Oscillatory and Thermo Rheological Studies of Wheat and Chickpea Flour Blended Doughs for Producing Arabic Flat Bread

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ABSTRACT

Doughs made from blends of white wheat flour and wholegrain wheat flour mixed with chickpea flour were studied rheologically and morphologically in an effort to understand the effect of chickpea flour on the rheology of doughs. The doughs were subjected to a variety of rheological tests to understand how chickpea flour substitution affects wheat dough rheological behavior. Strain sweep, frequency sweep, and temperature sweep tests were carried out. Strain sweep tests show that chickpea flour dough has a significantly strong nonlinear behavior compared to white wheat flour dough and wholegrain wheat flour dough. Frequency sweep tests show the solid like behavior of the doughs. From the theoretical analysis of strain sweep and frequency sweep experimental results, we conclude that up to 10% substitution of chickpea flour to wheat flour does not alter the doughs rheological behavior. Temperature sweep tests show that the chickpea flour dough follows zero-order gelatinization kinetics, whereas white wheat flour dough and wholegrain wheat flour doughs follow first-order gelatinization kinetics.

Keywords: Wheat flour dough: Chickpea flour: Rheology: Diabetes

INTRODUCTION

There is tremendous evidence available now linking diet and non-communicable diseases among the human population. Many nutritionists and health professionals have made dietary recommendations to eat healthy foods for controlling such non-communicable diseases, including certain types of cancer (Alkandari et al. 2019). Various legumes, such as, chickpea, being rich in many health-promoting phytochemicals have been investigated recently (Hamad et al. 2018, Franco et al. 2020, Aldughpassi et al. 2021, Bye et al. 2021). Recently, the food processors have developed many formulations by incorporating legume mixtures to provide health benefits to the consumers (Boye et al. 2010). The well-informed consumers are expected to utilize more of legumes into their dietary patterns to combat various non-communicable diseases (Rondini et al. 2013). Chickpea (*Cicer arietinum* L.) is being commonly consumed in many parts of the world, mainly in the South-East Asia, Middle East, and many African countries. Chickpea (*Besan*) flour is made use of in developing many processed products. Chickpea is not only rich in proteins (25.3-28.9%) but also rich in two essential amino acids, mainly lysine and arginine (however, low in cysteine and methionine, in which wheat is rich) and can improve the nutritional quality of wheat products derived from such blends (Manan et al. 1984, Singh et al. 1988, Hulse 1991, Nasir et al. 2013). Legume grains are reported to contain higher levels of resistant starch (RS) which is known to be poorly digested, thus serving as a dietary fiber (Tharanathan et al. 2003). Legumes are rich in soluble as well as insoluble dietary fiber, mainly the RS, that is known to retain its functionality even after cooking (Rochfort et al. 2007). The benefit of dietary fiber for the prevention of obesity, constipation, heart-related diseases, adult-onset diabetes, and colon cancer is attracting a great interest lately (Duranti 2006).

The adult-onset diabetes has become a serious clinical and public-health concern in the State of Kuwait. In 2008, about 21.4% of the population was suffering from type-2 diabetes and this is predicted to go up to double by the year 2025 (Badran et al. 2012). The expenses on treating diabetic patients in Kuwait is 374 million US$ and is expected to be 924 million US$ in 2030. The reasons for this increase in the incidence of diabetes may be due to genetics, obesity, sedentary lifestyle, and unhealthy eating habits. Compared with the cereal grain starch, the digestibility of legume starch is much less, its use in developing food products based on cereal-legume mixtures can be employed for correcting the abnormal sugar spikes in the blood of consumers of such foods (Zafar et al. 2020).

Bread dough rheology is a subject of intense investigation due to its rich rheological behavior. It is established that dough is composed of a network of hydrated proteins: gluten and gliadin and intermeshed within the network are water-swollen starch granules. The protein network gives the dough most of its rheological characteristics, while water acts as a solvent and the starch granules act as modulus modifiers, increasing the modulus as their percentage increases. The protein network and starch granules make a gel-like structure, and as such, the linear rheology of dough is well described by the critical gel model, also called the power law model (Ng et al. 2008, Tanner et al. 2008, Amirkaveei et al. 2009, Tanner et al. 2011). The simplicity of the power-law model allows for an easy characterization of the dough linear rheology through two main parameters: the gel strength and gel exponent. Moreover, the thermo-rheological behavior of dough was investigated previously (Ahmed et al. 2013, Dolores Alvarez et al. 2014, Dolores Alvarez et al. 2016, Dolores Alvarez et al. 2017, Xu et al. 2017). The study of the non-isothermal kinetics of dough is considered a good technique for elucidating gelatinization and protein denaturing. Zero, first and second gelatinization kinetics orders have been reported in the literature for different types of bread doughs by the studies mentioned above. There are no previously conducted rheological studies that targeted the effect of chickpea flour substitution on the rheology of doughs.

The major objective of the current study is to evaluate the rheological characteristics of wheat and chickpea flour doughs with a view to provide information that could be useful for producing wheat-chickpea flour based-baked products (pan bread and Arabic flat bread) that would offer better choices to the diabetic persons for eating healthy foods. This paper shows the rheology of mixed chickpea-wheat flour bread doughs. We have carried out extensive modeling of the rheological results through various concepts and theories. Through modeling, we have tried to establish relationships between dough composition and dough rheological behavior.

MATERIALS AND METHODS

Materials

Chickpea flour (BF) was obtained from the local Kuwaiti market. The wholegrain wheat flour (WWF) and white flour (WF) for this study were obtained from the Kuwait Flour Mills & Bakeries Company.

Flour Blends

WWF and WF were substituted by BF at the levels of 10%, 20%, 30%, and 40%. The WWF, WF and BF were dry free flowing powders, and were mixed by tumbling in a steel container. These blended samples were then sifted thru a 10XX sieve to obtain a uniform mixture. The farinograph water absorption values (FWA) for these flours and their blends were determined as per the standard AACC Method No. 54-21 (AACC International, 2010).

Dough Preparation

Ten g of WWF, WF, BF or their blend was mixed using the water absorptions given in the Results Section to the optimum dough development time (reaching a maximum peak height) as per AACC Method 54-40A with a 10 g mixograph (National Manufacturing Co. Lincoln, Nebraska, USA, Model 10 g mixing bowl). The time of mixing is variable from 3 to 4 minutes depending on the type of flour or blend of flours.

Scanning Electron Microscope (SEM) Studies

The microstructure of WWF, WF, BF and 35% BF substituted dough samples were examined through a scanning electron microscope (SEM) (JEOL, JSM-5410LV, Tokyo, Japan). The flour samples were measured directly in the powder form whereas the BF substituted dough was first freeze-dried, then powdered before the SEM measurements were taken. Each sample was coated with gold in a sputter coater (Structure Probe, West Chester, PA) before being scanned and photographed at different magnifications.

Oscillatory Rheological Measurements

All Oscillatory rheological measurements of WWF, WF, BF, and blended doughs made with 10 to 40% substitution of wheat flour with chickpea flour were carried out using ARES G2 rheometer (TA instruments, New Castle, DE, USA). The ARES G2 is a strain-controlled rheometer having a so-called force rebalance transducer. Such transducer is capable of measuring torque values ranging from 0.05 µN.m to 200 µN.m. The rheometer is also equipped with a high-resolution motor, which can generate and control angular frequencies from 1 x 10^{-7} to 628 rad/sec. Dough samples were prepared by mixing required volume of distilled water to wheat flour and chickpea flour blends according to AACC method (2010) using 10g mixograph (National Manufacturing Co., Lincoln, Nebraska, USA).

Samples were placed in a 2 mm gap between two stainless steel parallel plates (plate diameter 25 mm). The sample perimeter was coated with a thin layer of high temperature resistant silicon oil in order to prevent sample dehydration. The temperature of the sample was maintained as desired using a forced convection oven (FCO) capable of measuring temperatures ranging from -150° C to 600° C.

Dough is a complex material, and as such it exhibits both viscous and elastic (viscoelastic) behaviors. At relatively small (large) strain values, complex materials exhibit linear (nonlinear) behavior. For more details regarding the linear and nonlinear viscoelastic behaviors of materials, please refer to Macosko (1994). In this work, strain sweep tests were conducted for finding the linear viscoelastic region (LVR). The LVR was tested at strain values ranging from 0.01 to 10% at 30° C and at frequency of 1 Hz to ensure that frequency sweep and temperature sweep tests are carried out within the linear viscoelastic regime. We found that a strain value of 0.03% is small enough to be in the LVR and large enough to have a significant stress signal in the frequency range to be tested in the frequency sweep tests. The tests were repeated 3 times for each sample.

Frequency sweep experiments were performed, and elastic (G') and loss (G'') shear moduli were obtained at 30 °C. Frequency sweep tests (from 100 to 0.1 rad/ sec) were carried out in the linear viscoelastic regime at a constant strain of 0.03% at 30 °C, and were repeated 3 times for each sample.

The temperature ramp tests were performed from 30 °C to 95 °C with 1.5 °C / min ramp rate, with 0.03% strain and angular frequency of 1 Hz. In the second step, temperature ramp tests were performed from 95° C to 50° C, with the same parameters mentioned above. The test was repeated 3 times for each sample.

THEORETICAL BACKGROUND

Viscoelastic Behavior

We use the critical gel model to describe the linear viscoelastic behavior of the dough. In the frequency domain, the storage and loss moduli can be described by the following equations (Ng et al. 2008, Tanner et al. 2008, Tanner et al. 2011):

$$G'(\omega) = G'(1)\,\omega^{p} \quad (1)$$

and

$$G''(\omega) = \tan\delta\ G'(\omega) = \tan\left(p\frac{\pi}{2}\right)\ G'(\omega), \quad (2)$$

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where ω is frequency, p is power and $G'(1)$ is the numerical value of the storage modulus at a frequency of 1 rad/s. and δ is the phase angle. The above description suffices for describing the linear viscoelastic behavior of dough using only two parameters.

For large amplitude oscillatory shear, we use the model provided by Phan-Thien et al. (2000):

$$\sigma_{12} = f\left[\sum_{j=1}^{N} \frac{\gamma_0\,\omega\,\lambda_j\,g_j}{1+\,\omega^2\lambda_j^2}\left(\cos\omega t - e^{\frac{t}{\lambda_j}} + \omega\lambda_j \sin\omega t\right)\right], \tag{3}$$

where f is the damage function, σ_{12} is shear stress, γ_0 is strain amplitude, λ_j is relaxation time of the j^{th} mode, g_j is the modulus of the j^{th} mode, N is the number of relaxation modes and t is time. In this work, we use a damage function that is dependent on strain and time (Almusallam et al. 2016).

$$\frac{df}{dt} = \frac{-|\gamma| f}{\lambda_{dest}} + \frac{1-f}{\lambda_{create}}, \tag{4}$$

where γ is strain, λ_{dest} is network characteristic destruction time and λ_{create} is network characteristic creation time.

Non-Isothermal Gelatinization Kinetics

Gelatinization kinetics can be modeled in a similar way to reaction kinetics (Ahmed et al. 2013):

$$\pm\frac{dG'}{dT} = HR \cdot G'^{q} k_0 \exp\left(-\frac{E_a}{RT}\right), \tag{5}$$

where q is order of gelatinization kinetics, k_0 is gelatinization rate constant at the reference temperature, R is the gas constant, T is temperature and E_a is the activation energy. Note the ± sign on the left-hand side of Equation (5). This is so to enable the modeling of the upward gelatinization curve using (+) sign and the downward gelatinization curve using $(-)$ sign. $HR = \frac{dT}{dt}$ is the heating rate. We solve Equation (5) using the Runge-Kutta method.

RESULTS AND DISCUSSION

Dough Characterization

The proximate composition of flours was determined by the AACC methods and reported on % dry basis (International 2010) in Table 1. The substitution of wheat flour by chickpea flour necessitated the adjustment of water content during the mixing procedure. Table 2 shows the water content required for making doughs composed of wheat flour and chickpea flour.

Proximate Composition	WWF	WF	BF
Moisture content, %	10.58	10.54	7.61
Crude protein, %	13.3	15.20	26.99
Crude Lipids, %	4.52	2.94	7.15
Ash, %	1.28	0.64	2.47

Table 1. proximate composition of wholegrain, wheat and chickpea flours

Replacement level by BF	White flour (WF) water absorption, %	Whole wheat flour (WWF) water absorption, %
100:0 (no BF)	60.3	68.3
90:10	61.0	66.1
80:20	61.4	66.0
70:30	60.5	64.2
60:40	58.3	61.3

Table 2. Water absorption of flour

Significant quantities of glycoproteins have been reported to accumulate if the plants suffer from water stress during their period of growth (Zadražnik et al. 2017). As the BF levels for wheat flour substitution increased, the dilution effect of wheat gluten proteins becomes a dominant factor for the lower FWA values and affecting other dough characteristics.

Scanning Electron Micrographs

The scanning electron micrographs of WF, WWF, BF raw flours, their individual doughs, and 60:40 ratio blended doughs are presented in Figures Figure to Figure , respectively. These micrographs show the morphological characteristics of particles of wheat flour, chickpea flour, as well as the development of continuous sheet-like structures covering the starch granules after dough making. As reported recently by Zafar et al. (2020), the WWF particle size distribution showed the widest spread with a polydispersity index (PDI) of 1.0 (±0.0), WF with PDI of 0.740 (±0.04) and BF with PDI of 0.388 (±0.07) ($p<0.05$). The BF showed a lot of protein bodies and protein wedge-like structures (subfigures Figure -e and -f). The reason for higher number of protein bodies in BF is its higher protein content of about 27% compared to about 13-15% in wheat flour. The white flour obtained from hard wheat cultivar used in this study, produced a granular flour with intact particles (subfigures Figure -a and -b). A few of the bran particles can also be seen in the WWF scanning electron micrograph (subfigures Figure -b and -c).

When these flours were made into respective doughs using optimal amounts of plain distilled water, a strong protein sheet-like structure was developed in white flour dough (subfigures

Figure -a and -b), but the starch granules maintained their morphological identities as no heating was involved to disrupt the granular structures. Heating of dough during baking is known to gelatinize all of these starch granules leading to the development of a continuous matrix of gelatinized starch (Sidhu et al. 1990, Sidhu et al. 1997). In case of wholegrain wheat flour dough, a few of the intact bran particles could also be seen (subfigures

Figure -c and -d). The wholegrain wheat flour particle size is reported to influence not only the dough properties and bread crumb structure but also the starch gelatinization (Lin et al. 2020). Because of a much higher amount of protein present in the chickpea flour (BF), a continuous sheet-like structure was developed during dough making that had coated all the starch granules of chickpea flour (subfigures

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Figure -e and -f).

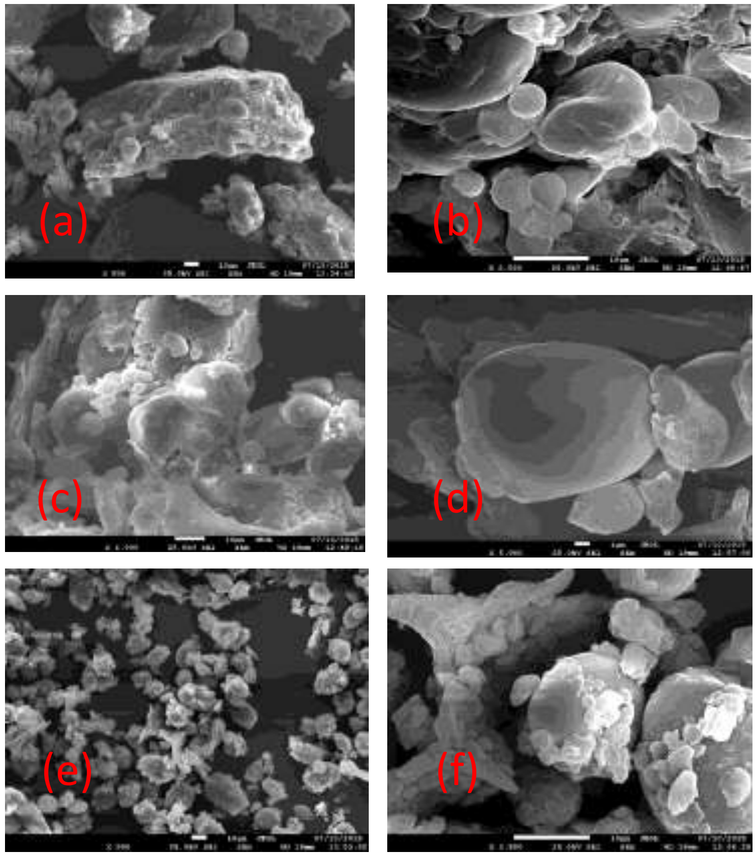

Figure 1.SEM of white wheat flour, whole wheat flour and chickpea flour. [Parts (a) and (b): white flour; parts (c) and (d): whole wheat flour; parts (e) and (f): chickpea flour].

In this study, when flour blends were prepared in the ratio of 60:40 using wheat flour and chickpea flour, a very interesting feature was observed in the scanning electron micrographs (Figure). As the chickpea flour is reported to be very rich in protein content which upon mixing into a dough, develops a sheet-like structure that covers most of the starch granules, as shown in Figure . Some of the protein bodies could still be seen as intact in the higher magnifications.

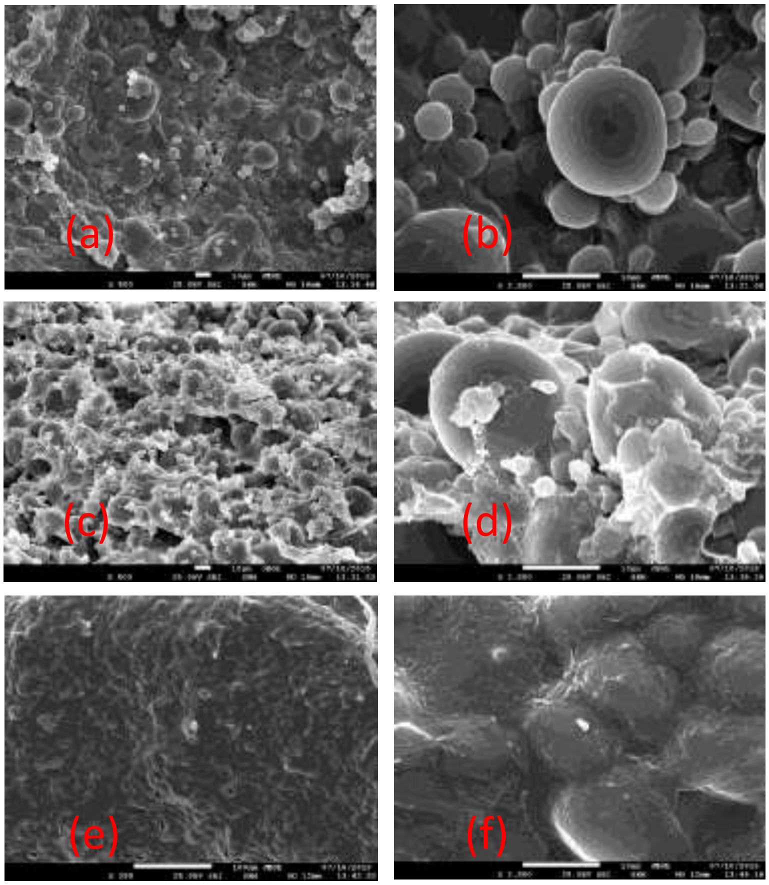

Figure 2. SEM of white wheat flour, whole wheat flour and chickpea flour dough samples. [Parts (a) and (b): white flour dough; parts (c) and (d): wholegrain wheat flour dough; parts (e) and (f): chickpea flour dough].

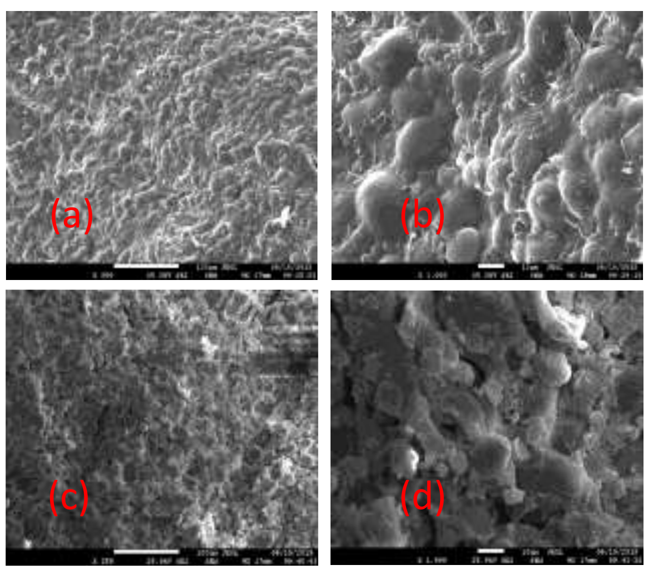

Figure 3. SEM of samples of wheat flour and chickpea flour blended doughs. [Parts (a) and (b): WF-BF with 60:40 blends; parts (c) and (d): WWF-BF with 60:40 blends].

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Rheology results

Strain Sweep Results

Figure Figure (a to c) shows the storage modulus vs. strain for the pure flour doughs, the chickpea — wheat flour dough blends, and the chickpea — wholegrain wheat flour dough blends, respectively. A strain sweep test spans the linear and non-linear rheological regimes. As such, it is more difficult to model than the frequency sweep test. Our approach in modeling the strain sweep tests is to combine the linear viscoelastic Maxwell model with a nonlinear damage function as in the approach of Phan-Thien et al. (2000). The power law model can be converted into a discrete relaxation spectrum using an approach provided by Tanner et al. (2011).

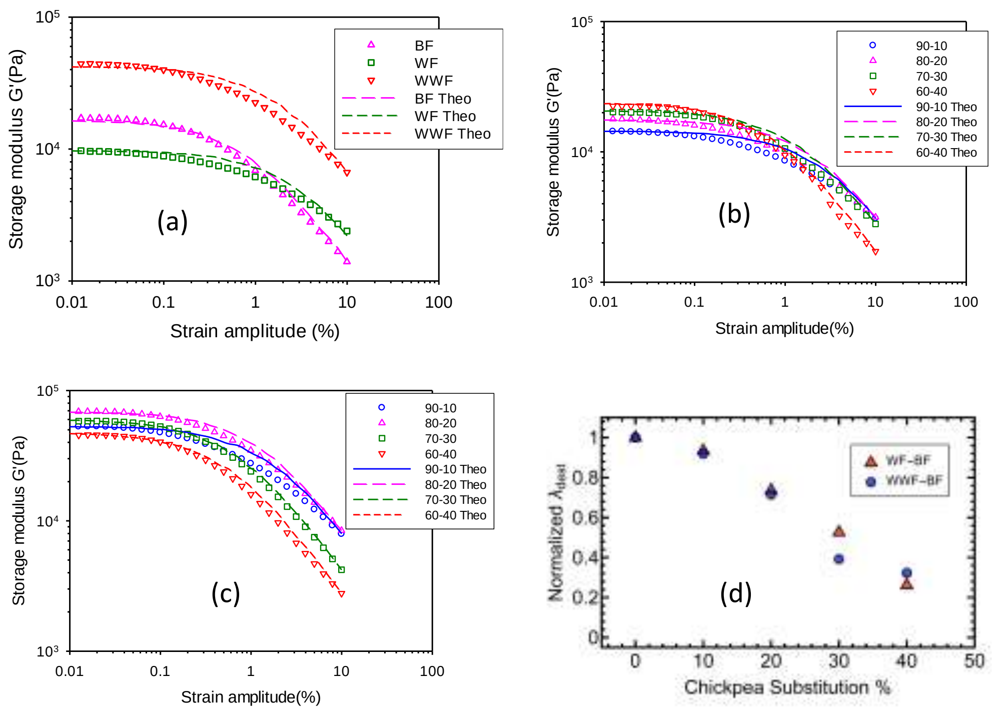

Figure 4. Storage modulus results for strain sweep tests of (a) pure dough samples, (b) chickpea flour - white flour blended doughs and (c) chickpea flour - wholegrain wheat flour blended doughs. Lines refer to theoretical fits. Part (d) shows the normalized network destruction time as a function of the substitution percent of chickpea flour. Triangles display data for chickpea flour - white flour blended dough, while circles display data for chickpea flour - wholegrain flour blended dough.

Furthermore, $G'(1)$ in the power law model was adjusted so that the G' predictions at low strain match the experimental data of strain sweep at low strain. λ_{create} was chosen so that the network returns from a damage function value of $f = 0.1$ to $f = 1$ at rest in 1 minute. By using this condition, it was then found that λ_{create} = 20.76 s^{-1}. This value is used in all the flour samples we analyzed. Thus, there is an assumption that network creation is independent of dough composition, while network destruction rate depends on dough composition. We determine λ_{dest} by matching the theoretical predictions of the normalized G' to its experimental counterpart at 10% strain. This is a little crude, but the procedure captures the strain sweep behavior of G' very well. By fixing the value of λ_{create} and allowing λ_{dest} to be used as a fitting parameter, we can evaluate the nonlinearity of the dough using a single parameter. The smaller the value of λ_{dest}, the faster the destruction rate and the more severe is the decrease in value of G' compared to its small strain value. We saw in the results of the pure dough samples that the most nonlinear behavior was of BF, followed by WWF and then WF. Thus, we can safely say that BF dough showed a very nonlinear behavior compared to wheat flour or wholegrain wheat flour doughs. This is attributable to the higher protein content in BF compared to WF and WWF. Bonilla et al. (2020) noticed that larger nonlinearity in the shear modulus-strain amplitude curves was observed for doughs made from wheat flour types that contain higher gliadin to glutenin ratio. Therefore, the presence of gliadin and/or any protein other than glutenin imparts strain softening characteristics to the dough.

If we attribute glutenin to the stretchiness of dough, then we must conclude that the addition of a substantial amount of chickpea flour alters the stretchiness characteristics of the dough. To explore this point in more details, we plot in Figure -d λ_{dest} of the blended dough normalized by λ_{dest} of the respective unblended wheat flour dough as a function of chickpea flour percent. The two blend groups: white flour - chickpea flour and wholegrain wheat flour - chickpea flour blended doughs displayed the same decay in the normalized λ_{dest} values as chickpea flour percent is increased. Moreover, we notice a very minor reduction in the values of the normalized λ_{dest} for chickpea content less than 10%. At larger chickpea content, the reduction of the normalized λ_{dest} values becomes significant. Hence, we conclude that a chickpea flour substitution of up to 10% causes a minor change in dough stretchiness. A substitution higher than 10% requires supplementing the dough with gluten to make good quality bread.

Linear Viscoelastic Behavior

The data in Figure shows the frequency sweep results for storage and loss moduli of white, wholegrain wheat and chickpea flour doughs and the blended doughs. The figure also shows fits of the data using the power law model. The figure shows that the values of G' are larger than G'', illustrating the elastic nature of the pure dough samples. The fits to the power law model capture the trend of the data, though are not exact fits. Subfigures Figure -c and d show G' and G'' for the blended doughs composed of white flour-chickpea flour, while subfigures Figure -e and f show G' and G'' for the blended doughs composed of wholegrain wheat flour-chickpea flour. The storage modulus of white flour — chickpea flour blended dough shows that the higher the amount of chickpea flour in the blend, the higher was the storage modulus value. On the other hand, for wholegrain wheat flour — chickpea flour blended doughs, the smallest storage modulus values were observed for blends with the largest amount of chickpea flour in the blends. This behavior can be explained by the moduli of the pure dough samples. We note that WWF dough has the highest storage and loss moduli. On the other hand, BF and WF doughs have remarkably similar elastic and loss modulus values, with BF dough having moduli that are only marginally larger than those of WF dough. Thus, the dilution of WWF with BF will make the resulting blend weaker, while the dilution of WF with BF will make it marginally stronger.

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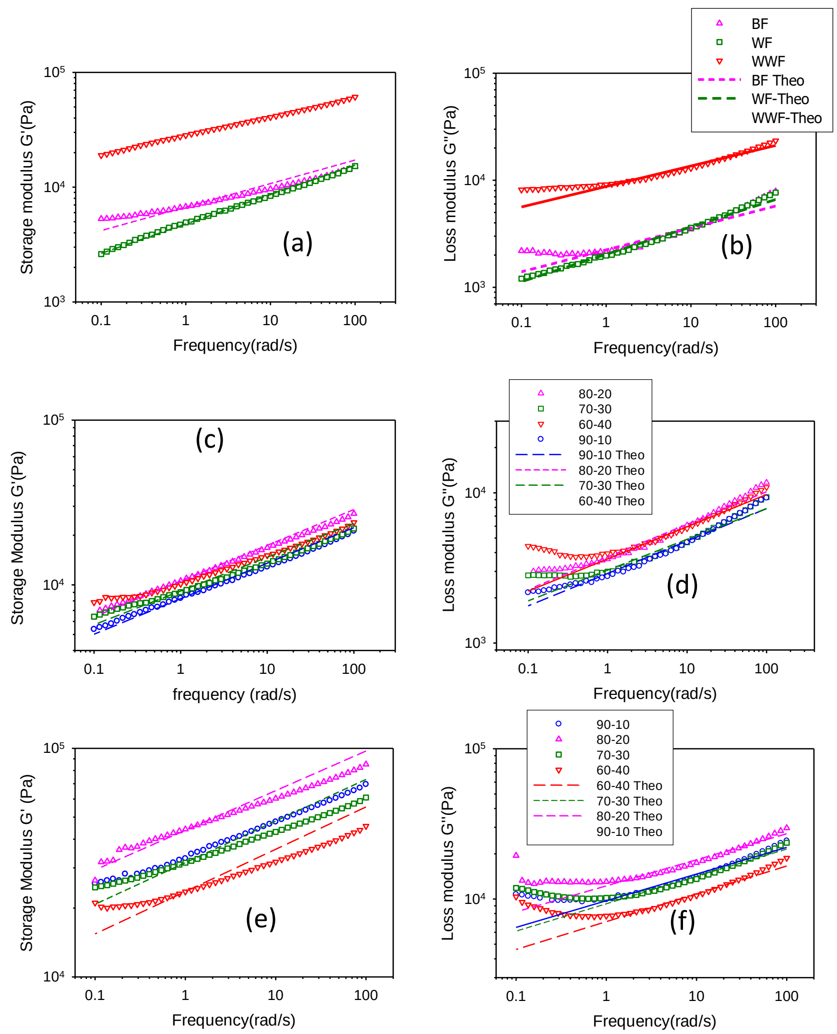

Figure 5. Storage modulus (first column) and loss modulus (second column) during linear viscoelastic response for pure dough samples (first row), chickpea flour - white flour blended dough (second row) and chickpea flour - wholegrain flour blended dough (third row). Lines refer to theoretical fits.

The fitting parameters $G'(1)$ and p were obtained using the nonlinear optimization routine SOLVER on Microsoft Excel. Disagreements between the power law model and the experimental modulus results are always at the low and high frequency limits of the frequency sweep curves. $G'(1)$ exemplifies the dough strength, while p exemplifies its gel nature. It is known that p value is 2 for liquids and 0 for gels. The highest p value for pure dough samples was that of WF dough (0.256). The chickpea-white flour blended doughs also showed relatively high p values (all are above 0.2) compared to p values for chickpea-wholegrain wheat flour blended doughs (all are below 0.2). This could be explained by the fact that white flour has higher quantity of gluten proteins as well as better strength of gluten than the wholegrain wheat flour due to the dilution effect of the extra bran particles present in it. Values of the gel exponent are similar to those reported in the literature for doughs. For example, Jasim et al. (2013) obtained a p value of 0.32 for white flour dough, compared to 0.14 for 10% date-fiber substituted dough. Amirkaveei et al. (2009) obtained p values for different commercial wheat flours, ranging from 0.27 to 0.38. Scepanovic et al. (2018) obtained a p value of 0.25 and $G'(1)$ of 14.1 kPa for commercial wheat flour.

Sample Name	$G'(1)$ (Pa)	p	λ_{dest} (s)
BF	6702.54	0.205	0.117
WF	4775.94	0.256	0.380
WWF	28172.62	0.192	0.245
BF-WF-10%	8240.62	0.216	0.355
BF-WF-20%	10544.27	0.217	0.280
BF-WF-30%	9175.63	0.205	0.200
BF-WF-40%	10376.69	0.214	0.099
BF-WWF-10%	34026.35	0.178	0.225
BF-WWF-20%	43805.41	0.173	0.175
BF-WWF-30%	31616.10	0.182	0.096
BF-WWF-40%	23618.91	0.185	0.079

Table 3. Parameters characterizing flour samples oscillatory behavior.

Temperature Sweep Results

Figure shows results for temperature sweep experiments for chickpea flour dough (part a) and white and wholegrain wheat flour doughs (part b). Chickpea flour dough showed minor hysteresis. This implies that there is only little to minor denaturation of the chickpea protein in this temperature range. In fact, it is clear from the temperature sweep curve of BF dough that the maximum in the forward temperature sweeps was reached at temperatures close to 95 °C.

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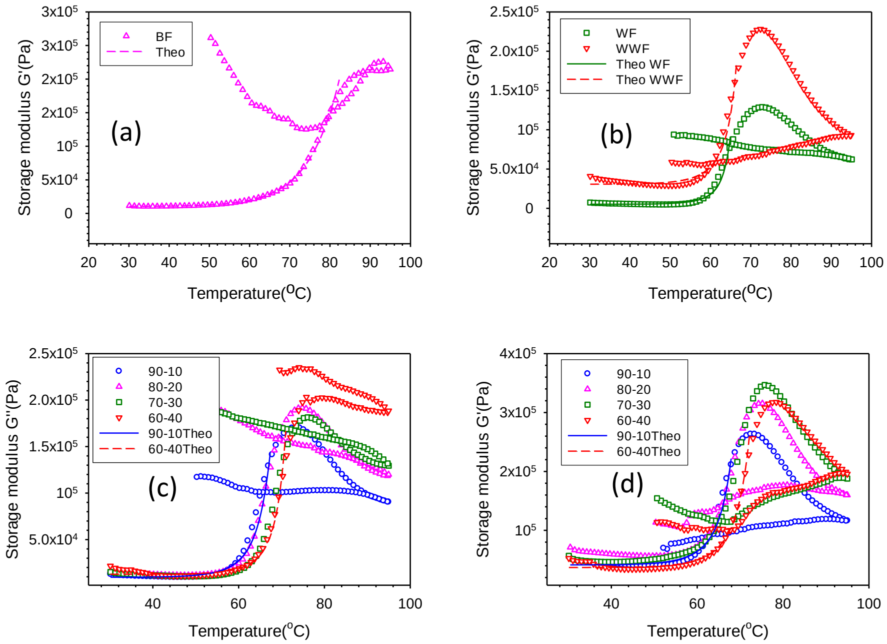

Figure 6. Plots of storage modulus vs. temperature for chickpea (a) and white and wholegrain flour samples (b), chickpea-white flour blended dough (c) and chickpea wholegrain flour blended dough (d). Lines refer to theoretical fits.

We contrast the chickpea flour dough behavior with the behavior of the wheat flour dough and the wholegrain wheat flour dough, where a maximum in the forward temperature sweep is clearly present, and a decrease in modulus value after the maximum is clear (c.f. Figure -b). The backward temperature sweep curves do not show any resemblance to the forward sweep curves, implying a total change in microstructure after the maximum in the forward temperature sweep has been reached. Gelatinization of the WF and WWF flour doughs is more pronounced than chickpea flour dough, as is clear from subfigures Figure -a and Figure -b. This is perhaps due to the presence of more gluten content in the WF and WWF than there is in the chickpea flour. The blended chickpea-white flour doughs and the blended chickpea-wholegrain flour doughs show a shift of the upward curve to higher temperature as we increase chickpea flour content as well as an increase in value of the maximum in the forward temperature sweep curves. (c.f. subfigures Figure -c and Figure -d). Both behaviors are expected as the upward curve is slower in chickpea dough than it is in white and wholegrain. We use Equation (5) to fit the upward part of the gelatinization kinetics curves, using q, k_0 and E_a as adjustable parameters. The best fitting parameters were found using the least squares method, and the command 'fminsearch' in MATLAB was used to obtain those parameters. R-squared values are shown in Table 4, and derivatives of the experimental G' data with respect to temperature were checked against the model prediction derivatives to ascertain consistency. The values of the gelatinization kinetics order for the WF and WWF doughs and their blended doughs are all above 0.5, and most are close to a value of 1, compared to the gelatinization kinetics order for the chickpea flour dough where it is very close to 0. Interestingly, zero gelatinization kinetics order was also reported by Alvarez et al. (Dolores Alvarez et al. 2016, Dolores Alvarez et al. 2017) for chickpea flour batter and slurry.

	Upward Gelatinization Curve			
Sample Name	k_o (Pa $^{1-n}$ s^{-1})	E_a (J/s)	q	2

BF	4.007E+19	1.185E+05	1.165E-01	.93
WF	5.209E+22	1.582E+05	9.610E-01	.0
WWF	3.973E+21	1.582E+05	1.128E+00	.98
BF-WF-10%	5.105E+22	1.514E+05	6.900E-01	.97
BF-WF-20%	1.907E+24	1.655E+05	8.165E-01	.97
BF-WF-30%	8.474E+21	1.533E+05	8.767E-01	.97
BF-WF-40%	1.416E+23	1.630E+05	9.247E-01	.92
BF-WWF-10%	8.245E+22	1.605E+05	9.065E-01	.95
BF-WWF-20%	4.047E+23	1.611E+05	7.542E-01	.97
BF-WWF-30%	3.640E+22	1.471E+05	5.298E-01	.0
BF-WWF-40%	1.539E+21	1.502E+05	8.844E-01	.95

Table 4. Parameters characterizing temperature sweep data

CONCLUSIONS

The data presented here showed clearly that when white flour and wholegrain wheat flour were substituted with chickpea flour at levels ranging from 0 to 40%, the rheological characteristics and dough functionality were significantly affected. The presence of chickpea flour lowers the storage modulus for wholegrain - chickpea flour blended doughs, while it slightly increases the storage modulus for white - chickpea flour blended doughs. On the other hand, strain softening increases with increasing chickpea content, which shows that chickpea substitution needs to be kept at low percent to avoid a drastic change to dough stretchiness characteristics. The temperature ramp experiments revealed that the gelatinization followed 1st order gelatinization kinetics for wheat flour dough and zero-order for chickpea flour dough. Moreover, gelatinization was found to be irreversible for wheat flour dough and reversible for chickpea flour dough, implying that chickpea flour dough takes longer time to cook than wholewheat flour dough.

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