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ORIGINAL RESEARCH PAPER

RHEOLOGICAL BEHAVIOR OF INDIAN TRADITIONAL FERMENTED WHEAT BATTERS USED FOR PREPARATION OF KURDI AND SEERA

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Traditional Indian cereal based fermented food products like *Kurdi* (Maharashtra) and *Seera* (Himachal Pradesh) are prepared from batter of fermented wheat grains. These wheat batters were prepared by soaking wheat grains (*Triticum Astivum L.*, variety: PBN51) in water at different temperatures (30, 37.5 and 45°C) for four days (natural fermentation), crushed, centrifuged and characterized for rheological properties. The present study was aimed to test the effect of soaking temperature (during natural fermentation of wheat grains) on the rheological behavior of wheat batter. It was determined that viscosity and yield stress of the wheat batter decreased with increase in soaking temperature of natural fermentation. Yield stress decreased by 65% and 82% for wheat grains soaked at 37.5°C and 45°C, respectively as compared to those soaked at 30°C. This was attributed to the degradation of the carbohydrates by the natural flora of microorganisms. Increasing the soaking temperature during natural fermentation decreased the fluid consistency index and increased the flow behavior index of the batter, demonstrating a lower viscosity and increased fluidity. All the samples revealed shear thinning behavior. Gelatinization temperature of the wheat batter decreased with increase in soaking temperature as demonstrated by viscoelastic analysis (loss modulus, storage modulus, Tan δ) of the samples.

Keywords: Kurdi, viscoelastic properties, flow behaviour, soaking temperature

Introduction

Fermentation is a well-known method used for preserving the foods and beverages. It has been practiced for over thousands of years by the primitive people (Borgstorm, 1968). It is a procedure used for preparing consumable food products by the utilization of various microorganisms (Wood, 1998). Fermented foods prepared from cereals are one of the important parts of the diet of many people. The preparation of cereal based traditional fermented food products remains a household art even today. They are prepared by using relatively simple procedures and equipments (Battcock and Azam-ali, 1998; Sankaran, 1998; Aidoo, *et al*. 2006). Fermented foods, prepared from cereals, like *idli*, *dosa*, *jalebies*, *kurdi*, *seera*, *bhaati jaanr*, *kodo ko jaanr* etc, have been a part of Indian traditional food (Thakur *et al.*, 2004; Beuchat, 1983; Soni *et al.*, 1985; Batra, 1986; Tamang and Thapa, 2006; Thapa and Tamang, 2004). Fermented foods are receiving world-wide consideration due to their health encouraging effects. Enhancement of flavor, manifestation, nutritional worth and storage stability with reduction in cooking time are the additional benefits of fermented foods. They also offer variety in the diet (Tamang *et al.*, 1988). Even though, cereal and legume based fermented foods like *idli*, *dosa*, *dhokla*, *khaman*, *wadi*, *papad* and *kinema*, from various parts of India, have been well studied and recognized, there are no records of similar foods (*kurdi* and *seera*) widly spread in the state of Maharashtra, India (Nout and Sarkar, 1999; Nout *et al*., 2006).

Kurdi is a customary cereal starch based fermented food prepared by soaking, crushing and fermenting wheat grains (Thakur *et al.*, 2004), which is subsequently thermally gelatinized, hand extruded and dried (Beuchat, 1983). Preparation of *kurdi* is an art passed from mother to daughter without any written documentation. *Kurdi* is known as a ceremonial food, having special significance to the village people of Maharashtra, India. It is largely consumed on special occasions such as marriage, religious and cultural festivals. A similar type of food named *Seera*, also called *Nishasta*, had been prepared in Himachal Pradesh, India (Thakur *et al.*, 2004). Both *kurdi* and *seera* are prepared by the process of natural fermentation of starch extracted from wheat by removing the wheat whole bran. However, *kurdi* is an hand extruded product, whereas, *seera* is a sweet dish.

Knowledge of the rheological behavior of this fermented food dispersions is crucial for quality control, product development; sensory evaluation, process design, consistency and for process scale up. Several studies have reported the visco-elastic properties of flour batter (Hsia *et al.*, 1992; Sanz *et al.*, 2005) and dough (Uthayakumaran *et al.*, 2002; Izydorczyk, 2001; Campos, 1997; Lazaridou *et al.*, 2007). Rheological properties are amongst the most important physical properties defining the behavior of wheat batter used for preparing *kurdi*. These flow properties directly influence the flow behavior of the thermally gelatinized wheat batter extruded through a manual hand extruder. However, there is no comprehensive information on the rheological behavior of these wheat batters prepared from fermented wheat grains. Present research was aimed to investigate rheological behavior of some fermented wheat batters.

Materials and Methods

Materials

Commercial wheat grains (*Triticum Astivum L.*, variety: PBN51) were procured from Wheat Research Station, Vasantrao Naik Marathwada Agricultural

University, Parbhani, Maharashtra, India. Proximate composition of wheat grains, determined as per AOAC (1980), is listed in Table 1.

Table 1. Proximate composition of wheat grains (variety: PBN51)

Sr. No.	Constituent (%)	Mean ± S.D.
1.	Moisture	8.8 ± 0.3
2.	Fat	2.5 ± 0.2
3.	Protein*	11.5 ± 0.5
4.	Ash Content	1.5 ± 0.2
5.	Crude Fibre Content	1 ± 0.2
6.	Carbohydrates by difference	74.7 ± 0.9

* Calculated as N x 6.25.

Preparation of wheat batters from fermented wheat grains

150 g wheat grains (variety: PBN51) were soaked in 450 ml water and incubated at different temperatures - 30, 37.5 and 45 °C, for fermentation to take place. Water was replaced after every 6 h in order to get fresh microbial growth, which helps to have better natural fermentation of the wheat grains. Water was removed on the fourth day and the obtained softened wheat grains were crushed using a grinder (Anjalis grinder, Mumbai, India) at 2500 rpm for 30 s. Brans (i.e. bran and germ) were separated by filtering with a muslin cloth. The resulting filtrate was centrifuged (Remi Compufuge, Mumbai, India) at 3000 rpm for 10 min, settling down the carbohydrates. Supernatant was disposed of and the sedimented residue (i.e. wheat batter) was analyzed for rheological properties. Mentioned methodology of preparing wheat batter is largely used to prepare traditional Indian fermented food products named *Seera* (also called *Nishasta)* (Thakur *et al.*, 2004) in Himachal Pradesh and *Kurdi* (Beuchat, 1983) in Maharashtra, India. Prepared samples were allowed to equilibrate for 1 h before rheological characterization.

Rheological characterization of wheat batters prepared from fermented wheat grains

Rheometer (MCR 101, Anton Paar, Austria) with a parallel plate assembly was used to investigate the rheological behavior of the prepared wheat batters. Parallel plates (diameter: 25 mm, D-PP25-SN0) were separated by a distance of 0.5 mm during the rheological testing. The recorded data were analyzed using Rheoplus/32V3.40 software, supplied by the manufacturer. A temperature of 30±0.5°C was maintained constant during the rheological testing using a Peltier system. In the conditioning step, an equilibration time of 3 minutes was set. Twenty five shear stress/shear rate data points were obtained, at 6 points/decade, during the shearing of the samples from 0.01 s^{-1} up to a shear rate of 100 s^{-1}. Test was performed in the experimental time of 200 s (Bhattacharya & Bhat, 1997). The whole process of sample preparation was repeated in triplicate, while all rheological investigations were performed in duplicate samples.

A non-Newtonian fluid model (Equation 1) was used to estimate the flow properties of the samples. (Chen *et al*., 2008)

$\sigma = k * \gamma'^{n} + c$ Equation (1)

where,

σ = shear-stress,

k = fluid consistency index,

γ' = shear-rate,

n = flow behavior index,

c = yield stress.

Suitability of the non-Newtonian fluid model was judged by determining the root-mean-square (rms) error (Equation 2):

$$\text{rms error} = \sqrt{\frac{\sum_{n=1}^{N}\left(W_{experimental} - W_{calculated}{}^{2}\right)}{N}} \times 100 \qquad \text{Equation (2)}$$

where, N is the number of data points and W indicates shear-stress.

A strain sweep step was performed in order to determine the linear viscoelastic range. The critical strain of samples was determined to be near 5%. A temperature sweep step was then applied where the oscillation frequency was set at 1 Hz and a strain of 1 % was imposed. The temperature sweeps involved heating at a rate of 2°C/min from 30 to 80°C. Duplicate scans were performed, and the storage modulus (G'), loss modulus (G") and Tan δ (ratio of loss modulus to storage modulus, G"/G') were recorded.

Statistical analysis

Statistical analysis on the data was performed using a method developed by SAS Institute Inc. (1993). When analysis of variance (ANOVA) revealed a significant effect ($p < 0.05$), data means were compared using a least significant difference (LSD) test.

Results and discussion

Determination of the rheological behavior of fermented wheat batter

Figures 1, 2 and 3 present the plot of shear stress vs shear rate, viscosity vs shear rate and yield stress vs soaking temperature, respectively, obtained for the fermented wheat batter samples. It was determined that yield stress, shear stress and viscosity decreased with increase in soaking temperature. Also, it can be seen that viscosity decreased with increase in shear rate. This behavior was consistent in all the batter samples. Thus, all the batter samples demonstrated shear-thinning behavior (Yu, 2013). The error in repeatability of test was between 5 and 10% for all the analyzed samples.

Wheat grains consists of about 75% carbohydrates, forming its major component. Due to the soaking of wheat grains, the bran of the grain gets loosened up, making the carbohydrates easily available to the natural bacterial flora, which composition is unknown for this type of fermentation method (Singhal, 2005). They could be any of these types: bacteria like *P. pentosaceus*, *P. acidilactici*, *Pediococcus sp*., *Lactobacillus sp*., or/and fungi like *R. oligosporus*, *A. oryzae*, *S. rouxii*, *S. cerevisiae* (Singhal, 2005; Knorr, 1998; Hui and Khachatourians, 1993; Hoover and Steepson, 1993; Boskov-Hansen *et al*., 2002). These microorganisms hydrolyzes the 1,4-α and/or 1,6-α linkages of the carbohydrates, resulting in reducing sugars. This way, high molecular weight carbohydrates are converted into low molecular weight reducing sugars (Fellows, 2000). Also, the acids produced during fermentation, lowers the pH of the batter, increasing the activity of microorganisms, accelerating the conversion (Fox and Mulvihill, 1982). High molecular weight carbohydrates imparts more resistance on the rotating spindle of the rheometer, due to the entangled structural arrangement, increasing the viscosity and yield stress. However, the degradation of carbohydrates to reducing sugars reduces the number of structural entanglements in the wheat batter. Thus, reducing the intensity of resistance imparted by it on the rheometer spindle, decreases the viscosity and yield stress (Cooper-White and Mackay, 1999). Increasing the soaking temperature of wheat grains, results in a increased activity of the natural flora. This leads to increased hydrolysis of carbohydrates producing more of reducing sugars. (Mheen and Kwon, 1984) Thus, more of the polymeric structure of the carbohydrates will be broken down into the low molecular weight reducing sugars, further reducing the intensity of resistance imparted by it to the rotating spindle of the rheometer, decreasing viscosity and yield stress. Yield stress decreased markedly by about 65% for wheat grains soaked at 37.5°C and 82% for wheat grains soaked at 45°C in comparison with samples soaked at 30°C.

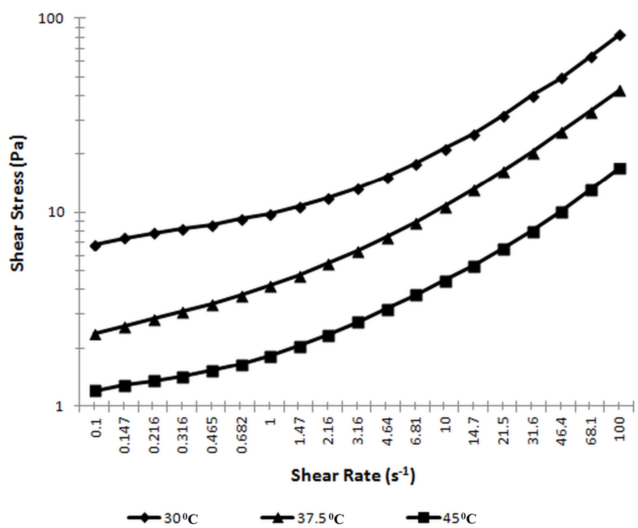

Figure 1. Plot of shear stress vs shear rate obtained for the prepared wheat batters

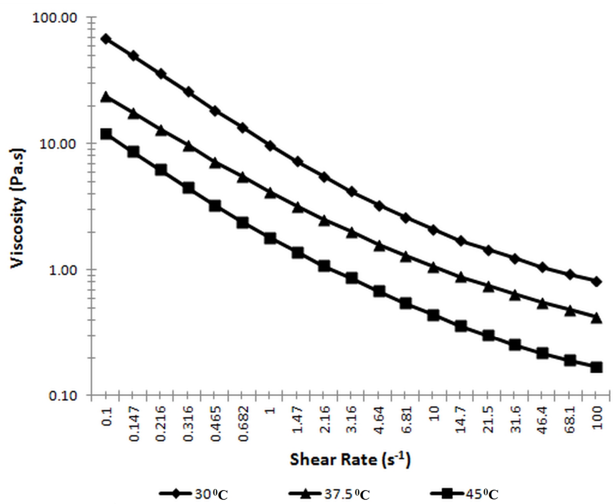

Figure 2. Plot of viscosity vs shear rate obtained for the prepared wheat batters

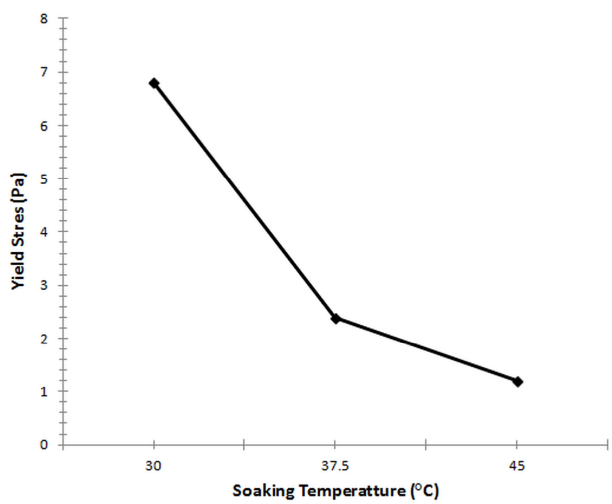

Figure 3. Plot of yield stress vs s obtained for the prepared wheat batters

Determination of yield stress, fluid consistency index and flow behavior index using the non-Newtonian fluid model

Figure 4 plots the model-fitting of the non-Newtonian fluid model to the experimental data points obtained for the prepared batters; whereas, the values of rms error, yield stress, flow behavior index and fluid consistency index are enlisted in Table 2. It was determined that, the non-Newtonian fluid model very well fitted the experimental data points with a very low rms error (less than 0.5%). Thus, non-

Newtonian fluid model can be suitable to define the flow behavior of the prepared batters. (Latha *et al.*, 2002).

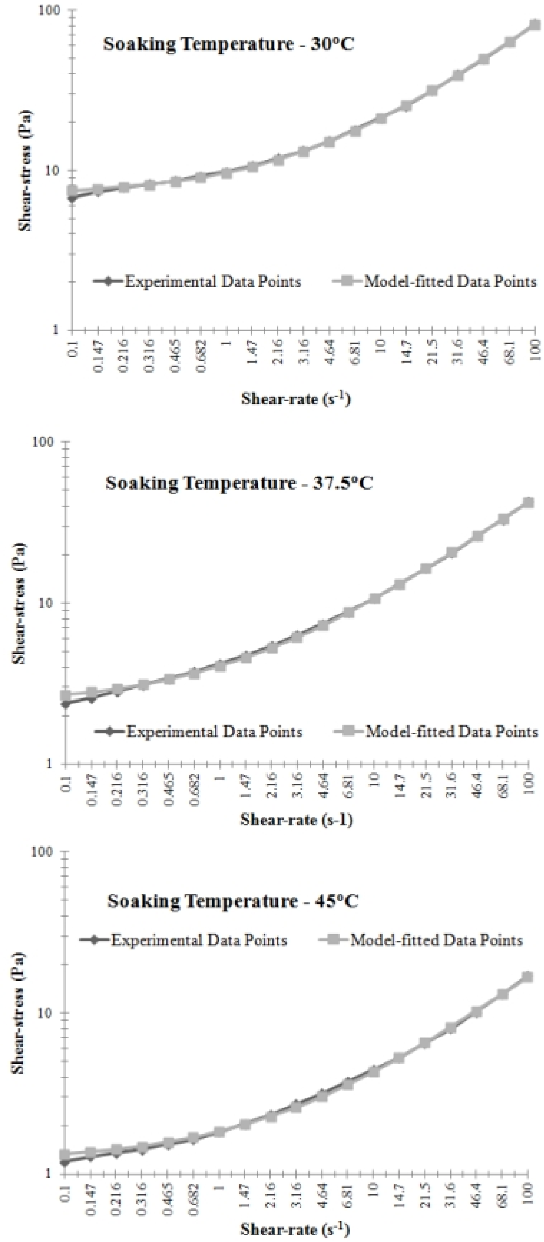

Figure 4. Model-fitting of the non-Newtonian fluid model to the experimental data points obtained for the prepared batters

Table 2. Flow parameters values of studied butters determined with the non-Newtonian model equation

Soaking Temperature (°C)	**rms error (%)**	**Flow behavior index (n), no unit**	**Fluid consistency index (k), Pa.s**	**Yield stress (c), Pa**
30.0	0.29 ± 0.03[a]	0.68 ± 0.05[a]	2.65 ± 0.01[a]	7.00 ± 0.06[a]
37.5	0.10 ± 0.02[b]	0.70 ± 0.01[b]	1.74 ± 0.04[b]	2.33 ± 0.07[b]
45.0	0.15 ± 0.04[c]	0.73 ± 0.03[c]	0.61 ± 0.02[c]	1.21 ± 0.06[c]

a-c Different superscripts for data in each column represent significant differences (p< 0.05)

Batter produced from wheat grains soaked at higher temperature demonstrated higher flow behavior index (n), and lower fluid consistency index (k) and yield stress (c). This reflected lower batter viscosity (Chen *et al*., 2008), resulting in easier hand extrusion when preparing *kurdi*. These flow properties match up with the thick solution with suspended irregularly shaped particles. (Bourne, 1982) It strongly influences the potential of producing voids and handling ability of the batter. Batter viscosity is affected by batter temperature, ingredient composition and the amount of water present. However, in our study batter temperature, amount of water and ingredients were maintained constant in all the prepared batter samples. Thus, the change observed in the viscosity and flow behavior properties could be a result of the chemical changes happening in the wheat grains due to the varied soaking temperatures, affecting the intensity of fermentation. (Sanz *et al.*, 2004) Increasing the soaking temperature of the wheat grains favoured the fermentation process, converting more of the polymeric structure of carbohydrates into reducing sugars. This led to lower resistance of the batter to the rotating spindle of the rheometer decreasing viscosity, k and c indexes.

Viscoelastic properties

Three discrete phases of transformation were observed in G' (storage modulus) during the thermal scanning. These phases were observed for all batter samples (Figure 5). The G' originated at around 100, 10 and 4 Pa for batter samples prepared from wheat grains soaked at 30, 37.5 and 45°C respectively; whereas, increased markedly when temperature rose above 35, 40 and 50°C respectively, before reaching a stable high value in the range of 60-80°C. In the first phase (<45°C), energized molecules softened the batter. Second phase characteristics are attributed to carbohydrates gelatinization.

Third phase characteristics are believed to be due to mixture stability consisting of gelatinized carbohydrate molecules, representing a temporary steady state. (Chen *et al*., 2008) Batters prepared from the wheat grains soaked at higher temperatures shifted the second phase of the G' curve to lower temperature range. This was attributed to the increased hydrolysis of the carbohydrates brought about at higher soaking temperature, due to the increased activity of the natural flora of microorganisms.

Thus, increase in soaking temperature of the wheat grains to 37.5 and 45°C brings about 20 and 30%, respectively, decrease in the gelatinization temperature of the batter samples. G" (loss modulus) curves were similar to those of G' curves during thermal scanning (Figures 5 and 6). Batters prepared from wheat grains soaked at higher temperatures exhibited lower G" values. Furthermore, the G" reached stable values above 60°C. Tan δ (Figure 7) values decreased with increase in the soaking temperature of the wheat grains.

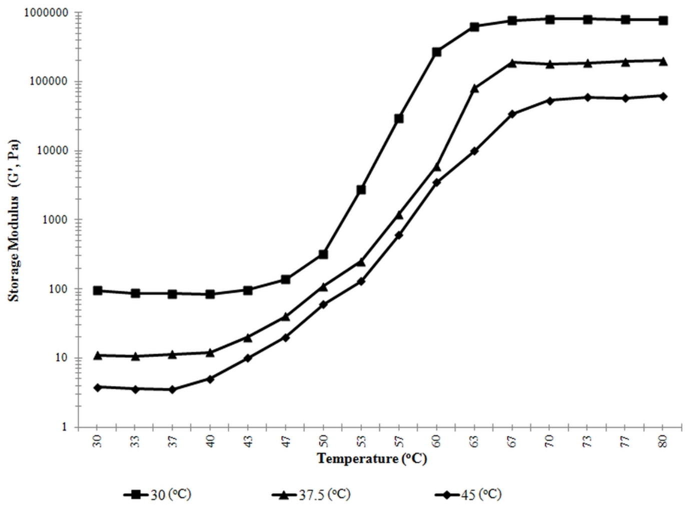

Figure 5. Storage modulus (G') profile of batter under rising temperature conditions

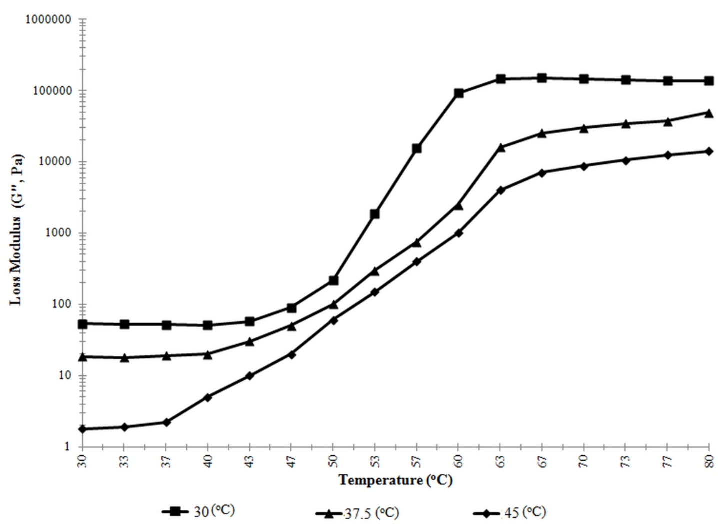

Figure 6. Loss modulus (G") profile of batter under rising temperature conditions

Generally the point of intersection between G' and G" curves is considered to be the gelatinization temperature (Clark and Ross-Murphy, 1987). Nevertheless, prior to thermal gelatinization, G' is larger than G". However, G'>G" (i.e. Tan δ < 1) cannot be always considered to be the only precondition to determine thermal gelatinization temperature (Lai *et al.*, 1996).

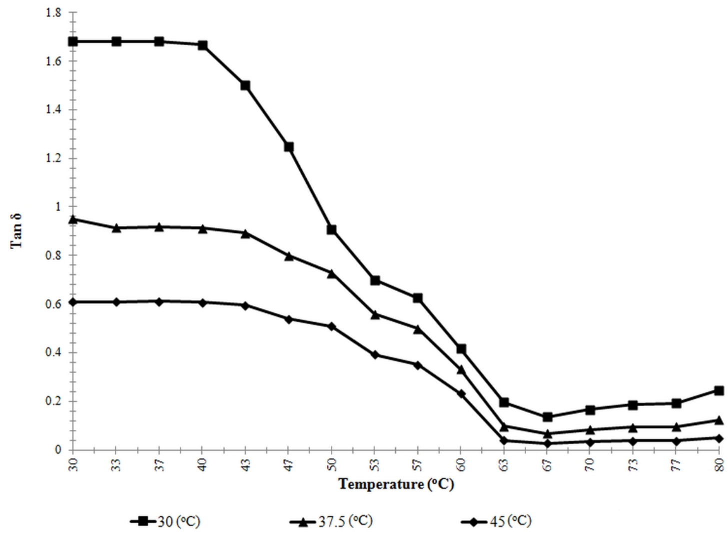

Figure 7. Tan δ profile of batter under rising temperature conditions

Conclusion

All the prepared fermented wheat batters exhibited shear-thinning behavior. Viscosity, shear-stress and yield stress of the batters decreased with increase in the soaking temperature of the wheat grains. The non-Newtonian fluid model fitted the experimental data points with a very low rms error. Wheat grains soaked at a higher temperature produced batter with higher flow behavior index but lower fluid consistency index and lower yield stress, which reflected lower batter viscosity. By measuring viscoelastic properties, it was determined that both G' and G" increased noticeably after the batter samples get gelatinized. The gelatinization temperature of the batters decreased with increase in wheat grain soaking temperature as determined from G', G" and Tan δ curves.

Conflict of Interest

There is no conflict of interest including any financial, personal or other relationships that could inappropriately influence their work.

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