Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 11 (19): 3405-3412, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.3405.3412

Dynamic Rheological Properties of Chickpea and Wheat Flour Dough's

[1,2]Idriss Mohammed, [1,3]Abdelrahman R. Ahmed and [1]B. Senge
[1]Department of Food Rheology, Institute for Food Technology and Food Chemistry,
Technical University of Berlin, Sekr. KL-H1, Konigin-Luise-Str. 22, D-14195 Berlin, Germany
[2]Department of Food Science, Faculty of Agriculture, Aleppo University, Syria
[3]Department of Home Economics, Faculty of Education, Ain Shams University, Cairo, Egypt

Abstract: Using of chickpea flour to improve the nutritional value of bread has received considerable interest not only because of its high protein content but also because of its high lysine content compared to wheat flour. The aim of this study was to test the effects of chickpea flour supplementation on the dynamic rheological properties of dough. The chickpea flour was used to replace 10, 20, 30 and 100% of wheat flour. Oscillation and creep shear tests were applied to test the effects of chickpea flour supplementation on the dynamic rheological properties of dough. The amplitude sweep measurement results showed that a linear viscoelastic behaviour of module at the range of $10^{-4} \leq \gamma \leq 10^{3}$. Oscillation measurements results cleared that the storage modulus (G') is greater than the loss modulus (G'') and the measurement curves of module run nearly parallel in frequency sweep. All dough's had a distinctive solid state characteristics (dispersion structure) not gel-like structure. Increase in the share of chickpea flour additions caused the (G') and (G'') curves to shift towards higher values compared to the wheat flour dough. While the tan δ curve tended to shift towards lower values. The creep test showed that increase of the chickpea flour addition to the dough system (increasing of solid state properties) lead to decrease the maximum deformation, elastic recovery (from 2.67 to 1.60), increase of zero shear viscosity and shear modulus. So, wheat flour can carry up to 30% (w/w) of chickpea flour and produce dough has an acceptable dynamic rheological properties.

Key words: Chickpea flour, wheat flour, dynamic rheology, oscillation and creep test, rheological properties

INTRODUCTION

Pulses, including beans and chickpea are one of the most important crops in the world because of their nutritional quality. They are rich sources of complex carbohydrates, protein, vitamins and minerals (Wang *et al*., 2010). Pulses have shown numerous health benefits, e.g., lower glycemic index for people with diabetes (Goni and Valentin-Gamazo, 2003) increased satiation and cancer prevention as well as protection against cardiovascular diseases due to their dietary fiber content (Chillo *et al*., 2008). Legumes are recognized as the best source of vegetable protein legumes (Molina *et al*., 2002). However, in recent years, there has been an increasing interest in other legumes such as chickpea (*Cicer arietinum* L.). Chickpea is a popular crop in the arid and semi-arid areas of North-Western China (Zhang *et al*., 2007). Due to their good balance of amino acid, high protein bioavailability and relatively low levels of anti-nutritional factors, chickpea seed have been considered a suitable source of dietary proteins. Chickpea dry seeds can also be consumed as whole or decorticated after cooking and processing in different ways. In addition to these uses, the flour of decorticated chickpea seeds is used in several dishes and as a supplement in weaning food mixes, bread and biscuits (Alajaji and El-Adawy, 2006). The mostly consumed product is bread and this has prompted the need to improve its nutritive values by applying additives for adequate feeding of the population.

Rheology is defined as a study of the deformation and flow of matter (Bourne, 2002). The applications of rheology have expanded into food processing, food acceptability and handling. Many researches have been conducted to understand the rheology of various types of food such as food powder (Grabowski *et al*., 2008), liquid food (Park, 2007), gels (Foegeding, 2007), emulsions (Corredig and Alexander, 2008).

Dynamic oscillatory measurements and creep-recovery has been used to characterise the mechanical properties of proteins, starch, lipids in the dough and the interactions between the components (Edwards *et al*., 1999). The complexity of the dough makes it difficult to use fundamental methods in characterising differences in flour qualities and predicting baking performance (Safari-Ardi and Phan-Thien, 1998).

Corresponding Author: Abdelrahman R. Ahmed, Department of Home Economics, Faculty of Education,
Ain Shams University, Cairo, Egypt Tel: +4917653360144

Therefore, the aim of this study was to determine the effect of the partial or complete replacement of wheat flour by chickpea flour on the dynamic rheological properties and physical processes of dough.

MATERIALS AND METHODS

Raw materials: Chickpea seeds (*Cicer arietinum* L.) variant kabule was bought on December 2010 from Turkish supermarket (Gazi) in Berlin-Germany. Chickpea flours were obtained after grinding chickpea grains in a laboratory hammer mill (Retsch-Germany) until they could pass through a 1.0 mm screen. Commercial wheat flour type 405 was obtained from Lidl Market (Berlin-Germany).

Chemical analysis: Proximate composition was carried out according to the official methods (ICC, 2001). Moisture content was determined by drying the samples at 105°C to constant weight. Ash content was determined by calcinations at 900°C. Nitrogen content was determined by using Kieldahl method with factor of 5.7 to determine protein content. The total lipid content was determined by defeating in the soxhelt apparatus with hexane. The determination of starch content was assessed using a polarimetric method according to Ewers, modified by (Davidek *et al*., 1981). All the measurements of analyzed samples were made in triplicate.

Dough's preparation: Five blends were prepared by mixing the wheat flour with chickpea flours in the proportions of 100:0, 90.10, 80:20, 70:30 and 0:100 (wheat:Chickpea w/w) using a mixer with a spiral blade which is usually used for dough mixing. The doughs were prepared by mixing different blends with 62% water for 5 min in a mixer at 25°C. Immediately after mixing, dough was transferred to the measuring system of the rheometer.

Dynamic rheological testes: A rheometer paar physica universal dynamic spectrometer 200 (Physica®, Anton Paar GmbH, Austria Europe) was used for measuring the rheological properties of dough samples. Operation, including temperature control and data handling, was conducted using PC-based software provided by the rheometer manufacturer (Rheological Instruments AB, Lund, Sweden). Each time, a sample was taken of a given blend (wheat flour + chickpea flour), containing 6 g of dry matter and combined with a specific amount of water, equivalent to the water absorption of the blend at the level of 62% (at 14% moisture basis). The consistency of the sample obtained at that level of dough moisture permitted its placement by hand within the measurement system of the rheometer. The dough was kneaded for 5 min using a mixer with a spiral blade. Next, the sample was transferred onto the lower plate of the rheometer and pressed down with the upper plate, 25 mm in diameter, until a gap of 2 mm was obtained. The excess of the sample, protruding beyond the edge of the upper plate, was trimmed off while drops of fluid silicon oil were placed around the uncovered surface of the sample to protect the sample from loss of moisture during the test. In this condition the sample was left to rest for 1 min. That period permitted the relaxation of normal stresses generated in the course of compression of the sample. All rheological tests were made at a constant temperature of the lower plate (25°C), controlled by means of an external thermostatic bath. The sample was first subjected to dynamic oscillation shear tests in the mode of oscillation strain control. The amplitude of relative strain was $10^{-3} \leq \gamma \leq 1$ and fell within the linear viscoelastic region for all samples. The limits of the region were determined based on an experiment in which increasing stress was applied, at constant oscillation frequency of 1 Hz.

Applying oscillation frequencies within the range from 0.1 to 20 Hz at constant strain $\gamma = 10^{-3}$. Each logarithmic frequency decade corresponded to 30 measurement points. The cycle of dynamic tests was followed by a 10 min period of relaxation. Then, the dough sample was subjected to the creep test, applying a constant shear stress of 50 Pa for 60 sec on the sample and allowing the sample to recover the strain in 180 sec after removal of load. The dynamic tests and the creep tests were made in three replications, each on a freshly prepared sample of dough. The figures present the measurement results after their averaging.

Modeling of the resulting curve

Oscillation measurements: Dynamic oscillatory tests of dough samples were conducted using the frequency sweep mode. The measured responses of the material were the maximum amplitude of the strain and the phase difference (or phase angle) between the applied stress and the resulting strain wave. If the data of frequency sweeps for each material at different concentration are plotted as $G'(\omega)$or $G''(\omega)$ in a double logarithmic diagram, different lines with equal slope are obtained for different samples of dough. The mathematical forms of these equations are given below:

$$G'(\omega) = G'_{1Hz} \cdot \omega^{X} \text{ (in Pa)} \quad (1)$$

$$G''(\omega) = G''_{1Hz} \cdot \omega^{Y} \text{ (in Pa)} \quad (2)$$

For an individual material the coefficients G'_{1Hz} and G''_{1Hz} are the storage and loss moduli, respectively, extrapolated to the values of the initial measuring frequency, ω_1 or ω_2.

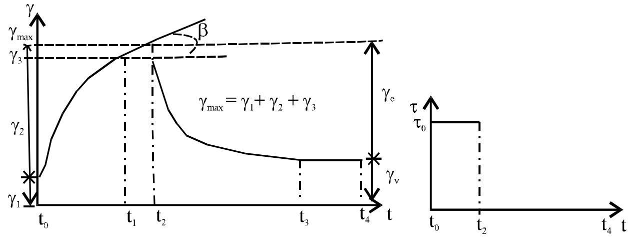

Fig. 1: Creep and creep recovery curve

Creep measurement: A constant stress τ, is applied to the sample from time t_0 to t_2 (phase of applied stress; load). During this stage the deformation γ reaches its maximum value γ_{max} at time t_2 (creep). γ_{max} depends on stuffiness (rigidity modulus) and zero shear viscosity η_0. At time t_2, stress τ is removed instantly (load removed or off-load; recovery phase, respond, Fig. 1).

During this recovery phase, the entire stored deformation energy is used up for the restoration process. At time t_4, can calculate the elastic part γ_e (i.e., solid properties) as well as the viscous part γ_v (i.e., liquid properties) of deformation (Fig. 1). The viscous part of deformation energy dissipates as friction heat. The recovery value γ_e/γ_{max} is an equivalent to the percentage of the solid properties which arise in creep tests. Further rheological parameters can be derived from these data:

$$\eta_0 = \frac{\tau}{\dot{\gamma}_3} \text{ (in Pa·s)} \tag{3}$$

The zero shear viscosity η_0 characterizes the flow ability at the end of the applied load phase. This viscosity is measured at very small shear rates and represents a material-dependent constant of the examined sample. High values of η_0 correspond to small flow abilities (Tanner, 1986). The estimation of η_0 results from Eq. 1 and 2 at a steady-state shear rate $\dot{\gamma}_3$.

$$\dot{\gamma}_3 = \frac{\gamma_3}{t_2 - t_1} \text{ (in s}^{-1}\text{)} \tag{4}$$

The compliance or creep function $J_e(t)$ characterizes the flowability as time-dependent parameter during the creep recovery phase:

$$J_e(t) = \frac{\gamma(t)}{\tau} \text{ (in Pa}^{-1}\text{)} \tag{5}$$

The equilibrium compliance J_e corresponds to the elastic properties of material and can be calculated as follows:

$$J_e = \frac{1}{G_0} = \frac{\gamma_e}{\tau} \tag{6}$$

The final or total rigidity modulus G_0 (also end stiffness) represents the elastic properties of the substance examined at lowest levels of deformation (non-destructive method):

$$G_0 = \frac{1}{J_e} \text{ (in Pa)} \tag{7}$$

or

$$G_0 = \frac{\tau}{\gamma_e} \text{ (in Pa)} \tag{8}$$

It can be calculated as the quotient of the commanded stress τ and the reversible elastic part γ_e of deformation. Finally, the relaxation time λ defines the time needed for the commanded stress to reach of its initial value τ (creep recovery phase) (Schwarzel, 1990):

$$\lambda = \frac{\eta_0}{G_0} \text{ (in sec)} \tag{9}$$

Statistical analysis: Analysis of Variance (ANOVA) was carried out using SAS program (Statistical Analysis System version. 9.1) (SAS, 2004). The rheological properties of wheat dough with or without chickpea were analysed using ANOVA. When the treatment factor effect was found significant, indicated by a significant f-test ($p<0.05$), differences between the respective means were determined using Least Significant Difference (LSD) and considered significant when $p<0.05$. The averages of three measurements for the viscoelastic moduli of dough samples were used.

RESULTS AND DISCUSSION

Chemical composition of wheat and chickpea flours: Data in (Table 1) indicate that proximate composition varied among wheat flour as well as chickpea raw flour. Protein, fat and ash contents in chickpea raw flour were higher than that recorded in wheat flour. However, starch was detected in wheat flour at higher level than that found in chickpea raw flour. These results confirmed by statistical analysis which highly significant differences ($p<0.05$) were observed between the two type of flours.

Oscillation measurements

Amplitude sweep: Amplitude sweeps were run on pure wheat flour dough, composite flour dough's and pure chickpea flour dough at a constant oscillation frequency of 1 Hz in order to evaluate the linear viscoelastic region. Figure 2 shows that dynamic measurements, i.e., G′ and tan δ were practically independent at all values of strain amplitude (γ) examined.

On the basis of these results, the linear viscoelastic behaviour was at the range of $10^{-4} \le \gamma \le 10^{-3}$ with a dominant solid state behavior (G′>G″ and loss factor < 1), followed by a decrease of both moduli and an increase in loss factor at structural break (tan δ = 1) for pure chickpea flour and composite flour while The value of moduli increased with an increase in strain amplitude for pure wheat flour dough. This increase might be attributed to the difference between interaction of starch-gluten in wheat flour and the interaction in pure chickpea dough. Such a notable domination of the storage modulus over the loss modulus indicates that wheat dough is a highly structured material and behaves like a viscoelastic body in which the elastic properties (G′) clearly dominate over the viscous properties (G″) which is in agreement with earlier studies (Letang *et al*., 1999). The total and macro structure is experiencing a break down, (completely destroyed). A sub-structure is not available. The deformation of destruction γ_z with G′ = G″ is located by Wheat flour dough at 0.6 and by chickpea flour dough at 0.1. The curves of tan δ indicated that the chickpea dough came to structural instability faster than wheat flour dough, despite the high protein content, the high level structure and the relatively greater particle size of chickpea flour in comparison to the wheat flour. With the additions of chickpea flour to dough samples, the total protein concentration of chickpea-dough samples increased, as a result, the tendency of the proteins to aggregate and the interactions of gluten network were enhanced. The effect of glutenin in increasing the G′ and G″ of dough was reported (Song and Zheng, 2007). The storage and loss modulus level of the blend flour dough's among each other has little differences in comparison to the wheat flour dough.

Table 1: Proximate chemical composition of wheat flour (WF) and chickpea flour (CF)

Constituent[a] (%)	Moisture	Fat	Protein[b]	Starch	Ash
WF	12.5	1.8	11.9	63.5	0.40
CF	9.5	5.0	25.5	51.2	2.80

[a]Expressed on a dry matter basis. [b]N×5.7

Frequency sweep: The relations G′, G″ and tan δ with frequency sweep for pure wheat flour dough, composite flour dough's and pure chickpea flour dough are presented in Fig. 3.

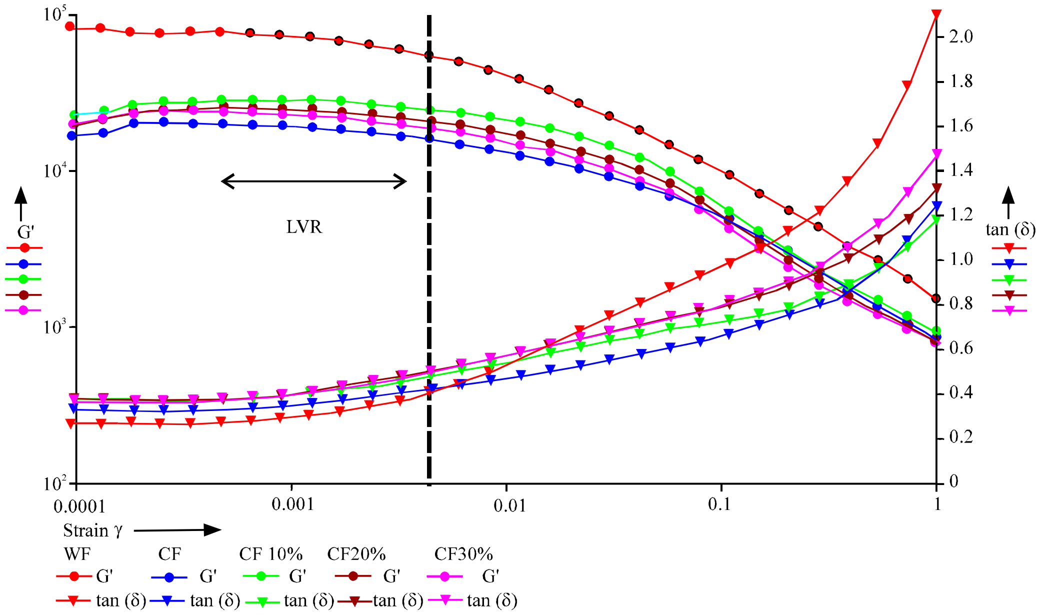

Fig. 2: The variation of moduli with amplitude for wheat flour, chickpea flour and composite flour dough's

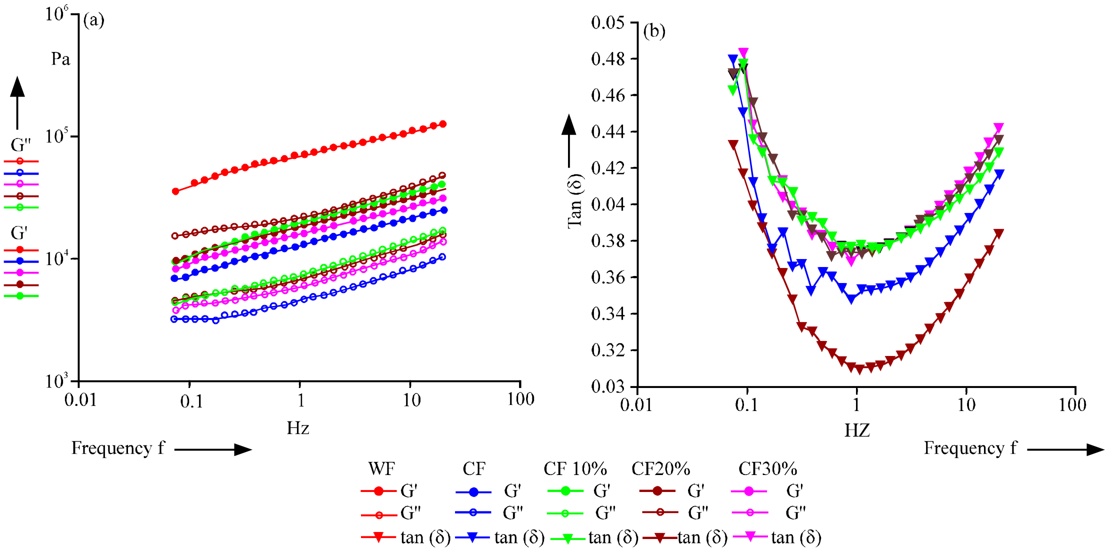

Fig. 3(a-b): The variation of moduli with frequency for wheat flour, chickpea flour and composite flour dough's. (a) Storage modulus G′ and loss modulus G″. (b) Loss factor

The presented data indicate that increase of oscillation frequency within the range from 0.1 to 20 Hz caused an increase in the values of the dynamic moduli-the storage modulus and the loss modulus for pure wheat-and chickpea flour dough as well as for composite flour dough. Whereas, the values of the tangent of the phase angle, being the ratio of G″/G′, decreased gently while the oscillation frequency increased from 0. 1 to approximately 1 Hz while higher frequencies caused an increase of those values. A similar frequency dependence was noted by Pedersen *et al.* (2004) for cookie doughs but not confirmed with (Rasper, 1993) who is reported that when higher frequencies is used, G″ becomes greater than G′ due to viscoelastic solid conversion to elastoviscous liquid. These results mean that the capacity of the tested dough for dissipation (whose measure is the value of G″) and storage (whose measure is the value of G′) of the energy used for its deformation increases with increase in the oscillation frequency. Energy is dissipated through friction that takes place during the slippage of one dough structural element past another, e.g., chains of gliadin proteins which are synonymous of the viscous component of gluten. Whereas, the storage of energy takes place through reversible rearrangements within the particular elements building the structure of dough, e.g., high molecular weight glutenin subunits which represent the elastic component of gluten (Song and Zheng, 2007).

The additions of chickpea at different concentration (10, 20 and 30%), had a similar effect on the run of the mechanical spectra of wheat dough. Increase in the percentage share of the additions caused a shift of curves G′ and G″ towards higher values. The data indicate that the additions applied caused an increase in tested dough elasticity (G′) and viscosity (G″), the increase in elasticity dominating over that in viscosity, as a result of which tan δ decreased. Frequency sweep experiments showed that for all tested dough formulations the elastic (or storage) modulus, G′, was greater than the viscous (or loss) modulus, G″, in the whole range of frequencies and both moduli slightly increased with frequency which suggests a solid elastic-like behavior of the chickpea doughs. Therefore, tan δ (= G″/G′) values for all dough formulations were lower than 1 (Fig. 3). Similar observations on dynamic rheological studies have been reported previously for wheat flour doughs (Dobraszczyk and Morgenstern, 2003; Edwards *et al.*, 2003), as well as for rice flour dough (Gujral *et al.*, 2003; Sivaramakrishnan *et al.*, 2004). G' and G" level increased with the increase of the chickpea proportion in the mixtures which characterized a different module developments in logical dependency on the chickpea concentration, this result is conflict with Hao *et al.* (2008), who reported that the decrease of G' and G" with the increasing of alfalfa powder concentration from 10% to 20% was possibly due to the cutting effect of large amount of alfalfa granules which disturbed the structure and intensity of continuous gluten network during the forming of dough. This material behaviour results primarily from particle interactions of the dispersed phase from the point contact of the larger flour particles with increased viscoelasticity. Conditional protein interactions should increase the viscoelastic relation due to the effect as a dispersion medium.

Maximum of structure stability is determined generally at a frequency of 1 Hz. Increase of moduli in the frequency range f<1 Hz due to the enhancement of the viscous behavior. While at higher frequencies f>1 Hz, their increasing may be due to destruction of structures which occurring at higher loads. Chickpea flour dough showed an increased level of dynamic moduli compared to the wheat flour dough and dough exposed to be higher solid state properties. In contrast, the wheat flour dough showed as a viscous, soft and deformable dough with better processing properties. Chickpea fortification made the dough particles increasingly sticky, causing them to aggregate during mixing. Chickpea flour contains significant levels of soluble Non-starch Polysaccharides (NSP), about ten times higher than bread wheat flour (Naivikul and D'Appolonia, 1979) and this may have contributed to the increased stickiness. Increasing chickpea fortification decreased water absorption and resulted in less stable doughs. This observation is in contrast with a similar study by Hui (1996), who reported that substituting wheat flour with 8, 15 and 25% chickpea flour reduced water absorption about 2%. However, similar results have been reported previously for wheat incorporating legume flours or their protein concentrates (Rasmay *et al*., 2000). Many of these effects can be attributed to weakening of the gluten matrix due to the incorporation of chickpea flour which contains no gluten. Chickpea proteins are comprised mainly of globulins (53-60%) with lesser concentrations of albumins, prolamins and glutelins (Dhawan *et al*., 1991).

High value of the exponent which calculated from equation 1 refer to the configuration of structure and the frequency-dependent structural stability. Wheat flour showed a high values of the exponents and structural stability of the dough compared to the chickpea flour dough.

Creep tests: The different creep curves for all the samples are shown in Fig. 4. The instantaneously recovered elastic strain just after the removal of load was high for the pure wheat dough. There was a considerable variation in the creep behavior between the composite flours and pure chickpea flour dough.

The creep deformation and the recovery for the composite flour with chickpea flour were almost similar to that of pure wheat dough except for the pure chickpea flour dough. The result of the creep curve analysis for both creep phase and the recovery phase is given in Table 2. The zero shear viscosity η_0 which gave the flowability of the material at the end of applied load, was very high for pure chickpea flour dough sample. Flowability decreased with increasing the chickpea flour concentration in mixture when compared with the wheat flour dough.

From the Table 2 is seen that the wheat flour dough compared to the chickpea flour dough showed higher values of the maximum deformation, compliance and the recovery energy but lower values of the zero shear viscosity and shear modulus for wheat flour dough, this indicate of better flow properties of the dough. On the other hand, the high value of zero shear viscosity and shear modulus for chickpea and composite flour dough, lead to lower in the fluidity of the dough (tendency to rigidity). With increasing the chickpea flour concentration in dough system (blend flour), the maximum deformation and elastic recovery decreased (from 2.67 to 1.60) due to the increasing of solid state properties, thus poorer processing properties were proved. Although the

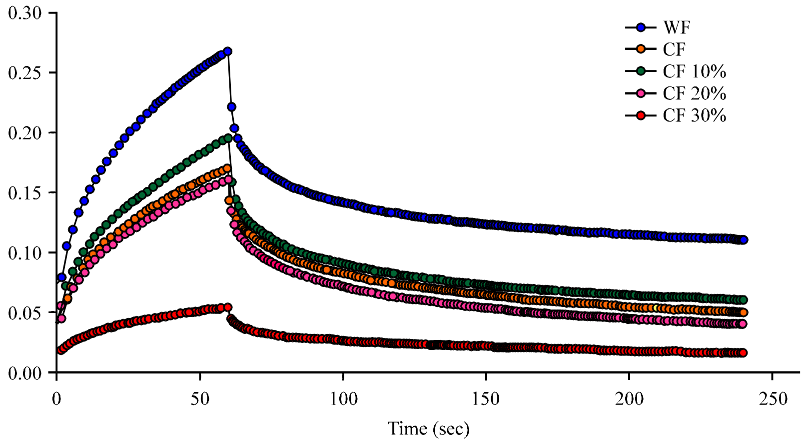

Fig. 4: Creep analysis curves for wheat flour dough, chickpea flour dough and composite flour dough

Table 2: Results of creep tests of wheat- and chickpea flour and the dependence on concentration

	Rheological parameter								
Example	J_e 10^{-5} Pa^{-1}	$\dot{\gamma}_3$ 10^{-4}	γ_e 10^{-2}	γ_v 10^{-2}	γ_{max} 10^{-2}	Restoration γ_e/γ_{max}%	η_0 Pa · s	G_0 Pa	λ s
WF	31.3	1.99	1.57	1.09	2.67	59	251.500	3197	78.7
CF 10%	26.9	1.62	1.35	0.59	1.94	69	308.980	3706	83.4
CF 20%	24.4	1.33	1.21	0.49	1.69	71	376.900	4071	92.6
CF 30%	24.5	1.25	1.21	0.39	1.60	76	401.340	4106	97.7
CF	7.74	0.39	0.38	0.15	0.53	72	1.290.100	12916	99.9

deterioration in the structural development has been demonstrated in the dough system after the addition of chickpea flour to the wheat flour, the blends flour dough's show permissible dough processing properties through the dominance of the wheat flour proportion. So, wheat flour can carry up to 30% (w/w) of chickpea flour and produce dough has an acceptable dynamic rheological properties.

CONCLUSION

The rheological properties of dough and their phase change behaviors were discussed. The value of moduli increased with an increase in frequency for pure wheat- and chickpea flour dough as well as for composite flour dough. The results showed that rheological properties of all dough's were characterized as dispersion system and indicated the distinctive elastic behavior (G'>G''). Increasing of chickpea proportion in the mixtures caused increasing of G' and G"- level. The flowability was very low for pure chickpea flour dough sample compared to pure wheat flour dough. The flowability decreased with increasing the chickpea flour concentration in blend-dough. Despite all this, the addition of chickpeas to the wheat flour did not significantly affect on the properties of dough. Moreover, the nutritional values have been improved by the addition of chickpeas. In general, it is clear that the addition of chickpea flour up to 30% is not affected on the working properties of the dough.

NOTATION

f = Frequency, Hz
G' = Storage modulus, Pa
G" = Loss modulus, Pa
G* = Complex shear modulus, Pa
G_0 = Total rigidity modulus, Pa
J = Compliance, Pa^{-1}
J_e = Elastic part of compliance, Pa^{-1}
J_v = Viscous part of compliance, Pa^{-1}
J_{max} = Maximum viscoelastic compliance, Pa^{-1}
t = Time
x = Exponent used to determine the storage modulus
y = Exponent used to determine the loss modulus
λ = Relaxation time
ω = Angular frequency, Hz
γ = Deformation
$\dot{\gamma}$ = Shear rate, s^{-1}
$\dot{\gamma}_3$ = Steady-state shear rate, s^{-1}
γ = Elastic part
γ_{max} = Maximum deformation
γ_v = Viscous part
γ_z = Destroyed deformation
δ = Loss angle,°
tan δ = Loss factor
η = Viscosity, Pa · s
η_0 = Zero shear viscosity, Pa · s
$I\eta^*I$ = Complex viscosity, Pa · s
τ = Shear stress, Pa

REFERENCES

Alajaji, S.A. and T.A. El-Adawy, 2006. Nutritional composition of chickpea (*Cicer arietinum* L.) as affected by microwave cooking and other traditional cooking methods. J. Food Compos. Anal., 19: 806-812.

Bourne, M., 2002. Physics and Texture. In: Food Texture and Viscosity: Concept and Measurement, Bourne, M. (Eds.). 2nd Edn., Academic Press, New York, pp: 59-106.

Chillo, S., J. Laverse, P.M. Falcone, A. Protopapa and M.A. Del Nobile, 2008. Influence of the addition of buckwheat flour and durum wheat bran on spaghetti quality. J. Cereal Sci., 47: 144-152.

Corredig, M. and M. Alexander, 2008. Food emulsions studied by DWS: Recent advance. Trends Food Sci. Technol., 19: 67-75.

Davidek, J., J. Hrdlicka, M. Karvanek, J. Pokorny and J. Velisek, 1981. Laboratory Handbook for Foodstuffs. 2nd Edn., CR, SNTL-Alfa, Prague.

Dhawan, K., S. Malhotra, B.S. Dahiya and D. Singh, 1991. Seed protein fractions and amino acid composition in gram (*Cicer arietinum*). Plant Foods Hum. Nutr., 41: 225-232.

Dobraszczyk, B. and M.P. Morgenstern, 2003. Rheology and the bread making process. J. Cereal Sci., 38: 229-245.

Edwards, N.M., J.E. Dexter, M.G. Scanlon and S. Cenkowski, 1999. Relationship of creep-recovery and dynamic oscillatory measurements to durum wheat physical dough properties. Cereal Chem., 76: 638-645.

Edwards, N.M., S.J. Mulvaney, M.G. Scanlon and J.E. Dexter, 2003. Role of gluten and its components in determining durum semolina dough viscoelastic properties. Cereal Chem., 80: 755-763.

Foegeding, E.A., 2007. Rheology and sensory texture of biopolymer gels. Curr. Opin. Colloid Interface Sci., 12: 242-250.

Goni, I. and C. Valentin-Gamazo, 2003. Chickpea flour ingredient slows glycemic response to pasta in healthy volunteers. Food Chem., 81: 511-515.

Grabowski, J.A., V.D. Truong and C.R. Daubert, 2008. Nutritional and rheological characterization of spray dried sweet potato powder. LWT Food Sci. Technol., 41: 206-216.

Gujral, H.S., I. Guardiola, J.V. Carbonell and C.M. Rosell, 2003. Effect of cyclodextrinase on dough rheology and bread quality from rice flour. Agric. Food Chem., 51: 3814-3818.

Hao, C.H., L.J. Wang, D. Li, N. Ozkan, D.C. Wang, X.D. Chen and Z.H. Maoa, 2008. Influence of alfalfa powder concentration and granularity on rheological properties of alfalfa-wheat dough. J. Food Engin., 89: 137-141.

Hui, L.L., 1996. Chickpea proteins for food applications. Ph.D. Thesis, Victoria University of Technology, Melbourne, Australia.

ICC., 2001. Standard Methods of the ICC. International Association for Cereal Chemistry, Vienna, Austria.

Letang, C., M. Piau and C. Verdier, 1999. Characterization of wheat flour-water doughs. Part I: Rheometry and microstructure. J. Food Eng., 41: 121-132.

Molina, E., A.B. Defaye and D.A. Ledward, 2002. Soy protein pressure-induced gels. Food Hydrocolloids, 16: 625-632.

Naivikul, O. and B.L. D'Appolonia, 1979. Carbohydrates of legume flours compared with wheat flour. 3. Nonstarchy polysaccharides. Cereal Chem., 56: 45-49.

Park, Y.W., 2007. Rheological characteristics of goat and sheep milk. Small Ruminent Res., 68: 73-87.

Pedersen, L., K. Kaack, M.N. Bergsoe and J. Adler-Nissen, 2004. Rheological properties of biscuit dough from different cultivars and relationship to baking characteristics. J. Cereal Sci., 39: 37-46.

Rasmay, N.M.H., G.A. El-Shatanovi and K.E.W. Hassan, 2000. High-protein macaroni from legume flours and their protein concentrates. J. Ann. Agric. Sci., 45: 555-570.

Rasper, V.F., 1993. Dough Rheology and Physical Testing of Dough. In: Advances in Baking Technology, Kamel, B.S. and C.E. Stauffer (Eds.)., VCH Publishers, New York, USA., pp: 107-129.

SAS., 2004. SAS Online Doc. Version 9.1. SAS Institute Inc., Cary, NC.

Safari-Ardi, M. and N. Phan-Thien, 1998. Stress Relaxation and oscillatory tests to distinguish between doughs prepared from wheat flours of different varietal origin. Cereal Chem., 75: 80-84.

Schwarzel, F.R., 1990. Polymermechanik. Springer, New York.

Sivaramakrishnan, H.P., B. Senge and P.K. Chattopadhyay, 2004. Rheological properties of rice dough for making rice bread. J. Food Eng., 62: 37-45.

Song, Y. and Q. Zheng, 2007. Dynamic rheological properties of wheat flour dough and proteins. Trends Food Sci. Technol., 18: 132-138.

Tanner, I.R., 1986. Engineering Rheology. Oxford University Press, New York.

Wang, N., D.W. Hatcher, R.T. Tyler, R. Toews and E.J. Gawalko, 2010. Effect of cooking on the composition of beans (*Phaseolus vulgaris* L.) and chickpeas (*Cicer arietinum* L.). Food Res. Int., 43: 589-594.

Zhang, T., B. Jiang and Z. Wang, 2007. Gelation properties of chickpea protein isolates. Food Hydrocolloids, 21: 280-286.