resilience, gumminess, and chewiness, and the texture parameter of cake was averaged from 4 replications.

- *Stress relaxation of carrot sponge cake*

Stress relaxation of viscoelastic materials has been conducted using dynamic rheological techniques and also by uniaxial compression or extension of the materials under a fixed strain (Chen *et al.*, 2013). Stress relaxation of carrot sponge cake was measured according to the method proposed by Sozer *et al.* (2008) with some modifications. The carrot sponge cake was sliced horizontally to remove the top and then a 3×3×4 cm rectangular sample was taken through the center of the bread by cutting. The stress relaxation test was executed by using a Textural Analyzer (TA-XT Plus, Stable Micro Systems Ltd., Surrey, UK) equipped with a cylindrical probe of P/100 (100 mm diameter). The sample was deformed in penetration to a constant strain of 50% with test speed of 1 mm/s. The data acquisition rate was 200 points per second. The residual force was continuously recorded as a function of time for 60 s. The stress relaxation data were analyzed by using a Peleg-Normand model as well as a Maxwell model. Equation 1 is a model proposed by Peleg-Normand.

$$\frac{F_0 t}{F_0 - F(t)} = k_1 + k_2 t \qquad (1)$$

Where $F_0$ is initial force, F(t) is the momentary force at time t, and $k_1$ and $k_2$ are constants. The $k_1$ and $k_2$ values are the intercept and slope of regressive straight line plotted by normalized force and time, respectively. In addition, percentage stress relaxation (% SR) was calculated from the following equation (Equation 2):

$$\%SR = \frac{F_0 - F_{t=20}}{F_0} \times 100 \qquad (2)$$

Where $F_0$ is initial force, and $F_{t=20}$ is the force at 20 s after the initial strain was achieved.

Equation 3 is a Maxwell model with four elements:

$$F(t) = F_1 \exp(-t/\lambda_1) + F_2 \exp(-t/\lambda_2) + F_3 \exp(-t/\lambda_3) + F_4 \quad (3)$$

Where F(t) is the actual force as a function of time in a stress relaxation test, λ1, λ2, and λ3 are the relaxation times, and $F_1$, $F_2$, and $F_3$ are the decay forces. F4 is the additional spring. The experimental data were modeled by using non-linear regression in Curve Expert 1.34 software.Relative force ($F(t)/F_0$) was calculated from the following equation (Equation 4):

$$\text{Relative force (RF)} = \frac{F(t)}{F_0} \quad (4)$$

- *Statistical analysis*

Each measurement was conducted in quadruplicate. The experimental data were subjected to an analysis of variance (ANOVA) for a completely random design using a statistical analysis system (SAS 9.1 Institute, Inc, Cary, NC, USA). Duncan's multiple range tests were used to determine the difference among means at the level of 0.05.

## Results and Discussion

- *Texture profile analysis (TPA) of carrot sponge cakes*

It was found that guar gum addition affected all texture parameters of carrot sponge cake. In texture profile analysis, the hardness of samples measured showed that the cake became softer with increasing levels of guar gum (Table 1). The hardness of cakes was directly related to the density of the tested materials (indirectly to its volume). The weight of samples was not significantly different among any of the cakes in this study. Thus, the decrease in hardness was mainly related to the volume of these cakes.

In the study of Rosell *et al.* (2001) hydroxy propyl methyl cellulose and κ-carrageenan reduced the crumb firmness with respect to the control. On the other hand, cakes containing xanthan-guar gum blend without emulsifier blend were the firmest due to the thickening of the crumb walls surrounding the air spaces. Gómez *et al.* (2007) showed that guar gum led to the hardest conventionally baked wheat cakes.

The area under the curve up to the target deformation was taken as a measurement of consistency. TPA results showed a decrease in cake consistency with an increased level of guar gum. The consistency values decreased from 4773.11 to 2260.60 g.s with increasing guar gum levels from 0 to 0.75 %.

Cohesiveness quantifies the internal resistance of food structure. Briefly, cohesiveness is the ability of a material to stick to itself. TPA results showed significantly different in the cake cohesiveness and resilience with increased level of guar gum.

**Table 1.** TPA parameters of carrot sponge cakes contain different levels of guar gum

| Guar gum (gr) | Consistency (g.s) | Hardness (g) | Springiness | Cohesiveness | Gumminess (g) | Chewiness (g) | Resilience |
|---|---|---|---|---|---|---|---|
| 0 | 4773.11 $^{a}$ | 915.45 $^{a}$ | 0.90 $^{b}$ | 0.62 $^{b}$ | 713.12 $^{a}$ | 627.42 $^{a}$ | 0.25 $^{b}$ |
| 0.25 | 4479.58 $^{b}$ | 833.42 $^{b}$ | 0.91 $^{b}$ | 0.63 $^{a}$ | 664.16 $^{ab}$ | 603.28 $^{a}$ | 0.26 $^{ab}$ |
| 0.5 | 3425.41 $^{c}$ | 698.24 $^{c}$ | 0.92 $^{a}$ | 0.64 $^{a}$ | 445.16 $^{b}$ | 407.69 $^{b}$ | 0.26 $^{ab}$ |
| 0.75 | 2260.60 $^{d}$ | 458.54 $^{d}$ | 0.92 $^{a}$ | 0.65 $^{a}$ | 297.18 $^{c}$ | 274.08 $^{c}$ | 0.28 $^{a}$ |

Means with different letter within columns are significantly different (P<0.05).

Springiness measures elasticity by determining the extent of recovery between the first and second compression. Resilience is the ratio of recoverable energy as the first compression is relieved. TPA results showed an increase in the cake springiness from 0.90 to 0.92, with an increased level of guar gum.

Gumminess is determined by hardness multiplied by cohesiveness. Chewiness is determined by gumminess multiplied by springiness, and represents the amount of energy needed to disintegrate a food for swallowing. TPA results showed a decrease in the cake gumminess and chewiness from 563.12 to 297.18 g, 527.42 to 274.08 g, with increased level of guar gum, respectively.

*- Stress relaxation of carrot sponge cakes*

Fundamental viscoelastic properties of foods have frequently been measured by stress relaxation. The stress relaxation data of carrot sponge cakes in this study were analyzed by Peleg-Normand model and Maxwell model, and % SR. Figure 1 shows the relaxation curves of carrot sponge cakes at different levels of guar gum. As for most viscoelastic materials, after application of a constant strain, a decrease in force values necessary for maintaining the deformation was observed.

Initial force ($F_0$) values using stress relaxation data of carrot sponge cakes at different levels of guar gum were shown in Figure 2. Increasing guar gum levels in cake in the range of 0 to 0.75%, decreased the initial force values from 26.39 to 13.31 N ($P<0.05$).

Relative residual force values of the carrot sponge cakes during the stress relaxation test were shown in Figure 3 and they were increased with increasing guar gum levels. This indicated that the carrot sponge cakes had more solid-like behavior at higher guar gum concentration.

Table 2 lists the fitting parameters of the Peleg-Normand model for carrot sponge cakes with various guar gum content. The results showed that the stress relaxation data of carrot sponge cakes were fitted well by the Peleg-Normand model (R>0.999).

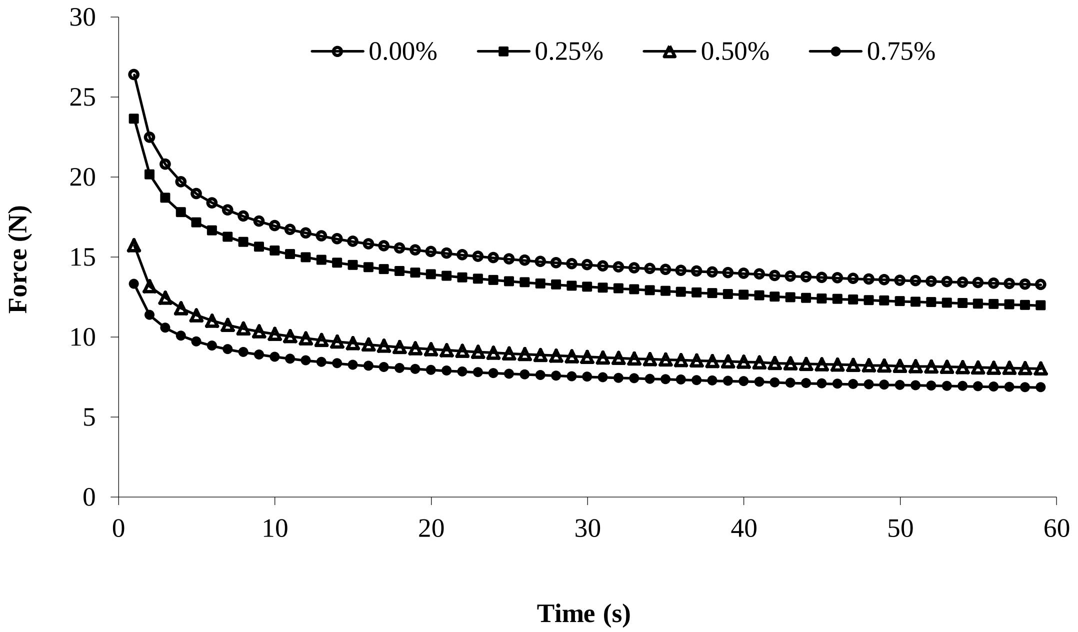


**Fig. 1.** Relaxation curves of carrot sponge cakes contain different levels of guar gum.

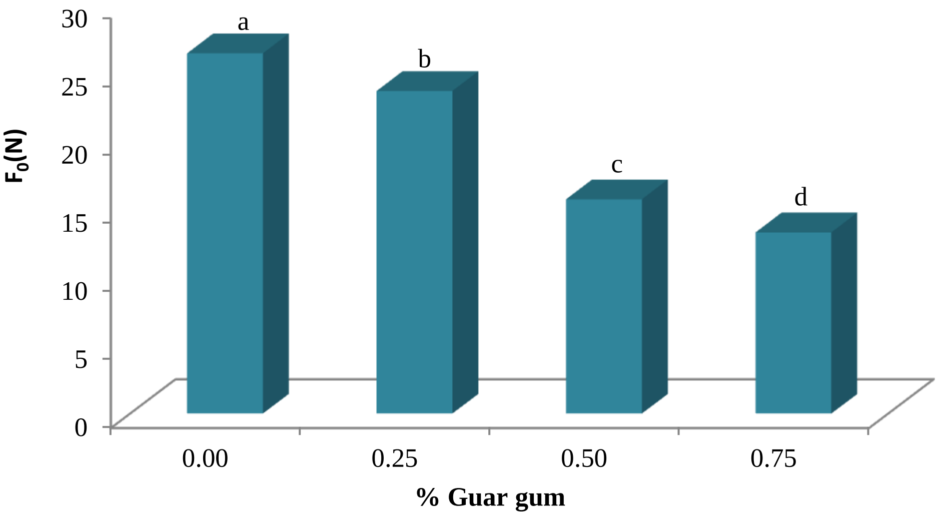


**Fig. 2.** Initial force ($F_0$) value using stress relaxation data of carrot sponge cakes contain different levels of guar gum. Means with different letter within columns are significantly different (P<0.05).

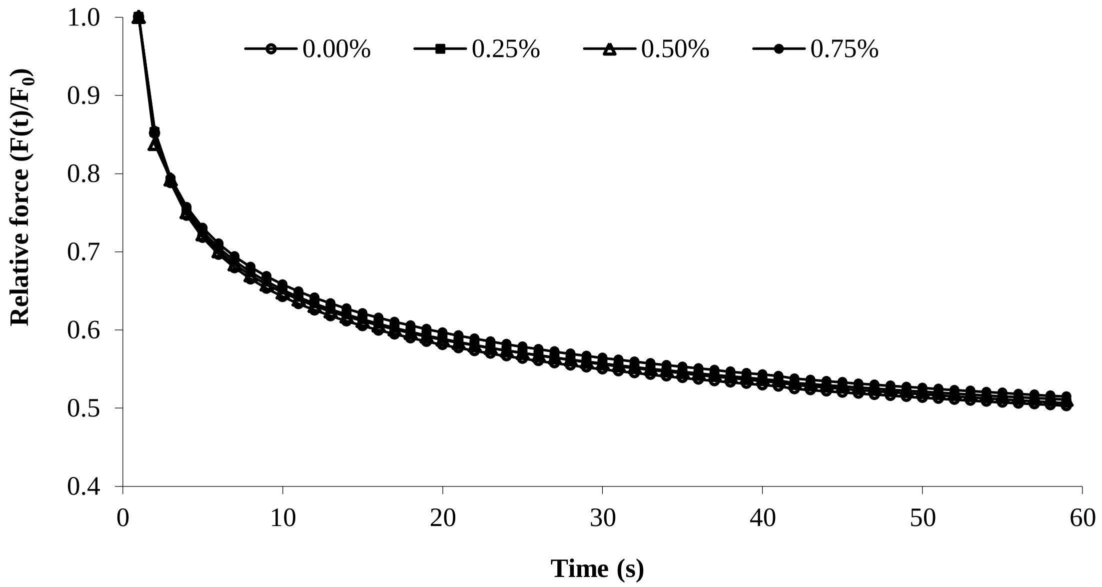


**Fig. 3.** Relative force data of carrot sponge cakes contain different levels of guar gum.

**Table 2.** Fitted parameters of the Peleg-Normand model using stress relaxation data of carrot sponge cakes contain different levels of guar gum

| Guar gum (%) | $K_1$(s) | $K_2$ | R | SE |
|---|---|---|---|---|
| 0.0 | 11.71 | 1.86 | 0.999 | 0.727 |
| 0.25 | 11.78 | 1.87 | 0.999 | 0.848 |
| 0.50 | 12.34 | 1.89 | 0.999 | 0.782 |
| 0.75 | 12.66 | 1.90 | 0.999 | 0.896 |

The Peleg-Normand model is easy to perform and to analyze the data. In Figure 4, the normalized force values determined during stress relaxation were well fitted to the Peleg-Normand model (Equation 1). The reciprocal of the $k_1$ value in the Peleg-

Normand model represents the initial decay rate. A high $k_1$ value was associated with a low decay rate, indicating a pronounced elastic behavior. The $k_2$ value is the representative of the degree of solidity and it varies between 1, for a material that is truly a liquid, to infinity, for an ideal elastic solid where the stress does not relax at all (Wu *et al.*, 2012). Thus we could have the $k_1$ and $k_2$ parameters by regression. Generally, both $k_1$ and $k_2$ values of the carrot sponge cakes increased with increasing levels of guar gum. Hence carrot sponge cakes with 0.50 and 0.75% guar gum were more rigid and high elastic than cake with low guar gum (0 and 0.25%). Singh *et al.* (2006) indicated $k_2$ was a better representative of elastic nature for food materials. Therefore the carrot sponge cakes in this study are more elastic measured at low substitution. Nussinovitch *et al.* (1992) indicated that the percent recoverable work (or elasticity) of bread decreased exponentially by increasing strain from 20 to 80%. Li *et al.* (2003) indicated that the relaxation properties of dough depended on its gluten protein and that relaxation spectra of glutens were similar to those for the corresponding doughs. Zhang *et al.* (2007) found moderate correlation coefficient (r=0.55-0.61) between stress relaxation of steamed bread and glutenin fraction of wheat cultivar.

Percentage stress relaxation (% SR) is a convenient and informative parameter to understand viscoelastic properties of food products, and is obtained directly from the stress relaxation versus time plot at an arbitrary time (Wu *et al.*, 2012). For the ideal elastic solid, % SR is equal to 0, while for the ideal liquid, % SR is 100. The results showed that % SR of carrot sponge cakes tested ranged from 41.90 to 40.33 (Figure 5), and thus the carrot sponge cake was classified as a viscoelastic solid. Safari-Ardi and Phan-Thien (1998) observed the sufficient resolution of the stress relaxation responses of wheat doughs at a strain level of 20%.

Since stress relaxation data of carrot sponge cakes has not been analyzed by Maxwell model, we tried to use different Maxwell model equations for fitting the experimental data. The number of Maxwell elements required to represent the viscoelasticity of the cake sample was determined by the R value. For one-element, two-element, three-element and four-element Maxwell models, the R values were approximately 0.77, 0.87, 0.94 and 0.999, respectively.

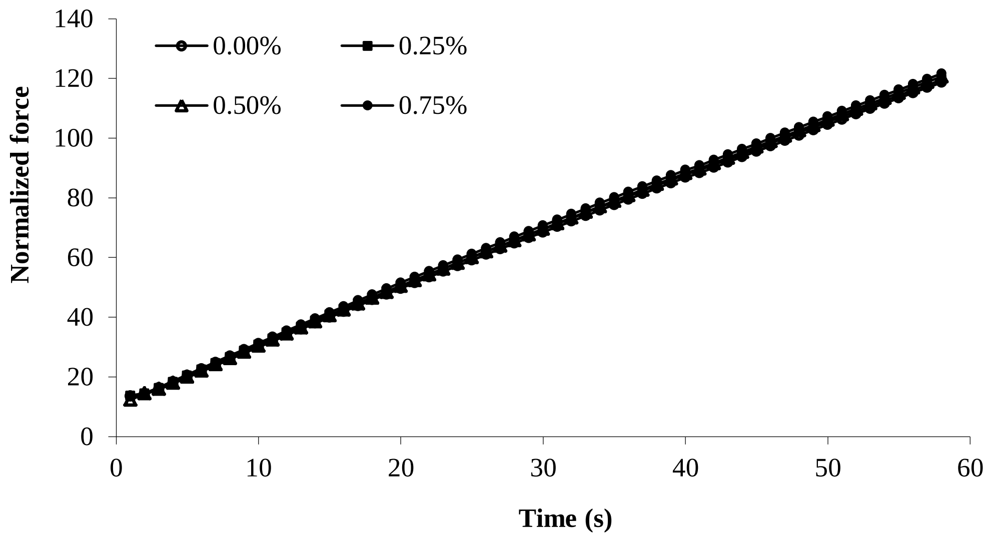


**Fig. 4.** Normalized force curves using stress relaxation data of carrot sponge cakes contain different levels of guar gum.

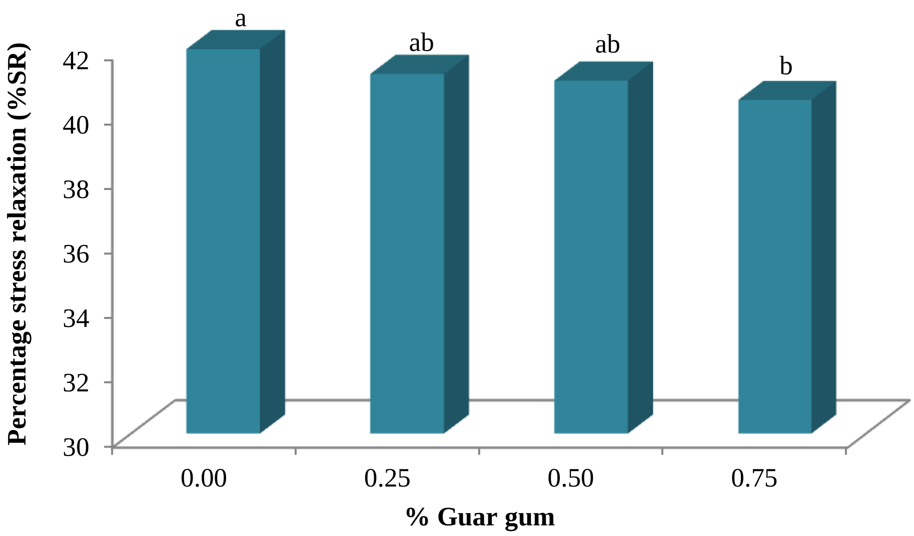


**Fig. 5.** Percentage stress relaxation (%SR) value using stress relaxation data of carrot sponge cakes contain different levels of guar gum.
Means with different letter within columns are significantly different (P<0.05).

**Table 3.** Fitted parameters of the Maxwell model using stress relaxation data of carrot sponge cakes contain different levels of guar gum

| Guar gum (%) | $F_1$(N) | $F_2$(N) | $F_3$(N) | $F_4$(N) | $\lambda_1$(s) | $\lambda_2$(s) | $\lambda_3$(s) | R | SE |
|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 4.89 | 3.79 | 5.18 | 12.50 | 4.20 | 0.81 | 30.43 | 0.999 | 0.016 |
| 0.25 | 4.82 | 3.48 | 4.14 | 11.17 | 32.26 | 0.80 | 4.48 | 0.999 | 0.011 |
| 0.50 | 3.17 | 1.57 | 3.30 | 7.67 | 27.01 | 0.18 | 3.28 | 0.999 | 0.015 |
| 0.75 | 1.86 | 2.26 | 2.74 | 6.42 | 0.76 | 4.22 | 31.29 | 0.999 | 0.007 |

Hence the four-element Maxwell model fitted to the data better than the other Maxwell models. Table 3 lists the fitting parameters of the four-element Maxwell model of carrot sponge cake with various guar gum levels content. The results showed that all stress relaxation data of steamed breads were fitted very well by the Maxwell model with four elements (R=0.999).

A three-element Maxwell model was found adequate for demonstrating the stress relaxation data of spaghetti and fiber-enriched steamed bread (Sozer *et al.*, 2008; Wu *et al.*, 2012), and a generalized Maxwell model satisfactorily fitted the stress relaxation data of various bulky and sponge foods (Del Nobile *et al.*, 2007; Bhattacharya, 2010).

The elastic component of the Maxwell element can be represented by the decay force ($F_1$, $F_2$ , $F_3$ and $F_4$), which indirectly measures the rigidity of the material being tested. Relaxation time ($\lambda_1$, $\lambda_2$ or $\lambda_3$) was defined as the time taken for a macromolecule to be stretched out when deformed (Cuq *et al.*, 2003). Although all decay forces ($F_1$, $F_2$ , $F_3$ and $F_4$) of the carrot sponge cakes obviously decreased with increasing guar gum levels, $\lambda_1$, $\lambda_2$ and $\lambda_3$ values were not significantly different at various substitution levels tested. This result showed that relaxation times in the Maxwell model were not sensitive to guar gum concentration.

Lower decay force and shorter relaxation time of cake with high guar gum content indicated that the cake had a less rigid and more elastic behavior, corresponding to the results from the Peleg-Normand model in Table 2.

Moreover, % SR of carrot sponge cakes obviously decreased with increasing guar gum content (Figure 5). This is the first study of using different mathematical models to describe the viscoelastic properties of carrot sponge cakes to our knowledge. The relaxation time of bran-enriched spaghetti was affected by cooking time (Sozer *et al.*, 2008). Hatcher *et al.* (2008) reported that significant correlations were found among textural characteristics (maximum cutting stress, resistance to compression, and recovery) and stress relaxation parameters (% SR, $k_1$ and $k_2$) of cooked yellow alkali noodles.

## Conclusion

In this study a novel formulation of carrot sponge cake production with guar gum was developed. The hardness of samples measured showed that the cake became softer with increasing levels of guar gum. TPA results showed a decrease in the cake consistency, gumminess and chewiness with an increased level of gum. The results showed that the stress relaxation test of carrot sponge cake can be performed at 50% strains. Mechanical stress relaxation data of carrot sponge cakes were fitted well by both four-element Maxwell and Peleg-Normand models. Increasing guar gum levels in the range of 0 to 0.75% increased the $k_1$ and $k_2$ in the Peleg-Normand model. Although all decay forces ($F_1$, $F_2$ , $F_3$ and $F_4$) of the carrot sponge cakes obviously decreased with increasing guar gum levels, $\lambda_1$, $\lambda_2$ and $\lambda_3$ values were not significantly different at various substitution levels tested (Maxwell model). On the contrary, increasing gum levels, decreased the initial force ($F_0$) and percentage stress relaxation (%SR) of carrot sponge cake.

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