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Effect of apple fibre on textural and relaxation properties of wheat chips dough

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RESEARCH ARTICLE

Abstract

In this study, the effect of apple fibre with different levels of fibres (5, 10, 15 and 20%) was investigated on viscoelastic nature and the textural properties of wheat chips dough using stress relaxation test and texture profile analysis. Apple fibre addition changed the stress relaxation properties of wheat dough, depending on fibre concentration. Increase in the fibre concentration increased resistance of the dough samples to the deformation by increasing their elasticity. Hardness and gumminess values increased while springiness, cohesiveness and resilience values decreased as apple fibre level increased. Significant correlations were found between stress relaxation and texture profile analysis parameters. In order to describe the effect of apple fibre on the viscoelastic properties of wheat dough, generalised Maxwell, Nussinovitch and Peleg models were fitted to experimental stress relaxation data. All three models were found to be efficient in describing the stress-relaxation behaviour of wheat dough; but, the Maxwell model was the most effective. In addition, power-law and exponential functions were successfully used to describe the effect of apple fibre concentration on the constants related with stress relaxation data and textural parameters.

Keywords: fibre, dough, stress relaxation, texture, wheat chips, viscoelastic

1. Introduction

Snack type foods have recently been popular over the world and are mostly consumed by the young people. As is well known, today's society has an increased busy schedule, leading them to tempt to eat fast food or snack type foods, which requires the shortest time and minimum effort (Becker *et al.* 1986; McCharthy 2001; Pęksa *et al.* 2010; Sozer and Dalgic, 2007). Therefore, they have an important role in human diet. Accordingly, the 'Snack foods' report by Global Industry Analysts revealed that the global snack market should be worth almost $ 300 billion by 2010 (Food Navigator-USA, 2008). Although the shelves of the supermarkets serve much different type of snacks, increase of the range of products is a mandatory activity for the snacks food industry because development of new food formulations is one of the driving forces to increase the sale rate of the products. Therefore, intense efforts have recently been exerted to develop or enrich the snack type foods with some ingredients having some functional properties (Izydorczyk *et al.*, 2005; Kayacier *et al.*, 2014; Mendonça *et al.*, 2000; Onwulata *et al.*, 2000; Rababah *et al*,. 2011; Yuksel *et al.*, 2014, 2015). In this respect, the food formulations enriched with dietary fibres have become very popular due to their functional effects on human health (Anderson *et al.*, 1994) because overconsumption of foods having high oil and calorie causes some health problems like cardiovascular disease and diabetes (Knucles *et al.*, 1997).

Dietary fibres are non-starch polysaccharides including cellulose, hemicellulose, pectin, β-glucans, gums, and lignins (Gallaher and Schneeman, 2001); therefore, they are one of the most popular functional food ingredients that can be effectively used in food formulations. For example, due to their high dietary fibre content, apples are considered to be an indispensible part of a healthy diet (Sun-Waterhouse *et* *al.*, 2008a,b). In addition, it includes various health beneficial polyphenols, such as procyanidin, catechin, epicatechin, chlorogenic acid, phloridzin, quercetin and their conjugates (Amiot *et al.*, 1997; Gardner *et al.*, 2000; Lee *et al.*, 2003; McGhie *et al.*, 2005). Such bioactive components present in apple have been reported to have anti-inflammatory and anticarcinogenic properties, as well as the ability to prevent a variety of chronic diseases (Boyer and Liu, 2004). On the other hand, there is a challenge to develop a snack food having high levels of polyphenols and/or fibre. Among technical challenges, to find an optimum formulation to process the chips dough with desired technological attributes and to obtain end products with desired quality after dough processing are important. In other words, addition of some ingredients in dough formulations causes some significant changes in viscoelastic and technological properties of products, which directly affects quality of end product as well as machinability of the dough. In this respect, stress-relaxation behaviour and texture profile analyses are very useful tools to understand the effect of addition of such ingredients (Sozer and Dalgic, 2007).

In dough processing, some technological properties of dough such as extensibility, recovery, swelling and elasticity determine the performance of the final quality of products. In addition, viscoelasticity is one of the most important rheological properties having a direct influence on the sensory properties of foods. Stress relaxation test is one of the fundamental tests applied in determination of viscoelastic nature of food materials (Andres, *et al.*, 2008). In a stress relaxation test, an instantaneous strain is applied to food material and required force or stress value to maintain the occurred deformation in the structure of the food is recorded as a function of test time (Andres, *et al.*, 2008; Steffe, 1996). In characterisation of the response of food material to static load, creep and dynamic oscillatory shear tests are also useful. However, in creep tests, a constant static stress that causes non-reversible or reversible deformation of a material is applied over a certain period of time and the resulting deformation is measured. In the dynamic oscillatory tests, viscoelasticity is also measured, however, sample recovery cannot be measured. Regarding the stress relaxation tests, the deformation is applied suddenly and then maintained at a constant level. For the food samples that would exhibit viscoelastic and recovery behaviours, stress relaxation tests appear to be useful. Accordingly, Mitchell (1976) reported that the stress relaxation test is widely used to describe the rheological properties of the many food samples because stress relaxation response can easily provide rapid characterisation of the studied material behaviour (Gunesekaran and Ak, 2002; Tabilo-Munigaza and Barbosa-Canovasa, 2005). For example, the stress relaxation data can be used for characterisation of fruit ripening (Hassan *et al.*, 2005), fruit firmness (Blahovec, 1996) and staling of bread (Limanond *et al.*, 2002).

In description of the viscoelastic characteristics of foods using stress relaxation, combined mechanical models composed of springs (considered as ideal solids) and dashpots (considered ideal as fluids) are used. Combined usage of spring and dashpot in parallel represents the start point for the development of mechanical analog and this is called as Kelvin-Voigt model (Del Nobile *et al.*, 2007). Mohsenin and Mittal (1977) also reported that the Maxwell model occurred with a Hookean spring and a Newtonian dashpot in series is quite suitable to understand the stress relaxation data. Del Nobile *et al.* (2007) reported that, when the system is subjected to a constant strain, the sum of stress for each element will be total stress, each element can have a different relaxation time and a relaxation spectrum may be obtained for a material having viscoelastic properties.

In the literature, a great number of studies have recently been conducted to determine viscoelastic nature of food formulations or model systems using creep-recovery and stress relaxation tests (Carrillo-Navas, *et al.*, 2014; Crockett *et al.*, 2011; Dogan *et al.*, 2013; Gurmeric *et al.*, 2013; Sarıçoban *et al.*, 2010; Schiedt *et al.*, 2013; Skendi *et al.*, 2010; Tsatsaragkou *et al.*, 2014; Van Bockstaele *et al.*, 2011; Wang *et al.*, 2014; Yildiz *et al.*, 2013). However, the number of study on stress–relaxation behaviour and texture profile of chips dough enriched with fibre is very limited. Moreover, there is no information about the effect of apple fibre on these properties. But, investigation on the effect of fibres on these properties should be conducted in order to rheologically describe their well-known techno-functional properties. Therefore, this study aims at: (1) evaluating the effect of dietary apple fibre concentration (5, 10, 15 and 20%) on viscoelastic properties (stress relaxation behaviour) and textural properties of the wheat chips dough; and (2) finding the best model to estimate experimental stress-relaxation data using the Maxwell, Nussinovitch and Peleg models.

2. Materials and Methods

Materials

Wheat flour (*Triticum aestivum* L., type 650 flour, Anatolia red and white hard flours) was purchased from Degirmencilik Flour Co. (Kayseri, Turkey). Apple fibre obtained from parenchymal tissue was acquired from Herbafoods Ingredients GmbH (Werder (Havel), Germany).

Methods

Physicochemical and compositional analysis

The physicochemical and compositional analyses followed and their corresponding methods used are listed in Table 1. All of the analyses were conducted in triplicates with two repetitions.

Table 1. Composition and properties of apple fibre and wheat flour.[1]

Composition and properties	Apple fibre	Wheat flour	Analysis methods followed
Proximate composition (%)			
Moisture	10	13	ISO 712:1998, ICC method (gravimetry)[2]
Ash	1.48	0.48	AOAC 923.03 (gravimetry)[2]
Fat	2.42	0.95	AOAC 945.38F (gravimetry, ether extraction)[2]
Protein	7.1	11.9	ICC method no. 105/1 (Kjeldahl digestion)[2]
Starch	–	58	ICC method no. 123/1 (HCl dissolution)[2]
Wet gluten	–	33	AOAC 976.05 (titrimetry, Kjeldahl digestion)[2]
Bran	–	8.1	ICC method no. 140 (enzymic determination)[2]
Sugar composition (%)			
Fructose	12	–	Declared at product label
Glucose	6	–	Declared at product label
Sucrose	5	–	Declared at product label
Total dietary fibre (%)		4.5	AOAC 992.16 (enzymatic-gravimetric method)[3]
Soluble dietary fibre	20	–	Declared at product label
Galacturonic acid	1.2	–	AOAC 992.16 (enzymatic-gravimetric method)[3]
Hemicellulose	18.8	–	AOAC 992.16 (enzymatic-gravimetric method)[3]
Insoluble dietary fibre	40.0	–	Declared at product label
Hemicellulose	3.2	–	AOAC 992.16 (enzymatic-gravimetric method)[3]
Pectin	7.8	–	AOAC 992.16 (enzymatic-gravimetric method)[3]
Cellulose	15.3	0.56	AOAC 992.16 (enzymatic-gravimetric method)[3]
Lignin	13.7	–	AOAC 992.16 (enzymatic-gravimetric method)[3]
Physical properties			
Water holding capacity (ml/g)	4.00	–	Declared at product label
Oil holding capacity (ml/g)	1.65	–	Declared at product label
Particle size (micron)	300 (98.7% pass)	177 (98.6% pass)	AOAC 965.22 (sieving)[2]
Minerals (mg/kg)			
K	3,307	1,380	XRF, NIR[4]
Ca	1,959	415.0	XRF, NIR[4]
Na	8.9	19.41	XRF, NIR[4]
Cl	17.0	–	XRF, NIR[4]
Mg	185.1	–	XRF, NIR[4]
P	465.2	254.5	XRF, NIR[4]
Fe	93.02	26.77	XRF, NIR[4]
Cu	43.9	3.47	XRF, NIR[4]
Al	25.4	–	XRF, NIR[4]
Zn	–	18.48	XRF, NIR[4]
S	318.7	–	XRF, NIR[4]

[1] The results except total dietary fibre are given on the wet basis of sample weight.
[2] Codex Stan 234 (Codex Alimentarius Commission, 1999).
[3] Total dietary fibre was determined according to the AOAC (1997) procedure. For fibre components analysis, the method of Jeltema and Zabik (1980) was adopted.
[4] The method (X-ray Fluorescence Analyses; XRF) reported by Nielson *et al.* (1991) was followed to determine the mineral composition of the fibres. The mineral content of flour samples was determined according to AACC Method 08-21.

Preparation of wheat chips dough

At the first step, dry mixtures of wheat flour and apple fibre were prepared at different levels. For this aim, wheat flour was substituted with the apple fibre at four different levels (5, 10, 15 and 20%). For the control samples 100 g of wheat flour was directly used while the sample substituted with 20% apple fibre, 80 g of wheat flour was mixed with 20 g of apple fibre. A dough mixer (Professional 600; Kitchen Aid, Benton Harbor, MI, USA) was used for mixing basic ingredients for 5 min and then, 50 ml of tap water was added to make dough. Then, the prepared dough samples were kneaded using the dough mixer (Professional 600; KitchenAid) for 10 min, then covered with a plastic wrap, and rested for 30 min at room temperature for proper hydration. All of the analyses were conducted in these samples. After the preparation of the samples, stress relaxation tests were performed accordingly.

Stress relaxation tests

Stress relaxation test was performed according to the procedures described by Sozer *et al.* (2008) and Wu *et al.* (2012) with some modifications. Stress relaxation tests were conducted at 25±2 °C using a Texture Analyzer (TA.XT Plus Stable Micro Systems Ltd., Godalming, UK) controlled with the Texture Expert software. An aluminium cylinder probe (SMS P/50, 50 mm diameter; TA.XT Plus Stable Micro Systems Ltd.) was attached to the equipment and a 30 kg load cell was used for the analysis. Pre-test, test and post-test speed values were set to be 5, 1 and 5 mm/s, respectively. A pre-load of 3 g and a platen travelling speed of 5 mm/s for a distance of 10 mm was set as the pre-test condition. Dough samples were weighed to be 10 g and circled and the samples were placed on the heavy duty platform of the machine before application of the stress relaxation test. Diameter of the dough was 20 mm. The stress-time plot was recorded for 300 s for a compression of 1 mm/s, whereas platen was retracted at 5 mm/s. As water uptake of chips dough samples was enhanced, stickiness was inherently reduced, thus preventing their adhering to the instrument and increasing the torque. Three different models, namely, Maxwell (Equation 1; Figure 1), Nussinovitch (Equation 2) and Peleg (Equation 3) were used to describe the effect of apple fibre on the stress relaxation behaviour of wheat chips dough samples, as following:

$$\sigma(t) = C_1 e^{-t/\tau_1} + C_2 e^{-t/\tau_2} + \sigma_e \tag{1}$$

where σ is stress at any time (MPa), C_1 and C_2 are decay stress of i[th] Maxwell element (MPa), t is time (s), τ_1 and τ_2 are relaxation time (s) and σ_e is equilibrium stress (MPa).

$$\sigma(t) = \sigma_0(A1 + A_2 e^{-t/10} + A_3 e^{-t/100} + A_4 e^{-t/1000} \tag{2}$$

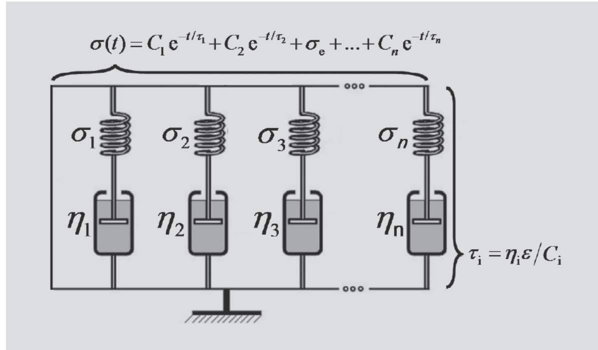

Figure 1. Schematic of generalised Maxwell model comprised of spring constants (C_1 to C_n) in parallel to i^{th} Maxwell element models of dashpots (η_1 to η_n), simulating the viscous behaviour and springs (relaxation constant η_i) for the elastic behaviour along with mathematical expression equations.

where σ_0 is initial stress (MPa), A_1, A_2, A_3 and A_4 are dimensionless constants and *t* is time.

$$\sigma(t) = \sigma_0 - \sigma_0\left(\frac{abt}{1 + bt}\right) \tag{3}$$

where σ_0 is initial stress (MPa), a and b are dimensionless constants and t is time (Andres *et al.*, 2008).

Non-linear regression analysis was applied to calculate the corresponding constants of the stress relaxation models using Statistica 8.0 software for Windows (Statsoft, Tulsa, OK, USA). All of the analyses were conducted in triplicates with two repetitions.

Texture profile analysis

Texture profile analysis (TPA) was conducted according to the procedure described by Manohar and Rao (1999) with some modifications. In this regard, the dough samples were subjected to TPA at 25±2 °C with three replicates using the Texture Analyzer (TA.XT Plus Stable Micro Systems Ltd.) with texture expert programs. Each dough sample weighed as 15 g was manually shaped as a sphere and put onto heavy duty platform. A double cycle compression test as described by Bourne (2002) was applied up to 40% compressive strain of the original portion height using an aluminium spherical probe (SMS P/1s; TA.XT Plus Stable Micro Systems Ltd.). Post-test, test and pre-test speed values were 5, 1 and 5 mm/s, respectively. A time of 5 s was allowed to elapse between two compression cycles. Force–time deformation curves were obtained with a 30 kg load cell and 5 g trigger force. Time versus force plots were used for calculation of TPA parameter values. Values for hardness, gumminess, springiness, resilience and cohesiveness were determined using the definitions as described by Bourne (2002). Figure 2 was used to quantify the TPA parameters. It shows the calculation procedures for the TPA parameters. Hardness (N) is defined as maximum force required compressing the

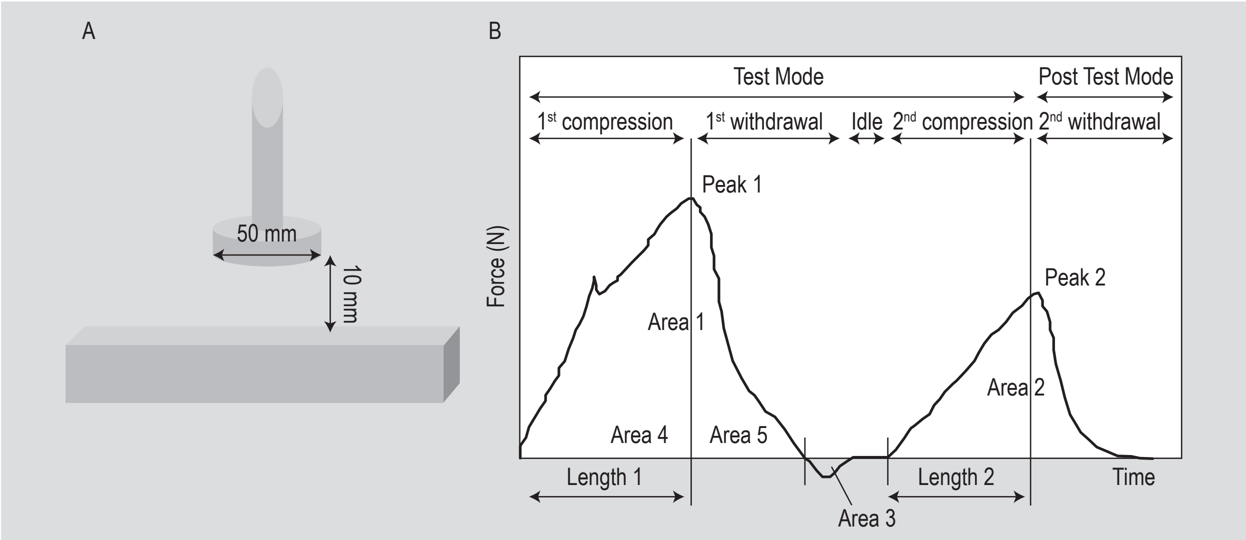

Figure 2. (A) Configuration of plates used for dynamic mechanical analysis in a TA.XT Plus Texture Analyser. (B) A typical texture profile analysis curve: peak force 1 = hardness; gumminess = area 2/area 1 × hardness; springiness = length 2/length 1; resilience = area 5/area 4; cohesiveness = area 2/area 1.

sample and it is the degree of resistance of the samples to scratching. Resilience is the measurement of how the sample recovers from deformation. Springiness is the ability of the sample to recover its original form after deforming force is removed. Cohesiveness is defined as the measurement of disintegration of the sample. Gumminess is the energy required to disintegrate the sample. All of the analyses were conducted in triplicates with two repetitions.

Statistical analysis

Additional statistical calculations were conducted using the Statistical Analysis System software (SAS, Cary, NC, USA). One-way analysis of variance (ANOVA) was performed by using the general linear model procedure. Duncan's multiple range test was used to show the differences among mean values with the significance level of 0.05. Bivariate correlations between the parameters were conducted by Pearson's test using Minitab 14.0 software (Minitab Inc., Coventry, UK).

3. Results and discussion

Physicochemical properties

Physicochemical properties of wheat chips dough samples enriched with different concentrations of apple fibre are shown in Table 2. Apple fibre addition decreased the moisture content of the samples. The reason why fibre addition increased the dry matter content could be attributed to the higher dry matter level of apple fibre, leading to such increase in dry matter contents of the samples (Yildiz *et al.*, 2013). On the other hand, fibre addition increased the ash content of the samples, as expected because it is well known that fibres are rich in minerals and their addition provides an increase in the mineral content of the samples. Protein content of the samples changed in the range of 7.93-7.30% and apple fibre addition caused a decrement in the protein level of dough samples. Regarding colour properties, brightness (L* values) of the samples decreased for the effect to have less moisture content in the dough and apple fibre addition

Table 2. Effect of apple fibre on some physicochemical parameters of wheat chips dough samples.[1]

Samples	Moisture (%)	Ash (%)	Protein (%)	L*	a*	b*
Control	42.02±0.05^{a}	0.319±0.07^{e}	7.93±0.14^{a}	79.69±0.35^{a}	1.75±0.06^{d}	21.40±0.41^{e}
5%	41.88±0.09^{a}	0.351±0.01^{d}	7.76±0.09^{ab}	66.36±0.38^{b}	6.65±0.22^{c}	24.34±0.36^{d}
10%	41.80±0.04^{a}	0.386±0.05^{c}	7.61±0.09^{b}	62.87±1.08^{c}	7.72±0.23^{b}	24.37±0.21^{c}
15%	41.70±0.02^{b}	0.418±0.03^{b}	7.45±0.11^{c}	58.98±0.37^{d}	9.29±0.10^{a}	24.74±0.17^{b}
20%	41.61±0.12^{b}	0.452±0.01^{a}	7.30±0.01^{d}	57.56±0.78^{e}	9.61±0.41^{a}	26.85±0.54^{a}

[1] The results are given on the wet basis of sample weight. Different lowercase letters show significance at P<0.05.

due to ash content of apple fibre decreased it. Also, on the other hand, redness (a*) and yellowness (b*) of the samples increased with the fibre addition.

Stress relaxation behaviour

Figure 3 illustrates the effect of apple fibre concentration on the stress-deformation properties of wheat chips dough samples. As can be seen, there was a first sharp increment followed by a decrement in the stress values of all the samples. Similar behaviours were previously reported for other foods having viscoelastic properties (Bertola *et al.*, 1996; Del Nobile *et al.*, 2007; Singh *et al.*, 2006). In other words, at the beginning of the stress relaxation test of the dough samples, there was a rapid increase in the curve with start of constant deformation. Apple fibre addition resulted in an increase in initial stress values of samples. This means that increase in apple fibre increased the resistance of the dough samples to deformation because the samples became harder with the addition of fibre. Increasing resistance of dough has both advantage and disadvantage in terms of expectations from dough. It can hinder or reduce the deformation of the dough resulted from forces applied during transportation or any other process occurred before production of end product. However, as a disadvantage, resistance increase can obstruct the machinability of the dough resulting in additional cost due to the change in production process parameters or equipment. Therefore, the fibre concentration be added should be carefully determined or the process system should be adjusted regarding dough properties.

In this study, three models, namely, generalised Maxwell (Figure 1), Nussinovitch and Peleg models were used to describe the stress relaxation behaviour of wheat chips dough samples. The predicting performances of the two-element Maxwell and Nussinovitch models were fairly good based on the determination coefficients (R^2). The Peleg model showed also a good performance that was close to those of the mentioned models with high R^2 values

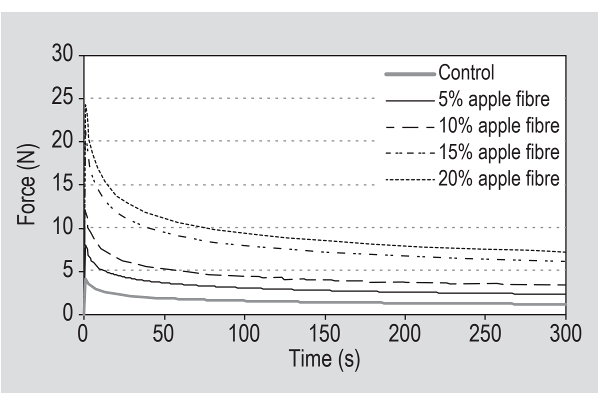

Figure 3. Change in the relaxation behaviour of wheat chips dough samples enriched with apple fibre.

(Table 3). Figure 4 illustrates the prediction performance of the three models. It is clear from the figures that the estimated results are very close to experimental data as well as to each other.

Table 3 shows the constant values of the generalised (two-element) Maxwell model (Equation 1). As can be seen from Table 3, apple fibre addition increased the C_1 values of dough samples, indicating that wheat chips dough samples enriched with apple fibre were more elastic than chips dough sample itself (control sample) and that apple fibre addition increased the elasticity of the wheat chips dough. The decreased elasticity could be partly attributed to the fact that apple fibre addition decreased total dry matter content, namely increased the moisture content of the dough samples. Similar result was reported by Lazaridou *et al.* (2007) who determined that loss tangent (tan δ) values increased with increasing dough moisture content. As is well known, tan δ is a dimensionless number giving a clear indication of whether the material behaves as solid-like or liquid-like behaviour and the larger the tan δ value, the more easily the product flows due to loss in elasticity. C_1 and C_2 representing the decay stress are the elastic components of the Maxwell element and they are the relaxation moduli and represent the rigidity of spring elements in the Maxwell model (Sozer and Dalgic, 2007). Costell *et al.* (1986) reported that it is possible to take basic cellular structure of the food systems as a reference in order to explain material behaviour represented by the first Maxwell element and defined by the values of C_1 and τ_1. The second elements defined by C_2 and τ_2 can be represented by the other structural features such as mobility of water molecules adsorbed in the polysaccharide network and reaccommodations of ternary and quaternary bonds between molecules (Yildiz *et al.*, 2013).

From the data in Table 3, it can be inferred that wheat chips dough enriched with apple fibre might be composed of structures of different decay force and apparent viscosities. This indicated that the structure of the dough samples can be classified into a number of Maxwell elements, which allows characterisation of the stress relaxation behaviour of the dough samples in this study. In addition, Wu *et al.* (2012) investigated the rheology of fibre enriched steamed bread using stress relaxation tests and texture profile analysis. They concluded that the higher decay force and shorter relaxation time of steamed bread having high wheat bran content showed that the bread had more rigid and less elastic behaviour. Our findings are agree with the findings of Wu *et al.* (2012). The results of the current study can be interpreted as that the apple dietary fibre addition increased resistance of the chips dough samples to deformation. It was reported that higher decay force means higher stress required to deform the material (López-Perea *et al.*, 2012). Bakery industry should consider the results of the current study in order to make the products more elastic, so more

Table 3. Parameters for Maxwell, Nussinovitch and Peleg models calculated for describing stress relaxation properties of wheat chips dough samples enriched with apple fibre.[1]

Samples	Generalised Maxwell model[2]				
	C_1	τ_1	C_2	τ_2	R^2
Control	1.639±0.35^e	8.935±0.24^a	1.143±0.14^e	439.79±4.25^d	0.983
5%	3.495±0.25^d	8.120±0.21^b	2.390±0.12^d	527.23±6.52^c	0.981
10%	4.963±0.10^c	7.900±0.22^b	3.231±0.14^c	572.57±5.21^b	0.981
15%	9.401±0.14^b	7.852±0.24^b	6.350±0.10^b	642.29±9.12^a	0.978
20%	10.911±0.12^a	7.568±0.21^b	7.462±0.08^a	648.53±10.11^a	0.980
	Nussinovitch model[3]				
	A_1	A_2	A_3	A_4	R^2
Control	0.032±0.001^d	0.342±0.01^a	0.112±0.01^a	0.156±0.04^a	0.984
5%	0.058±0.002^c	0.340±0.02^{ab}	0.094±0.04^b	0.141±0.04^b	0.982
10%	0.071±0.001^b	0.338±0.01^b	0.083±0.01^c	0.130±0.03^c	0.979
15%	0.092±0.003^a	0.337±0.01^b	0.079±0.02^e	0.122±0.02^d	0.978
20%	0.093±0.001^a	0.343±0.03^a	0.080±0.04^{ce}	0.123±0.04^d	0.979
	Peleg model[4]				
	a	b	R^2		
Control	0.828±0.01^a	0.273±0.03^d	0.946		
5%	0.816±0.01^b	0.316±0.02^c	0.951		
10%	0.813±0.02^c	0.361±0.04^a	0.953		
15%	0.797±0.03^d	0.361±0.08^a	0.957		
20%	0.798±0.04^d	0.354±0.07^b	0.960		

[1] Different lowercase letters show significance at P<0.05.
[2] C_i = decay force of the ith Maxwell element; τ_i = the time of relaxation of the ith Maxwell element; R^2 = coefficient of determination.
[3] A_1, A_2, A_3, and A_4 = dimensionless constants; R^2 = coefficient of determination.
[4] a and b = the constants of the equation; R^2 = coefficient of determination.

resistible to deformation occurred by mechanical effects during transportation and storage. Another point to be mentioned here that C_1 values were higher than C_2 values (Table 3) at all the apple fibre concentrations. Possible explanation could be done based on the destruction of the internal structure of the dough samples as a result of the mechanical stress applied during the stress relaxation tests (Sozer and Dalgic, 2007).

Table 3 also shows that fibre addition decreased τ_1 value of the chips dough samples, indicating that the dough samples enriched with apple fibre relaxed faster than dough sample itself. Faster relaxation is very important for the bakery industry. If the relaxation period lengthens out, it causes some problem in terms of the fact that volume of the dough can increase with relaxation of the sample, which cause mistakes in production line. Considering that softer gel samples have less viscous cell wall content, less polysaccharide entanglement and faster ability to dissipate the force (Kajuna *et al.*, 1998), it was possible to make a suggestion that fibre addition made the dough samples harder probably owing to less viscous cell wall contents, polysaccharide entanglement and faster ability of starch granules to dissipate the force. In other words, these phenomena would be more possible in the dough samples blended with the apple fibre. On the other hand, τ_2 values of the dough samples were observed to increase with apple fibre concentration. In this study, the first term of the Maxwell model was used to describe the structural behaviour of dough samples. Accordingly, Baragale *et al.* (1994) reported that the first term of Maxwell model had a major contribution (90%) to the total modulus and so,

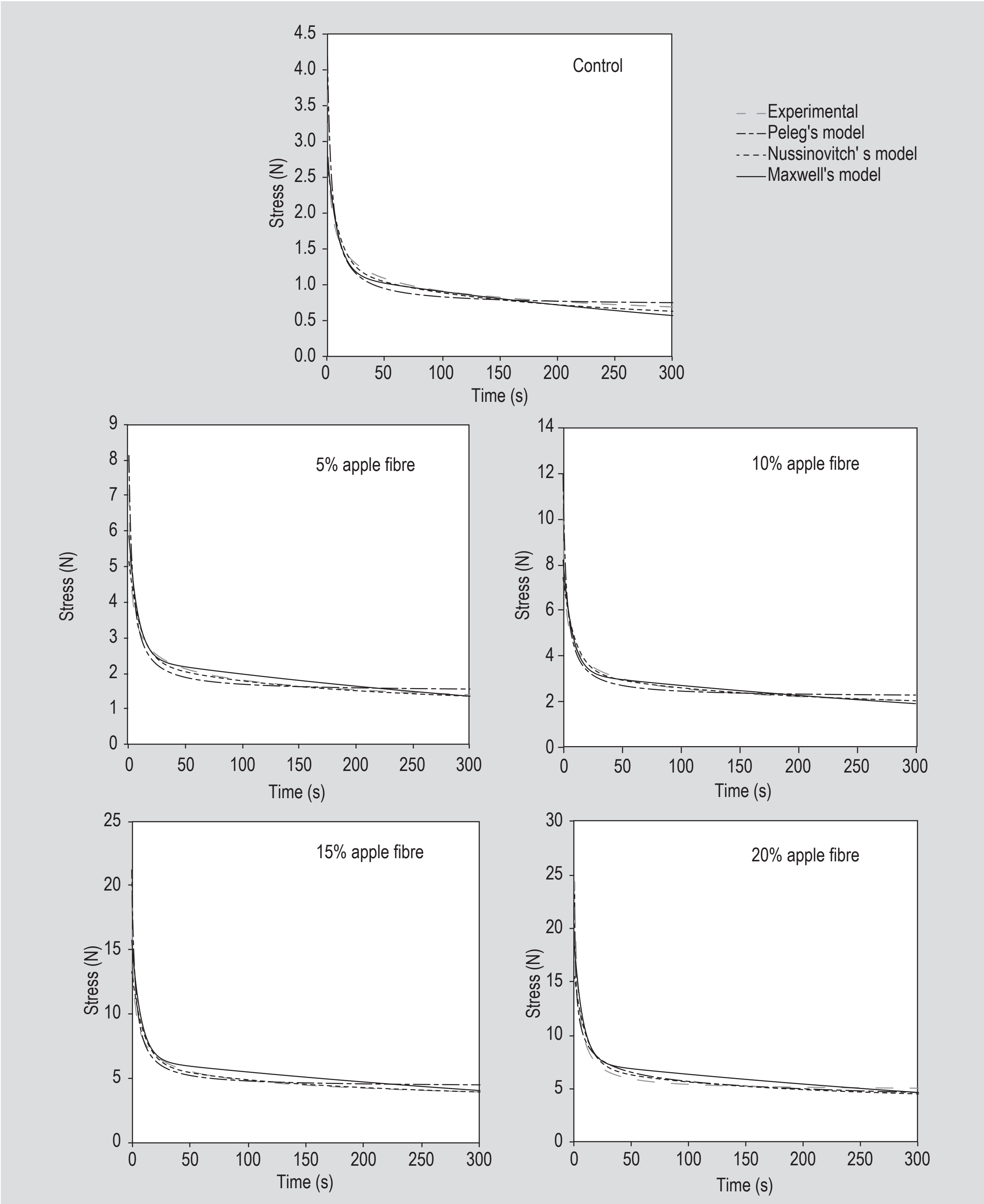

Figure 4. Experimental stress relaxation curves and estimated values fitted with Maxwell, Nussinovitch and Peleg models for wheat chips dough samples.

the first terms could be used to describe the structural behaviour.

The stress relaxation behaviour of the dough samples enriched with different fibre concentrations was also described using the Nussinovitch model. Nussinovich model is known as a simplified version of the Maxwell model because in this model, the relaxation times of Maxwell elements (τ_i) are given as constants. It allows to record relaxation data in short terms, avoiding the reaching of an equilibrium stress to end the test. This model was also proved to be appropriate for determining the relaxation behaviour of the starch/fibre gels with high determination coefficients (Yildiz *et al.*, 2013). Table 3 shows the constant values of the Nussinovitch model (Equation 2). Fibre addition was observed to increase A_1 values of the dough samples. Based on the information by Kajuna *et al.* (1998) who reported that A_1 is a measure of the force remaining unrelaxed; therefore, a measure of the rigidity of the materials, it is possible to say that chips dough samples with apple fibre had a higher rigidity than the chips dough itself; furthermore, the rigidity of the dough samples increased as the apple fibre concentration increased. A_3 and A_4 values were generally observed to follow a consistent pattern; however, these values were observed to decrease as the fibre concentration increased.

In this study, the Peleg model was also applied to determine stress relaxation behaviour of the dough samples. Table 3 shows the calculated constant values, namely, a and b values. The constant a represents the level at which the stress begins to decay during relaxation. The Peleg constant a being equal to 0 means that stress never relaxes and that the material is considered to be a solid material like rubber. However, in the cases where a equals to 1, the applied stress relaxes to 0 after the elapse of infinite time (Hassan *et al.*, 2005). It was also reported that the Peleg constant, *a* is a measure of how easily the material deforms (Rodríguez-Sandoval *et al.*, 2009). In this study, fibre addition decreased *a* values of chips dough sample (control) and these values decreased as fibre concentration increased. Given the above reports, it was possible to say that the apple fibre addition made the wheat chips dough more solid-like gel with high ability to store energy. In addition, more pronounced effects were observed as the fibre concentration increased. These results also suggested that apple fibre addition resulted in a less elastic and more solid wheat chips dough. These characteristics would dissipate less energy; thereby, require high force to be compressed (Guo *et al.*, 1999). It can be also suggested that more solid gels could be achieved with 15 and 20% of apple fibre additions. As for a values, they represent stress relaxation rate, namely, decay rate. Higher a values mean lower decay and, vice versa. Decrease in the a values caused an increase in the elasticity and so, chips dough samples having higher apple fibre level showed more elastic character.

In this study, apple fibre addition generally increased the b values of the wheat chips dough samples (Table 3). The b values of samples are the representative of the degree of solidity. The results were agree with the results of the study conducted by Wu *et al.* (2012). They reported that 20-30% bran fibre enriched steamed breads were more rigid and elastic compared to breads having low fibre (0-10%). Li *et al.* (2003) reported that the relaxation characteristics of the dough dependent on the gluten protein. Because the gluten protein was the main factor affecting the strength of steamed bread, it can be said that the fibre interfere with the gluten network resulting the significant change in the stress relaxation behaviour of the final product (Zhu *et al.*, 2001). It can be hypothesised that the starch gel samples enriched with apple fibre need more normalised force to achieve the same deformation than the control dough sample (Yildiz *et al.*, 2013).

Stress relaxation distribution curves of the dough samples are illustrated in Figure 5. In such figures, the continuous distribution curve of the relaxation times is illustrated with the superposition of two well district contributions; the first part is a little narrow and high which describes the short time response of the food structure and second part of the curve define the long-time response of the food matrix and so it is quite wide and long (Del Nobile *et al.*, 2007). Del Nobile *et al.* (2007) also reported that the curve of the relaxation time distribution type is directly related to the structure of a food matrix. It is clear from the figures that the relaxation distribution curves of the samples showed significant differences depending on increase in apple fibre concentration in the dough samples. It is also seen from these figures that the relaxation times after stress applied to return the initial structural phase increased with apple fibre concentration. For example, the relaxation time was lower than 800 s for the control dough samples. Del Nobile *et al.* (2007) reported that the relaxation times distribution curve approaches to zero in the range of 600-1000 s for spongy foods. Based on this report, it could be said that the relaxation times distribution curve for the control sample had a structure like spongy foods, it is quite soft; therefore, relaxation time distribution curve values did not reach to even 1000 s and they approached to zero after approximately 800 s. Addition of apple fibre caused an increase in the relaxation distribution times and they approached to zero after 1,800 s for the dough sample enriched with 15-20% of apple fibre. It was reported that the relaxation time distribution curve approached to zero at the time of 2,000-5,000 s for the foods having a bulky structure (Del Nobile *et al.*, 2007). From these results, it can be said that the release of the stress was faster at the beginning of the relaxation than that of at the end and so, control samples recovered the initial shape faster than did the samples enriched with apple fibre and increase in the apple fibre concentration delayed the recovery of the samples (Del Nobile *et al.*, 2007; Tang *et al.*, 1998). Similar results were reported in the literature for different foods. Del Nobile *et al.* (2007) reported that the curves vanished to zero at relaxation time between 600 and 1000 s for mozzarella cheese and white pan bread; this time was higher than 2,000 s for meat, ripened cheese and agar. Dietary fibres have different solubility characters. Apple fibre used in

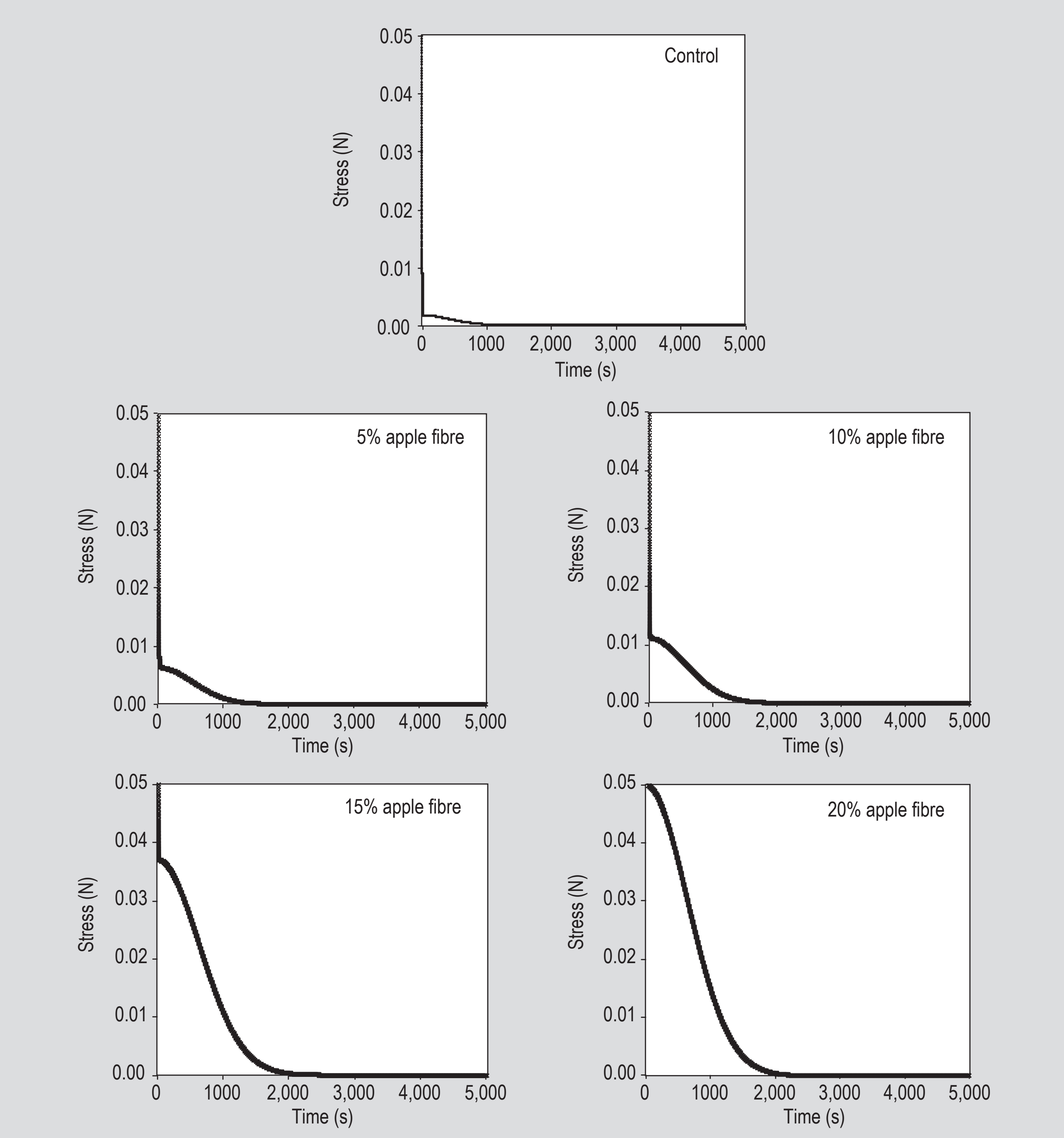

Figure 5. Distribution curves for the relaxation times of wheat chips dough samples enriched with apple fibre.

the study includes 40% insoluble and 20% soluble fibres. The main increase in the elasticity and decrease in the extensibility of the final dough samples added with apple fibre is the rich in insoluble fibre level. Wang *et al.* (2002) reported that the fibre addition mainly modified the water absorption of the dough samples and cause a significant change in the viscoelastic characteristics of the wheat dough. They reported that the addition of inulin having more soluble fibres increased the tenacity of the dough and extensibility of the bread was found to be high in the inulin added samples compare to samples added with pea or carob fibre having high level of insoluble fibres. Gomez *et al.* (2003) reported that the presence of the soluble dietary fibre fraction in dietary fibre can provide improved physiological functions in addition to the functional effects provided by the insoluble fraction.

Textural properties

Figure 6 shows a typical texture profile analysis graph of wheat chips dough enriched with apple fibre at different concentrations and Figure 7 shows the TPA parameters of the samples. As can be seen, hardness and gumminess values increased (P<0.05) with the increase in apple fibre concentration while springiness, cohesiveness and resilience values decreased (P<0.05). It is clearly seen from the both of figures; apple fibre showed a significant effect on the textural characteristics of the wheat chips dough. It was reported that the addition of dietary fibre into the wheat flour to enrich the nutritional composition cause an interaction with the structural elements of the three dimensional gluten networks and disrupts the starch and gluten matrix. Due to the interaction of fibre with gluten, a significant change occurs in the rheological characteristics of the blended dough. Similar results were reported by Ahmed *et al.* (2013). Lai *et al.* (1989) also reported that the addition of fibre into the wheat flour dough increased the strength of the structure of the bread dough and it showed solid-like behaviour causing the reduced extensibility and lower bread volume. Gularte *et al.* (2012) investigated the effect of fibre addition on textural properties of the cake and they reported that the addition of fibre increased the hardness and decreased the resilience. Also, they reported that the addition of inulin which is a soluble fibre reduced the springiness significantly. Our textural parameter results agree with the findings of Gularte *et al.* (2012). Similar results were also reported by Gómez *et al.* (2010) for the fibre enriched layer cakes.

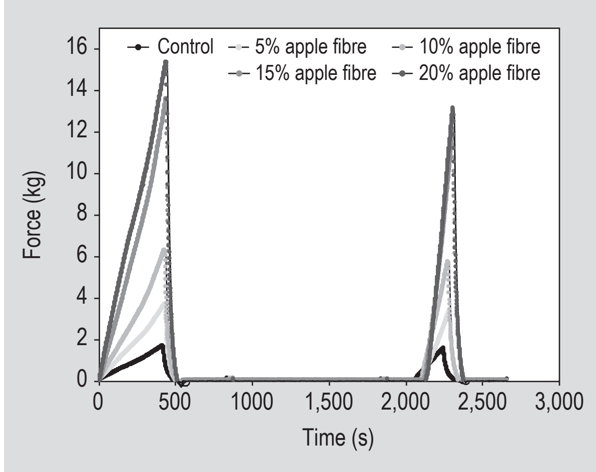

Figure 6. Effect of apple fibre on texture profile parameters of wheat chips dough samples.

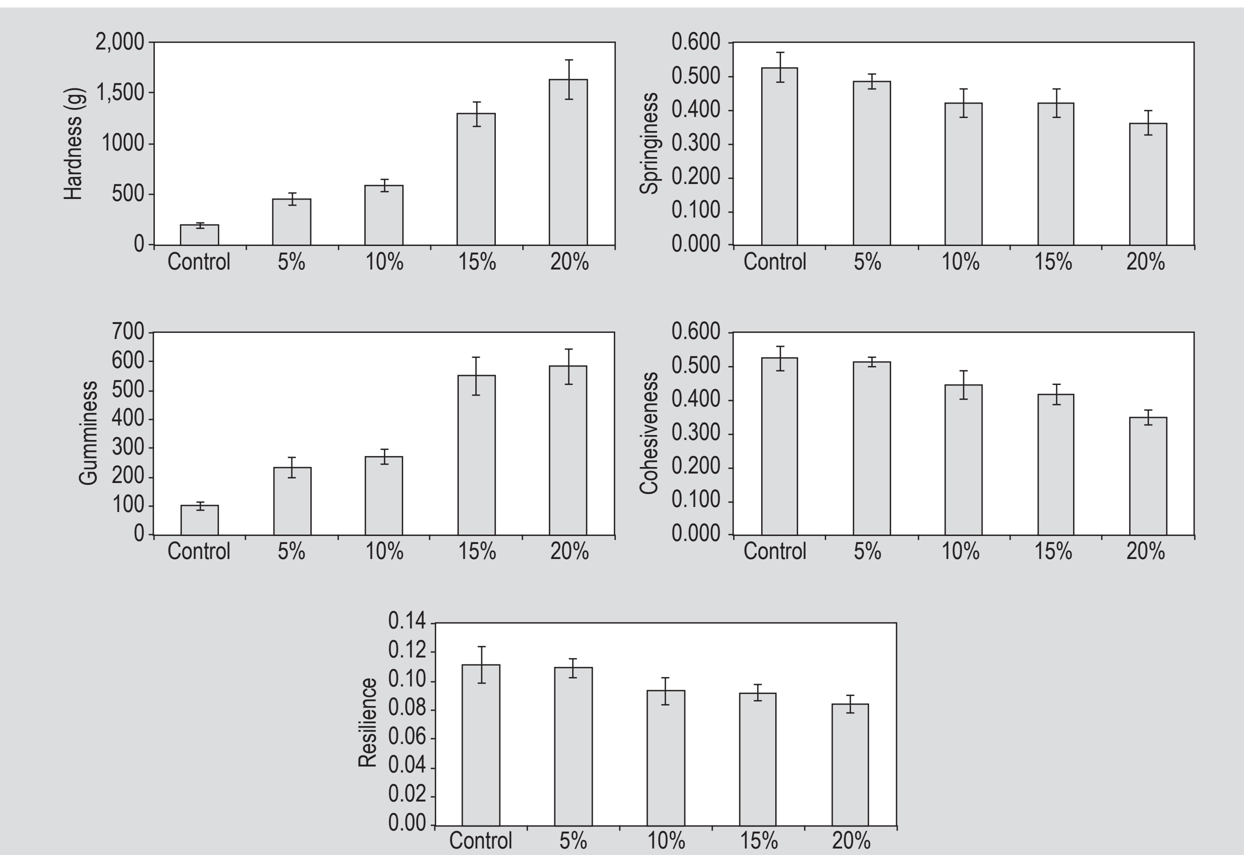

Figure 7. A typical texture profile analysis graph of wheat chips dough samples.

As each textural parameter might be closely related to stress-relaxation behaviour of food materials, significant correlations were thought to be found between textural parameters and stress relaxation behaviour of dough samples enriched with apple fibre. Therefore, a Pearson correlation test was conducted in this study and the calculated correlation coefficients were presented in Table 4. As can be seen from the table, there were significant (P<0.05) positive and negative correlations between stress relaxation constants (from generalised Maxwell model) and almost each textural parameter. Hatcher *et al.* (2008) reported similar correlations between the textural parameters and stress relaxation model constants and they concluded that the textural parameters are closely related to stress relaxation parameters. Kaur *et al.* (2002) also reported that the texture profile analysis parameters of some potato cultivars and they observed that the samples having higher textural parameter values had a higher Maxwell elastic moduli showing the correlation between the textural and stress relaxation test parameters. Hardness values showed negative correlation (r=-0.902) with springiness as expected. As it is well known that the springiness is the recovering ability of the sample during deformation (Bourne, 2002) and it is defined as how well a product physically springs back after it has been deformed during the first compression. Due to the significant decrease in the elastic behaviour and increase in the solid like structure, springiness values decreased. Wu *et al.* (2012) reported the negative correlation between hardness and springiness values for the steamed bread enriched with dietary fibre. Additionally, Wu *et al.* (2012) observed that there was a positive correlation with the fitting parameters of Peleg and Maxwell models and hardness values. Also, they concluded that there was a positive correlation between the springiness of steamed bread and model constants of Peleg model. Based on these correlations, it can be concluded that the effect of apple fibre addition on textural parameters of wheat chips dough samples can be seen based on stress relaxation parameters of the generalised Maxwell model. In other words, due to the correlation between the texture profile analysis parameters and stress relaxation fitting parameters, the viscoelastic behaviour could be evaluated using one of them.

Description of effect of apple fibre on model parameters

Power law and exponential functions were used to describe the effect of fibre concentration on the parameters of Maxwell, Nussinovitch and Peleg models and the model constants are given in Table 5. It is seen that the power law and exponential functions showed a good performance (R^2≥0.94) in prediction of the Maxwell model parameters. The efficiency of concentration models in the predicting the Peleg and Nussinovitch parameters was determined to be weak because of low coefficient of determination (Table 5). In the literature, power law and exponential functions were used to describe the effect of concentration on the rheological parameters effectively (Karazhiyan *et al.*, 2009; Yaşar *et al.*, 2007). Effect of fibre concentration on the TPA parameters and the related constants are given in Table 6. The power law and exponential functions could also be successfully used to predict the TPA parameters (R^2≥0.925)

4. Conclusions

It was concluded that the apple fibre addition showed a significant change in the structure of the dough samples resulting differences in the stress relaxation behaviours and parameters of texture profile analysis. Depending on the stress relaxation data, the Maxwell, Peleg and Nussinovitch models were used to describe the effect of apple fibre on viscoelastic characteristics of wheat chips dough. It was seen that Maxwell model well fitted to the experimental data. Given the stress relaxation constants calculated from these models, use of apple fibre can be recommended to change the stress relaxation properties. The physical

Table 4. Correlation matrix between the textural and stress relaxation (generalised Maxwell model) parameters.[1]

Parameters[2]	Hardness	Springiness	Cohesiveness	Gumminess	Resilience	C_1	τ_1	C_2	τ_2
Hardness	1	**-0.902**	**-0.950**	**0.987**	**-0.891**	**0.995**	-0.821	**0.998**	**0.928**
Springiness		1	**0.971**	**-0.884**	**0.982**	**-0.917**	**0.932**	**-0.910**	**-0.935**
Cohesiveness			1	**-0.915**	**0.975**	**-0.952**	0.837	**-0.949**	**-0.902**
Gumminess				1	-0.877	**0.994**	-0.844	**0.994**	**0.960**
Resilience					1	**-0.913**	0.871	**-0.904**	**-0.920**
C_1						1	-0.847	**1.000**	**0.955**
τ_1							1	-0.839	**-0.945**
C_2								1	**0.948**
τ_2									1

[1] The values in bold are statistically significant (P<0.05).
[2] C_i = decay force of the i^{th} Maxwell element; τ_i = the time of relaxation of the i^{th} Maxwell element.

Table 5. Different models describing effect of fibre concentration on stress relaxation parameters of wheat chips dough samples enriched with apple fibre.[1]

Parameters[2]	Power-law function $SRP = SRP_1[C^{a_1}]$			Exponential function $SRP = SRP_2 exp[a_2C]$		
	SRP_1	a_1	R^2	SRP_2	$a_2[(\%)^{-1}]$	R^2
Maxwell model						
C_1	0.699	0.925	0.976	2.705	0.072	0.962
τ_1	8.752	-0.045	0.940	8.294	-0.004	0.968
C_2	0.440	0.952	0.973	1.777	0.074	0.962
τ_2	404.1	0.161	0.974	498.2	0.014	0.955
Nussinovitch model						
A_1	0.032	0.371	0.970	0.053	0.031	0.937
A_2	0.336	0.046	0.307	0.337	0.001	0.466
A_3	0.116	-0.135	0.757	0.097	-0.012	0.882
A_4	0.165	-0.099	0.993	0.145	-0.009	0.953
Peleg model						
a	0.842	-0.018	0.884	0.824	-0.002	0.898
b	0.286	0.082	0.808	0.321	0.006	0.679

[1] SRP = constant for corresponding stress relaxation parameter; C = concentration; a_1 = constant (dimensionless) for concentration effect; a_2 = constant $((c\%)^{-1})$ for concentration effect.
[2] C_i = decay force of the i^{th} Maxwell element; τ_i = the time of relaxation of the i^{th} Maxwell element; R^2 = coefficient of determination; A_1, A_2, A_3, and A_4 = dimensionless constants;; a and b = constants of the equation.

Table 6. Different models describing effect of fibre concentration on textural parameters of wheat chips dough samples enriched with apple fibre.[1]

Textural parameters	Power-law function $TP = TP_1[C^{a_3}]$			Exponential function $TP = TP_2 exp[a_4C]$		
	TP_1	a_3	R^2	TP_2	$a_4[(\%)^{-1}]$	R^2
Hardness	56.17	1.128	0.974	305.4	0.086	0.970
Springiness	0.652	-0.182	0.945	0.524	-0.018	0.951
Cohesiveness	0.773	-0.246	0.965	0.579	-0.024	0.986
Gumminess	56.14	0.794	0.937	176.3	0.063	0.925
Resilience	0.144	-0.176	0.974	0.116	-0.016	0.944

[1] TP = constant for corresponding textural parameter; C = concentration; a_3 = constant (dimensionless) for concentration effect; a_4 = constant $((c\%)^{-1})$ for concentration effect; R^2 = coefficient of determination.

meanings of these constants reveal that wheat chips dough samples incorporated with apple fibre were more elastic than wheat chips dough itself, namely, it is possible to increase the elasticity of the wheat chips dough by apple fibre addition. Distribution curves for the relaxation times in the sampling dough for wheat chips processing also confirmed the above results, revealing that the relaxation times of the dough samples increased with apple fibre addition. Given this result, it is also recommended to use the apple fibre at higher concentrations in order to increase resistance of wheat chips dough to deformation occurred during the kneading. However, the addition of apple fibre increased the TPA characteristics of the wheat chips dough samples in terms of hardness and gumminess. Power law and exponential functions were successfully used to describe the effect of apple fibre concentration on the model constants of Maxwell, Nussinovitch and Peleg models and TPA parameters.

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