OPEN ACCESS Freely available online

Journal of Food Microbiolgy, Saftey & Hygiene

Research Article

Rheological and Textural Characteristics of Dough and Batter with Ghee Residue

Vinay GM*, AK Singh, Poornima

Department of Dairy Technology, ICAR-National Dairy Research Institute, Karnal, India

ABSTRACT

The Ghee Residue (GR) is a by-product of the dairy industry, a nutrient-dense material that can substitute bakery fat, thus reducing trans-fat in the bakery. Pearl millet is a potential nutri-cereal and has applications in the manufacture of gluten-free and gluten-reduced products. The textural properties of the biscuit dough were considerably decreased with the substitution of ghee residue. The extensibility of the dough increased compared to the control dough confirmed by the creep test while the elasticity of the dough decreased due to the dilution of gluten by GR and Pearl Millet Flour (PMF), which also reconfirms from the frequency sweep of the dough that all dough samples had higher storage modulus than loss modulus. Rheological analysis of dough revealed that the doughs were viscoelastic in nature, with a storage modulus greater than the elastic modulus and a loss tangent less than 0.5, indicating the elastic behaviour of dough. The pearl millet and ghee residue significantly reduced the colour attributes in the muffin batter. Examination of viscosity during the heating process gives an idea about the increase in gelatinization temperature, shear thinning behaviour and foam stability at high temperatures. The tangent loss factor provides information regarding the stability of ghee residue proteins at high temperatures.

Keywords: Biscuit dough; Ghee residue; Muffin batter; Pearl millet; Rheology

INTRODUCTION

Fast foods, such as pizza, burgers, bread with butter and other bakery products such as biscuits, cookies and cakes are becoming increasingly essential components of our diet. Bakery products are in high demand because of their availability in various types, packaging, convenient food consumption and low cost. Furthermore, the bakery industry is continually expanding with the introduction of new products, which has resulted in even more growth. The increased impact of Western diets, increased urbanization and an increase in the number of working women all contribute to the growth of the bakery industry. Bakery products are popular due to rapid economic expansion, the emergence of food chains, and shifts in eating habits.

Wheat is one of the most widely consumed food ingredients worldwide. Wheat is the main raw ingredient in bakery products due to the unique visco-elastic characteristics of gluten protein [1]. The prevalence of celiac disease is due to undigested gliadin that causes inflammation of the intestinal wall, so people are looking for alternatives. Gluten proteins are present in lower amounts in maize, barley and oats, but are absent in millets. Millets contain slowly digestible starch and are rich in fibres. The presence of enzyme inhibitors in a millet lowers starch digestion; therefore, millet can be a good choice for diabetes and obese individuals. In addition, millets are a rich source of micronutrients such as iron, zinc, copper, vitamin B group, polyphenols and a wide variety of phytochemicals. Higher levels of anti-oxidants in millets promote the minimization of oxidative stress and thus lifestyle-associated disease. Pearl millet has been tried by cohort workers as a substitute for the development gluten-free processed products due to its unique physicochemical, nutritional and techno-functional properties in addition to its easy availability. Pearl millet is a perfect base material for the preparation of gluten-free bakery products and efforts have been made to manufacture shelf-stable flour, bread, biscuits, extruded snacks, composite beverages, pasta, complementary foods and modified starches.

Correspondence to: Vinay G M, Department of Dairy Technology, ICAR-National Dairy Research Institute, Karnal, India, Tel: 7975625990; E-mail: vinaygm26@gmail.com

Received: 16-Apr-2024, Manuscript No. JFMSH-24-30803; **Editor assigned:** 19-Apr-2024, PreQC No. JFMSH-24-30803 (PQ); **Reviewed:** 03-May-2024, QC No. JFMSH-24-30803; **Revised:** 04-Jun-2025, Manuscript No. JFMSH-24-30803 (R); **Published:** 10-Jun-2025, DOI: 10.35841/2476-2059.25.10.348

Citation: Vinay GM, Singh AK, Poornima (2025) Rheological and Textural Characteristics of Dough and Batter with Ghee Residue. J Food Microbial Saf Hyg. 10:348.

However, pearl millet-based products are criticized for their poor colour, off-flavour and inferior textural attributes which can be overcome by appropriate formulation and incorporation of novel additives. The dough is made up of flour, sugar, fat and other main ingredients. Although the biscuit dough is cohesive in nature, it lacks the extensibility and elasticity of the bread dough [2]. Maximum strain is a measure of extensibility in biscuit dough, while per cent recovery is a measure of elasticity. The dough behaves viscoelastic below the yield strain and also at large deformations due to the weak protein network. During the amplitude sweep, the stress increases vigorously with a small increase in the strain and the stress-strain curve follows the plateau-like region.

Knowledge of dough rheology and textural attributes is vital since it affects biscuit quality and process efficiency. The quality of the final product entirely depends on dough preparation, handling and type of operation while dough making. The use of mechanical and heat energy alters the rheological properties of dough. Furthermore, these qualities are controlled by numerous aspects like mixing methods, mixing equipment, mixing time, kind and quality of ingredients, dough temperature and water content.

GR is a by-product that is moist brownish sediment obtained after straining of molten ghee during its manufacturing. It is nutrient-dense and contains 36%-65% fat, 18%-42% protein, 8%-30% moisture, 0.5%-15% lactose and 2%-5% ash. GR is high in milk nutrients and can act as a potential antioxidant and flavouring ingredient in food products. A significant amount of GR is discarded due to a lack of profitability or lack of knowledge regarding the options that the industry can employ to harness the nutritional and therapeutic properties of GR. Therefore, research has been carried out in this study to replace bakery fat with GR. In this study, we focus mainly on the characterization and rheology of dough in the substitution of bakery fat with GR [3].

MATERIALS AND METHODS

Materials

Commercial Refined Wheat Flour (RWF) and pearl millet flour were purchased from a local market in Karnal, Haryana. Fresh GR was supplied by the model dairy plant of ICAR-NDRI, Karnal, Haryana.

Biscuit dough preparation

Composite flour was made using PMF and RWF in a 1:1 ratio. GR was substituted with fat at 10%, 15%, 20% and 25% and they were coded as WBDGR10, WBDGR15, WBDGR20 and WBDGR25 respectively. The sample without the GR was used as a control and it was coded WBD50. The biscuit dough preparation was carried out as per the method described by Vinay. Briefly, both fat and sugar are creamed in a Hobart planetary mixer to a cream consistency. Then, GR was added and creamed. The precisely calculated quantity of dry constituents such as flour (100%), skim milk powder (4%), baking powder (1%), ammonium bicarbonate (0.6%) and sodium bicarbonate (0.4%) were sifted to remove large particles and provide aeration. These dry ingredients were added at low speed until the dough stage was reached [4].

Muffin batter preparation

Muffin batter was prepared as described by GM and Singh. In summary, flour (24%), whey protein concentrate (6%), skim milk powder (2%) and baking powder (1.2%) were sifted together with a 12-micron mesh screen and kept apart. Bakery fat (16%) was creamed for 3 minutes at medium speed (418 rpm) in the Hobart mixture. The 24% sugar powder was then slowly incorporated and creamed for 4 minutes at 418 rpm. Later cake gel (0.5%) was creamed for 2 minutes. To ensure uniform mixing and to avoid deaeration, dry ingredients were added in 4-5 portions at low speed (219 rpm). Finally, 26% water was added at low speed. The batter prepared as described above serves as the control and is labelled WB. In this experiment, RWF was substituted with 50% PMF and bakery fat was replaced with GR at 0%, 10%, 15% and 20% and they were labelled as WBP50, WBPGR10, WBPGR15 and WBPGR20, respectively.

Ghee residue analysis

The total solid content of GR was analyzed according to the Food Safety and Standard Authority of India (FSSAI) by gravimetric method. The fat content was determined according to FSSAI, while the protein content was assessed using the Micro Kjeldahl method as per FSSAI standards. The ash content was measured according to AOAC and lactose content was determined using the subtraction method [5].

Colour and water activity

The colour of both the dough and batter was measured by the Tristimulus spectrophotometer. The results gathered from the instrument were expressed in terms of the CIE-LAB system. The water activity of dough and batter was determined using a water activity meter from Aqua lab (Model Series 3 TE) provided by M/s Decagon Devices, WA, USA. The instrument was calibrated with charcoal before the test and triplicate readings were drawn.

Texture properties of dough

The texture characteristics of the biscuit dough were measured with the TA-HD plus texture analyser. Tests were carried out using a 50 kg load cell and a speed of 0.5 mm/s. Compression platen-p/75 probe and heavy-duty platform (HDP/90) were used to perform the test. The dough tempered to about 25°C was cut into pieces of 25 mm × 25 mm × 25 mm size. The sample was positioned centrally on the platform [6]. The texture profile analysis was then carried out according to the method mentioned by Kumar et al. The biscuit dough was applied 70% compression twice in a reciprocating motion with a 5-second delay to produce a force–time curve. Hardness (1st bite), cohesiveness, adhesiveness, gumminess, resilience and springiness of the biscuit dough were measured from a force-time curve.

Rheological parameters

The rheological properties of both dough and batter were analyzed using an Anton Paar-MCR 52 Rheometer (Anton Paar, GmbH, Germany). Parallel plate-PP50 (50 mm diameter), upper plate and bottom Peltier plate were used. To ensure consistency in the thermo-mechanical history of samples before testing, all doughs and batters were maintained at 25 ± 1.0°C for 1 hour after preparation. To relieve the residual stress developed during loading, a 5 minute rest period was provided after loading the dough/batter to the bottom Peltier plate. Subsequently, the upper plate was lowered to achieve a 1 mm gap, the excess sample was trimmed and any residue on the bottom plate was cleaned. To prevent moisture loss during experiments, liquid paraffin was applied on the side edges. An oscillatory amplitude sweep test was performed, with a strain ranging from 0.01% to 100% at a constant frequency of 1 Hz to determine the viscoelastic range. The experiments were performed in triplicate to ensure the reliability and consistency of the results [7].

Frequency sweep: A frequency sweep of the samples was conducted within the linear viscoelastic region, ranging from a frequency of 0.01 to 100 Hz. During the test, both the storage modulus (G') and loss modulus (G") were continuously obtained as a function of frequency.

Creep test of dough: The test was conducted as per the procedure described by Abebe et al. The dough sample was tempered at 25°C and a fixed shear stress of 50 Pa was applied for 60 s within the linear viscoelastic range. Subsequently, during the recovery phase, the shear stress was immediately removed and the sample was allowed to rest for 180 s to regain its elasticity. The Rheoplus/32 software of the Rheometer was used to calculate the creep and creep recovery parameters. The maximum compliance (Jc_{max}) value, corresponding to the maximum deformation during the creep phase, was reached over the 60 s period. The maximum compliance value at the end of the recovery phase (Jr_{max}) indicates a partial recovery after stress removal. The recovery percentage (%) was determined using the formula:

$$\text{Recovery (\%)} = \frac{Jr_{max}}{Jc_{max}}$$

Flow properties of batter: A continuous ramp was used to measure the apparent viscosity as a function of shear rate over the range of 1.0-1000 s^{-1}, with 100 points taken linearly in time at 25°C. To observe changes in viscosity with temperature, measurements were taken by applying a shear rate of 1^{-1} and heating from 25°C to 90°C at a heating rate of 2°C/min.

Viscoelastic properties of batter: Linear viscoelastic behaviour of the batter was conducted temperature sweep at a constant frequency of 1 Hz, ranging from 25°C to 85°C, with a heating rate of 2°C/min [8].

Statistical analysis

Data gathered from experimentations were documented as mean ± standard deviation and are analyzed using SPSS software (26.0 version). Data were analyzed using one-way ANOVA. The least significant differences were calculated using the Tukey (HSD) test and significance was determined at $p<0.05$.

RESULTS AND DISCUSSION

Chemical composition of ghee residue, RWF and PMF

The chemical composition of the GR was examined to determine the effect of the GR characteristics on the dough/ batter with substitution. GR had a total solid of 28.19%, fat ˜8.18%, protein ˜12.18%, ash ˜1.49% and lactose ˜6.32% on a wet basis. GR has sufficient fat and protein, which contributes to functional characteristics in dough/batter making. Refined what flour had protein ˜9.88%, moisture ˜9.33%, fat ˜1.67%, ash ˜0.65% and fibre ˜0.35%) and PMF protein ˜9.14%, moisture ˜6.53%, fat ˜5.62%, fibre ˜1.96% and ash ˜1.66%. Both flours used in this study had a protein content in the range of soft wheat, hence both are suited for biscuit preparation. Even though PMF has a good quantity of protein which lacks lacks the gluten protein necessary for viscoelastic properties [9].

Physical, textural and rheological attributes of dough

Colour and water activity of dough: The colour and water activity of various doughs are depicted in Table 1. The lightness and yellowness of the dough were reduced with the substitution of GR as a result of the presence of Maillard reaction products in GR. The lightness and yellowness values of the dough were maximum for WBD50 and the lowest for WBDGR25 ($p<0.05$), whilst the redness of the dough increased from -1.09 (WBD50) to 5.22 (WBDGR25) with increasing levels of GR. Kumar et al. reported a similar trend of L*, a* and b* values with the addition of a multigrain mix. GR substitution slightly enhanced water activity and was significantly higher ($p<0.05$) at 10% GR addition. The water activity of the dough was carried out to nullify the influence of water content during rheological testing. There was no consistent trend for the water activity of dough with added GR. The variation in water activity could be due to the fact that fat was replaced with GR; if there was enough fat available in the dough, it would coat the flour particles and water would be available in free form.

Table 1: Effect on colour and water activity of biscuit dough upon GR substitution.

Dough sample	L^*	a^*	b^*	Water activity
WBD50	$45.44^e \pm 0.34$	$-1.09^a \pm 0.23$	$19.22^d \pm 0.29$	$0.847^a \pm 0.001$
WBDGR10	$37.31^d \pm 0.21$	$1.76^b \pm 0.62$	$18.44^c \pm 0.4$	$0.872^b \pm 0.002$
WBDGR15	$35.73^c \pm 0.45$	$3.14^c \pm 0.41$	$16.01^b \pm 0.6$	$0.839^a \pm 0.013$
WBDGR20	$32.80^b \pm 0.21$	$4.56^d \pm 0.47$	$15.80^b \pm 0.15$	$0.851^a \pm 0.011$
WBDGR25	$29.67^a \pm 0.56$	$5.22^e \pm 0.05$	$13.23^a \pm 0.30$	$0.849^a \pm 0.013$

Note: Data are presented as Means ± S.D (n=3); [abcde]Means with different superscripts in column are significantly different from each other at $p<0.05$; WBD50: Dough from RWF: PMF (50:50) with 100% shortening; WBDGR10: 10% fat replaced with ghee residue; WBDGR15: 15% fat replaced with GR; WBDGR20: 20% fat replaced with GR and WBDGR25: 25% fat replaced with GR

Textural properties of dough: The fat content is mainly responsible for the textural properties of biscuits, as it is involved in tenderness and air incorporation. Table 2 shows the effect of GR substitution on dough. Bakery fat substitution with GR resulted in a decrease in hardness and gumminess linearly ($p<0.05$) except for resilience, which increased non-significantly ($p>0.05$). The other textural parameters also decreased but there was no consistent trend for adhesiveness, cohesiveness, springiness and chewiness and the dough made with GR at 15 per cent exhibited the lowest values ($p<0.05$) for the parameters mentioned above. Furthermore, as fat was reduced, the adhesiveness and resilience increased in the dough. In addition, the hardness of the dough will tend to decrease the spread ratio of the biscuits. Compared to other dough samples, the WBD50 dough sample had the maximum hardness ($p<0.05$). According to Umesha et al., the porosity of the biscuit dough affects its hardness. As a result, substituting fat for GR reduced the hardness. However, Metwal et al., observed that there was a reduction in the springiness and gumminess value of cookie dough with the inclusion of fenugreek and flax seed powder, which was mainly attributed to gluten dilution [10].

Table 2: Effect of GR substitution on textural properties of biscuit dough.

Dough sample	Hardness (N)	Adhesiveness (g.s)	Springiness (mm)	Cohesiveness	Gumminess (N)	Chewiness (N.mm)	Resilience
WBD50	$17.56^d \pm 2.29$	$-1069.14^a \pm 46.33$	$0.24^c \pm 0.03$	$0.24b^c \pm 0.03$	$4.18^c \pm 0.10$	$1.01^b \pm 0.12$	$0.02^a \pm 0.00$
WBDGR10	$14.97^{cd} \pm 0.79$	$-870.32^a \pm 317.64$	$0.26^c \pm 0.04$	$0.26^c \pm 0.04$	$3.08^b \pm 0.40$	$0.81^b \pm 0.23$	$0.02^a \pm 0.00$
WBDGR15	$11.85^{bc} \pm 0.20$	$-17.08^b \pm 0.34$	$0.04^a \pm 0.01$	$0.13^a \pm 0.01$	$2.00^a \pm 0.06$	$0.09^a \pm 0.01$	$0.03^b \pm 0.00$
WBDGR20	$10.14^{ab} \pm 1.06$	$-230.49^b \pm 16.91$	$0.08^{ab} \pm 0.01$	$0.20^b \pm 0.02$	$1.99^a \pm 0.06$	$0.16^a \pm 0.01$	$0.03^b \pm 0.00$
WBDGR25	$7.28^a \pm 0.58$	$-116.00^b \pm 9.16$	$0.11^b \pm 0.01$	$0.23^{bc} \pm 0.01$	$1.61^a \pm 0.08$	$0.14^a \pm 0.01$	$0.03^c \pm 0.00$

Note: Data are presented as Means ± S.D (n=5), [abcd] Means with different superscripts in the column significantly different from each other at $p<0.05$

Creep test of a dough: Maximum strain refers to the extensibility and firmness of the dough. Interpretation of this test can be made as the stronger dough offers high resistance to deformation and has lesser maximum strain compared to a soft dough; it was observed that when GR levels were increased, the extensibility of the dough decreased (Table 3). The other dough combinations showed more extensible behaviour than the WBD50 dough. The physical properties of the dough and its elastic nature were inextricably correlated. The elasticity of the dough was often represented in terms of recovery and percentage recovery [11]. Due to the shrinkage/elastic recovery of a dough, higher recovery and percentage recovery tend to diminish the diameter of the biscuit. Skendi et al. stated that elasticity provides the extent of bonding between the molecules, higher values of elasticity give less breakage in the dough. The WBD50 dough had the highest recovery and per cent recovery, the highest elastic recovery was due to the high protein content in the flour; however, when GR was incorporated into the dough, it resulted in an increase in the moisture content and protein dilution occured. Hence, a decreased trend was obtained on GR substitution, but an increasing trend was observed when the substitution level increased, which may be due to an increase in the protein content of GR.

Table 3: Effect of GR substitution on rheological characteristics of biscuit dough.

Dough sample	Max. strain	Recovery	Percentage recovery
WBD50	$0.03^{a} \pm 0.01$	0.02 ± 0.00	$63.27^{b} \pm 23.35$
WBDGR10	$0.09^{b} \pm 0.02$	0.015 ± 0.00	$18.52^{a} \pm 9.79$
WBDGR15	$0.06^{ab} \pm 0.02$	0.016 ± 0.00	$26.78^{ab} \pm 14.35$
WBDGR20	$0.05^{ab} \pm 0.02$	0.021 ± 0.00	$39.88^{ab} \pm 12.67$
WBDGR25	$0.05^{ab} \pm 0.01$	0.018 ± 0.00	$30.98^{ab} \pm 12.78$

Note: Data are presented as Means ± S.D (n=3), ^{ab}Means with different superscripts in column significantly different from each other ($p<0.05$)

It can be observed in Figure 1 that during the creep stage, the strain grew with time in response to the constant force applied, causing the dough to deform quickly. It was seen that after a certain period. the strain approximated a stable state by attaining equilibrium deformation. When the constant force was removed during the recovery stage, the dough strain was partially recovered from equilibrium deformation to a constant value over time. Furthermore, the dough creeps–recovery curves demonstrated normal viscoelastic behaviour, integrating viscous fluid and elastic components [12]. The results obtained (Figure 1) showed that the sample substituted for 10% GR (WBDGR10) had the highest strain with the lowest recovery and per cent recovery. It signified that the WBDGR10 dough was stiffer than the other dough samples in terms of dough strength.

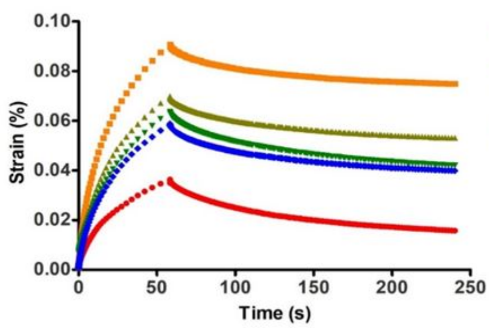

Figure 1: Creep recovery of ghee-residue substituted dough sample.

Frequency sweep of GR substituted dough samples: Frequency sweep tests were performed in the viscoelastic area acquired from the amplitude sweep tests to obtain relevant information from the viscoelastic properties of different dough samples. Both G' and G" were increased with the increase in frequency. Hadnađev, et al. observed the same frequency dependence for biscuit dough. The elastic or storage modulus expresses the amount of energy stored in the material or recovered during each deformation cycle. The viscous modulus or loss modulus estimates the amount of energy lost per cycle of deformation as a result of viscous dissipation. As shown in Figure 2, the storage modulus G' was larger than the loss modulus G" for all samples throughout the frequency range, indicating that the doughs examined were more elastic than viscous. Mastromatteo et al. also reported that the durum wheat dough samples were more elastic in nature rather than viscous. The dough sample WBGR15 had the highest G' and G" values. The WBGR25 dough sample, on the other hand, had the lowest G' and G" values [13].

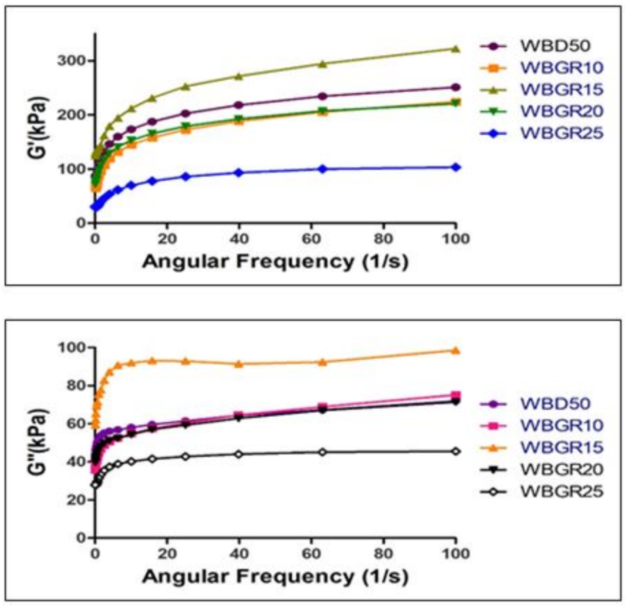

Figure 2: Elastic modulus (G') and loss modulus (G") as functions of frequency for different GR substituted samples; spectrum measured between 0.1 and 100 Hz.

One of the parameters that shows the ratio of loss modulus (G") and elastic modulus (G') is the loss factor (tan δ). When tan delta is less than one and G' is greater than G", indicating that the elastic properties dominate over the viscous properties in the dough. Tan δ was highest for the GR substituted in the dough sample *i.e.,* WBGR25, indicating that the dough is viscous and lowest for WBD50, indicating that the dough is elastic, as shown in Figure 3. It could be due to an increase in GR levels and an increase in water content of the dough samples. Meerts et al. observed that increasing the water content softened the dough samples and the tan δ was usually low in highly structured materials.

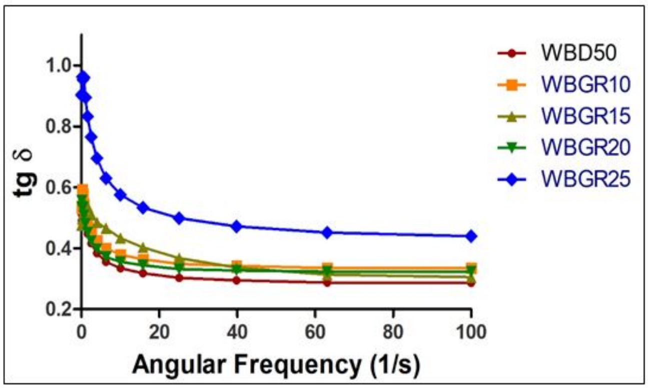

Figure 3: Dynamic viscoelastic loss factor with frequency dependence (tan δ).

Colour and rheological attributes of muffin batter

Colour attributes: The colour values of the batters are shown in Table 4. The lightness of the batter of RWF (WB) was 68.87. The lightness decreased in the composite flour (WBP50) batter to the value of 55.60 due to the inherent dull colour of pearl millet flour. Further decreasing trend of lightness value obtained by substituting of bakery fat with GR ($p<0.05$), which was due to the reddish-brown colour contributed by GR. Similarly, the redness value had an increasing trend and a decreasing trend of the yellowness value with the substitution of GR. GM and Singh observed similar results with the addition of ghee residue powder to a muffin batter [14].

Table 4: Effect on colour and viscosity of muffin batter upon GR substitution.

Batter sample	L^*	a^*	b^*	Viscosity
WB	$68.87^d \pm 0.19$	$0.08^b \pm 0.00$	$24.34^d \pm 0.10$	$13.83^a \pm 1.87$
WBP50	$55.60^c \pm 0.16$	$-1.57^a \pm 0.06$	$23.77^c \pm 0.11$	$26.67^c \pm 1.40$
WBPGR10	$45.77^b \pm 0.16$	$3.51^c \pm 0.01$	$23.20^b \pm 0.07$	$26.53^c \pm 1.95$
WBPGR15	$41.63^a \pm 0.27$	$4.82^d \pm 0.09$	$21.73^a \pm 0.22$	$19.20^b \pm 0.90$
WBPGR20	$41.19^a \pm 0.28$	$4.96^d \pm 0.04$	$21.43^a \pm 0.17$	$15.70^{ab} \pm 1.81$

Note: Means from triplicate determination; ^{abcd} Means with different superscripts in column significantly different each other ($p<0.05$); WB-Batter from RWF; WBP50-Batter from composite flour; WBPGR10-Batter from composite flour with 10% GR substitution; WBPGR15-Batter from composite flour with 15% GR substitution; WBPGR20-Batter from composite flour with 75% GR substitution

Viscosity as a function of shear rate: The apparent viscosity of the various batters is shown in Table 4. The apparent viscosity of batters was measured in the range of 0.1-1000 s^{-1} with 100 points at 25℃. Figure 4 shows the apparent viscosity of different batters with the shear rate. Wheat Batter (WB) had the lowest viscosity and WBP50 had the highest viscosity among all the batters. Viscosity is desirable for air incorporation as it decides the number of air cells within the batter and also the foam stability of the batter. When applied to the shear rate, the apparent viscosity decreases, showing the shear thinning behaviour of the batter [15].

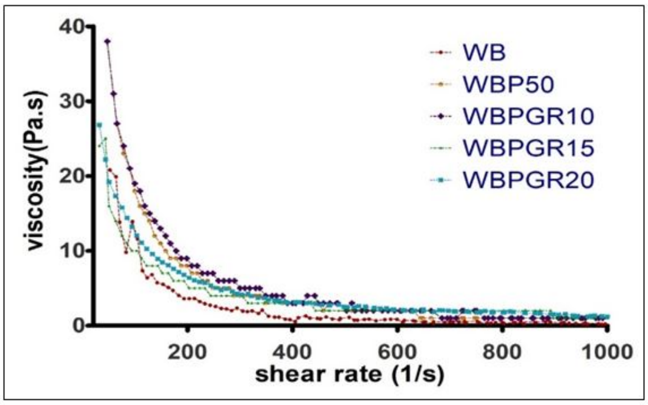

Figure 4: Flow properties of muffin batter influenced by GR substitution to bakery fat at 25°C.

Viscosity behaviour with temperature: Viscosity as a function of temperature was examined using a temperature sweep from 25°C to 90°C to determine the gelatinization temperature in the batter while baking (Figure 5). The viscosity of all the batter reduced as the temperature increased. Viscosity began to increase after 80°C, indicating the commencement of starch gelatinization, gelatinization began late due to the high sugar content causing an increase in the gelatinization temperature.

This test provides information regarding the volume of the final product, low viscosity batter yields low volume in the final product. During the heating process, higher viscosities hinder coalescence, migration and loss of air cells before the batter sets. High viscosity is desirable during heating to hold air cells to expand the air nuclei and resisting starch granule settling, resulting in improved cake volume structure and crumb grain [16].

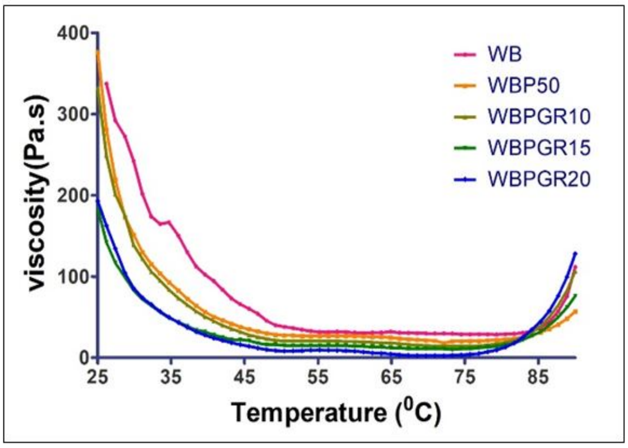

Figure 5: Evolution of viscosity during heating.

Viscoelastic behaviour of batters during heating: Linear viscoelastic properties of the muffin batter were scrutinized under a temperature sweep from 25°C to 85°C to approximate the structural changes in the batter during baking. The final structure of a muffin's depends on the viscosity, foam formation and stability of batter the baking process. Therefore, it is important to study the behaviour of the raw batter as a function of temperature. Storage modulus (G′), loss modulus (G″) and the overall viscoelastic response (tg δ) were plotted against the temperature with constant frequency (1 Hz) as shown in Figures 6 and 7. The G′ and G″ decreased with the progress of heating. The G′ of all batters was higher than G″, indicating soft gel behaviour. Matos et al. reported the same mechanical spectra of muffin batter made from rice flour with different proteins. The storage modulus increased with the substitution of bakery fat with GR [17]. The WBPGR20 batter had the highest storage moduli even at high temperatures; this shows the suitability of GR in the muffin batter matrix to hold aerosol. Matos et al. obtained similar results while studying the effect of casein protein incorporation in rice flour muffins, they found higher G′ and G″ compared to no protein batter.

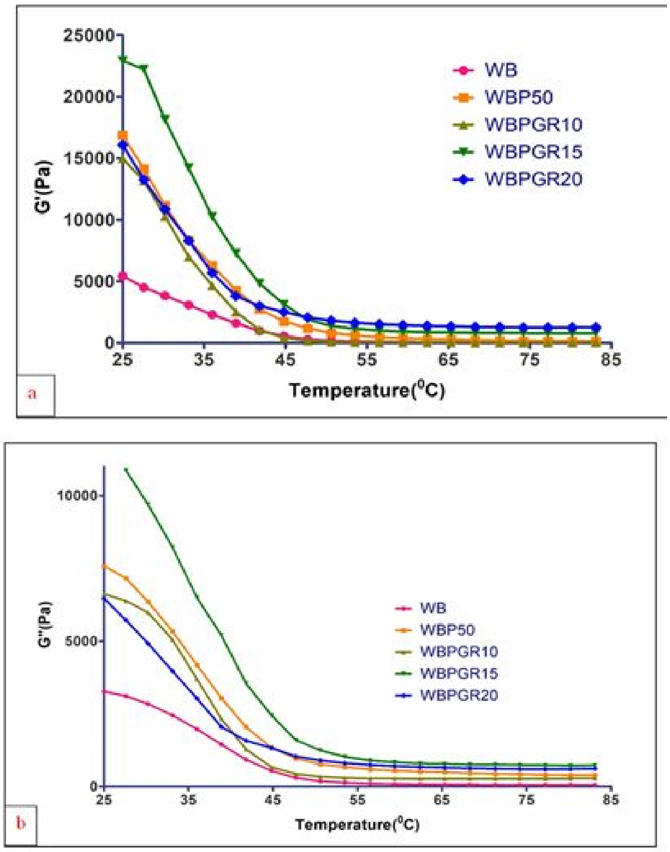

Figure 6: Influence of GR level in the muffin batter on the evolution of G′ and G″ with temperature. Heating rate: 0.032°C/s. Strain wave amplitude: 0.05 (WBP50, WBPGR10 and WBPGR15) and 0.1 (WB and WBPGR20). Frequency: 1 Hz (a) Storage modulus and (b) Loss modulus.

It was stated that lower tan δ values for refined wheat flour-based batter indicate a batter that was more elastic, stronger and more stable over time. The consistency of the batter determines the ultimate quality of the muffins. Figure 7 shows that, except for the Wheat flour Batter (WB), all other batters had a greater tangent delta, indicating that they behaved viscous at 85°C, which is undesirable. Further, Herranz et al. also mentioned that the higher tan delta values (tg δ near to 1) indicated that the protein in the batter is not heat stable. Figure 7 clearly shows that WBP50 batter made by substituting refined wheat flour with pearl-millet flour, dilutes the gluten protein and therefore pearl-millet proteins are the least heat stable. The refined Wheat flour Batter (WB) decreased substantially in loss tangent after 50℃. Wang, et al., reported gluten proteins form a more elastic gluten network at high temperatures and this protein is susceptible to unfolding and thermal transition around 60℃. The decreasing trend in tg δ was observed when GR is substituted, as we can see from Figure 7 WBPGR20 has the least tg δ among the GR substituted batters. Hence, the substitution of GR can improve the muffin batter quality in terms of viscosity and stable coalescence at a higher temperature. Matos, et al., observed the casein protein gives hard consistency and more solid behaviour due to more water absorption capacity of protein. From this observation, we can infer that GR has a similar effect as that of casein protein [18-20].

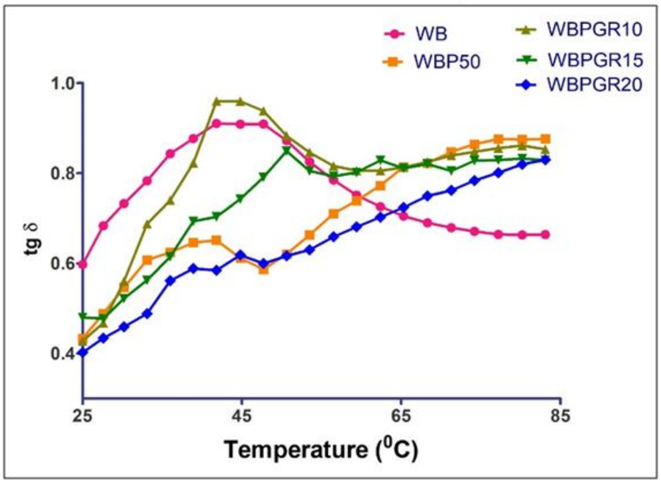

Figure 7: Influence of GR levels in muffin batter on the evolution of loss tangent values with temperature.

CONCLUSION

GR is a nutrient-rich material that is an underutilized product and is going to waste due to poor knowledge. When considering the nutritional profile and functional characteristics of them, an attempt has been made to replace bakery fat with GR. The substitution of GR in biscuit dough and muffin batter decreased lightness and yellowness and increased redness. Bakery fat substitution with GR resulted in a decrease in hardness and gumminess linearly ($p<0.05$) except for resilience, which increased non-significantly ($p>0.05$). Shortening replacement with the GR resulted in the maximization of strain but a lowering in the recovery of dough samples. The frequency sweep test showed that the dough samples had a higher storage modulus than the loss modulus, indicating that the dough was viscoelastic in nature. Dynamic viscoelastic loss factor showed that the 25% GR substituted dough sample had higher tangent δ indicated that the dough was less elastic compared to other doughs. Rheological analysis revealed that the control (WBD50) dough had the highest recovery and percentage recovery compared to all other doughs. The viscosity of the muffin batter increased with the substitution of refined wheat flour with pearl millet flour and a similar trend was found with the replacement of shortening with GR. Flow behaviour studied with shear rate, showed that all batters have shear thinning behaviour and viscosity also decreases dramatically with the increase in temperature, giving an idea of the commencement of gelatinization. The Wheat Batter (WB) showed a lower tangent delta, indicating it is more elastic, stronger and time stable. When shortening was substituted with GR, the tangent delta increased due to presence of unstable proteins.

DATA AVAILABILITY

The data obtained during the study are available from the corresponding author upon reasonable request.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

FUNDING STATEMENT

No funds, grants or other support was received.

ACKNOWLEDGEMENTS

The authors thankfully acknowledge Director ICAR-NDRI, Karnal for providing the necessary facilities to conduct this research.

AUTHORS' CONTRIBUTIONS

Vinay G M was responsible for the conceptualization and formal analysis, investigation, methodology, software, validation, visualization, andoriginal draft writing. Ashish Kumar Singh was responsible for the supervision, review, editing and resources.

REFERENCES

1. Punia S, Kumar M, Siroha AK, Kennedy JF, Dhull SB, Whiteside WS. Pearl millet grain as an emerging source of starch: A review on its structure, physicochemical properties, functionalization and industrial applications. Carbohydr Polym. 2021;260:117776.
2. Rona RJ, Keil T, Summers C, Gislason D, Zuidmeer L, Sodergren E, et al. The prevalence of food allergy: A meta-analysis. J Allergy Clin Immunol. 2007;120(3):638-646.
3. Nani A, Belarbi M, Ksouri-Megdiche W, Abdoul-Azize S, Benammar C, Ghiringhelli F, et al. Effects of polyphenols and lipids from *Pennisetum glaucum* grains on T-cell activation: Modulation of Ca^{2+} and ERK1/ ERK2 signaling. BMC Complement Altern Med. 2015;15:1-11.
4. Jukanti AK, Gowda CL, Rai KN, Manga VK, Bhatt RK. Crops that feed the world 11. Pearl Millet (*Pennisetum glaucum* L.): An important source of food security, nutrition and health in the arid and semi-arid tropics. Food Security. 2016;8:307-329.
5. Yadav DN, Anand T, Kaur J, Singh AK. Improved storage stability of pearl millet flour through microwave treatment. Agric Res. 2012;1:399-404.
6. Sharma M, Singh AK, Yadav DN, Arora S, Vishwakarma RK. Impact of octenyl succinylation on rheological, pasting, thermal and physicochemical properties of pearl millet (*Pennisetum typhoides*) starch. LWT. 2016;73:52-59.
7. Adebiyi JA, Obadina AO, Adebo OA, Kayitesi E. Comparison of nutritional quality and sensory acceptability of biscuits obtained from native, fermented and malted pearl millet (*Pennisetum glaucum*) flour. Food Chem. 2017;232:210-217.
8. Kumar P, Kaur C, Sethi S, Kaur Jambh H. Effect of extruded finger millet on dough rheology and functional quality of pearl millet-based unleavened flatbread. Cereal Chem. 2020;97(5):991-998.
9. Ganguly S, Sabikhi L, Singh AK. Effect of whey-pearl millet-barley based probiotic beverage on *Shigella*-induced pathogenicity in murine model. J Funct Foods. 2019;54:498-505.
10. Ganguly S, Sabikhi L, Singh AK. Evaluation of nutritional attributes of whey-cereal based probiotic beverage. LWT. 2021;152:112292.

12. Haegens N. Mixing, dough making and dough make-up. Bakery Products Sci Tech. 2014:307-324.
13. Wani AD, Prasad W, Khamrui K, Jamb S. A review on quality attributes and utilization of ghee residue, an under-utilized dairy by-product. Future Foods. 2022;5:100131.
14. GM V, Singh AK. Effect of ghee residue powder and pearl millet flour substitution on rheological, textural and sensorial characteristics of eggless muffin. J Food Process Preserv. 2024;2024(1):5519265.
15. Abebe W, Ronda F, Villanueva M, Collar C. Effect of tef grain flour addition on viscoelastic properties and stickiness of wheat dough matrices and bread loaf volume. Eur Food Res Technol. 2015;241:469-478.
16. Baixauli R, Sanz T, Salvador A, Fiszman SM. Muffins with resistant starch: Baking performance in relation to the rheological properties of the batter. J Cereal Sci. 2008;47(3):502-509.
17. Kumar KA, Sharma GK, Khan MA, Govindaraj T, Semwal AD. Development of multigrain premixes-its effect on rheological, textural and micro-structural characteristics of dough and quality of biscuits. J Food Sci Technol. 2015;52(12):7759-7770.
18. Devi A, Khatkar BS. Physicochemical, rheological and functional properties of fats and oils in relation to cookie quality: A review. J Food Sci Technol. 2016;53(10):3633-3641.
19. Kouhsari F, Saberi F, Kowalczewski PŁ, Lorenzo JM, Kieliszek M. Effect of the various fats on the structural characteristics of the hard dough biscuit. Lwt. 2022;159:113227.
20. Umesha SS, Manohar RS, Indiramma AR, Akshitha S, Naidu KA. Enrichment of biscuits with microencapsulated omega-3 fatty acid (Alpha-linolenic acid) rich garden cress (*Lepidium sativum*) seed oil: Physical, sensory and storage quality characteristics of biscuits. LWT-Food Sci Technol. 2015;62(1):654-661.