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Research Article

Effect of Ghee Residue Powder and Pearl Millet Flour Substitution on Rheological, Textural, and Sensorial Characteristics of Eggless Muffin

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Bakery products are becoming an essential part of the human diet. Millets are the staple grains in Asia and African countries, and they are the super future food because of their nutritive and disease-preventive nature. Pearl millet is one of the most nutritious cereal grains, and its protein lacks gluten, which makes it a suitable base material for the preparation of gluten-free products. However, gluten is necessary because of its unique viscoelastic nature, which makes the most innovative bakery items. In this study, 50% refined wheat flour (RWF) has been replaced with pearl millet flour (PMF) to prepare a muffin, and a ghee residue is utilized to make a ghee residue powder (GRP) as a functional ingredient to replace whey protein concentrate (WPC) in the eggless muffin. Substitution of fat with GRP reduced the specific gravity of batter from 1.05 to 0.99; lightness value was considerably decreased, whereas the redness and yellowness values increased from 1.06 to 8.32 and 23.62 to 26.20, respectively. Replacement of RWF with PMF affected the lightness and specific gravity of the batter. Substitution with PMF and GRP reduced the viscosity from 13.83 Pa·s to7.08 Pa·s. Gelatinization temperature of batters varied with substitution of flour and fat with PMF and GRP. Muffin volume dramatically decreased from 56.19 to 36.84 cm^3 with substitution of GRP and PMF. Weight loss was increased from 12.14 to 13.68% by substitution. The hardness and springiness were reduced with substitution. The GRP can replace fat up to 25%; thereafter, muffin's quality characteristic reduces; hence, 50% PMF and 25% GRP combination give satisfiable muffin product.

1. Introduction

Bakery products constitute an important component in our diet because of their convenience, availability in different forms, unique sensory profile, and availability at a lower price [1]. There is a growing demand for bakery products for home consumption and the food service industry. Bakery products are mainly segmented into biscuits and cookies, cakes and pastries, bread, rusks, and other goods. Cakes are the most consumed products after biscuits and cookies. The cakes are widely consumed as a part of celebrations and festivals. Recently, muffins are gaining importance over cakes due to affordability, convenience, innovation, and intractability. Muffin word is derived from the German word "Muffen" and is spelt as moofin. Muffins are generally a small type of cake or quick bread that have a typical porous texture and high volume which gives a spongy texture [2]. Muffins are made from high levels of sugar and fat [3]. They are also referred to as "cupcakes" and are characterized by caramelized sweet flavour and attractive appearance.

Nowadays, people prefer to eat vegan foods due to the health consequences of eggs (cholesterol, egg allergy, and avian influenza) [4]. However, the prevailing consensus is that the egg is the necessary basic component for baked goods. Due to their special foaming, solubility, emulsifying, and coagulating qualities, eggs are a crucial ingredient for achieving the ideal volume, texture, and colour in culinary products [5]. In addition to their usefulness as a component, eggs also have flavour, colour, and nutritional value [6]. Sometimes, the cost of the egg goes beyond 50% of the manufacturing cost of a product. So, the manufacturers are still finding cheaper ingredients to completely replace the egg. Lately, cohort studies have discovered egg substitutes such as whey protein, soy flour, hydrocolloids, blood plasma, casein, and starch in various bakery products. These egg replacers should give the same functional characteristics as an egg.

Commercial eggless cakes are manufactured using whey protein. Ratnayake et al. [7] studied the effect of three different commercial egg substitutes (whey protein, fibre/gum, and soy/wheat gluten-based) on yellow cake. The density of the batter made with whey protein was comparable; baking loss was more in all egg substitutes compared to a cake made from eggs. The puncture test reveals that the cake made from whey had lower hardness than other substitutes. Saleh [8] tried to develop to prepare a cake using a novel egg substitute zucchini puree. In their study, it was found that the cake had acceptable characteristics which were mainly attributed to the gums present in the peel of zucchini. The batter density was higher for zucchini-based cake when compared to soy flour cake, and the foam capacity and foam stability of zucchini-based cakes were comparable with the cake made from soy flour. The viscosity of the zucchini batter was less compared to all other egg substitutes. Agrahar-Murugkar et al. [9] studied the batter rheology and noticed that the tangent δ and viscosity were higher for composite flour than the batter from RWF.

Aslan and Bilgiçli [10] attempted to make a cake from lupin extract instead of soy extract, and based on their investigation, they concluded that the cake had a higher cake volume index and lower hardness. Hesarinejad et al. [11] examined the effect of *Chlorella vulgaris* as an alternative to egg whites in cakes and reported that the batter consistency and specific volume decreased and a significant increase in weight loss and hardness was observed.

Ghee residue (GR) is a by-product obtained during the preparation of ghee from cream or butter. Leftover material after ghee preparation is usually light to blackish brown in colour depending on the manufacturing process and temperature employed. The by-product obtained is usually considered a waste with no apparent economic value but its richness in certain nutritive compounds including 30-70% milk fat [12]. Traditionally, ghee residue has been widely used by mixing it with milk or skimmed milk powder, khoa, sugar, and flavours for the preparation of sweets like chocolate, burfi, *Peda*, *Pinni*, and toffees and in certain food preparations like soups and spreads [13, 14].

Pearl millet is one of the most nutritious cereal grains and can be compared with major staples, i.e., wheat, rice, and maize. The approximate per cent of endosperm, germ, and bran in pearl millet grains is 75%, 17%, and 8%, respectively [15]. The millet contains slowly digestible starch and enzyme inhibitors in it, which makes ideal dietary component to combat with lifestyle diseases [16]. Pearl millet has been attempted by a number of researchers as an alternative to develop gluten-free processed products because of its unique physicochemical, nutritional, and technofunctional properties besides its easier availability [17]. Pearl millet is an ideal base material for the manufacturing of gluten-free bakery products, and attempts have been made to prepare shelf-stable flour, biscuits, bread, pasta, extruded snacks, composite beverage, complementary foods, and modified starches using pearl millet [18–22].

Ranjan et al. [23] attempted to prepare cake and muffins by replacing RWF with ghee residues (10-40%). The cake and muffins made from 60% RWF and 40% GR had the highest overall acceptability. The body and texture, flavour, and taste were improved compared to the control (without GR) sample. The product was nutritionally better, especially in calcium content. Sojan et al. [24] developed cookies and biscuits by replacing the bakery fat with GR. It was noticed that up to 10% shortening can be replaced with GR, and that reduced the cost of production by ~16.6%.

In view of the potentiality of GR and pearl millet, here GR has been used as an egg and WPC substitute in the muffin preparation. The GR is converted into ghee residue powder for its longer shelf life and to improve its properties. In the recent past, with the emergence of celiac diseases that cause inflammation of the intestinal wall, there is a need for alternatives which can replace gluten. So pearl millet was chosen in this study to replace RWF.

2. Materials and Methods

2.1. Materials. Commercial pearl millet flour (% sugar, 75.09; % moisture, 6.53; % fat, 5.62; % protein, 9.14; % fibre, 1.96; and % ash, 1.66) and RWF (% sugar, 78.12; % moisture, 9.33; % fat, 1.67; % protein, 9.88; % ash, 0.65; and % fibre, 0.35) were supplied by B D Super Store market (Karnal, Haryana), and the proximate was carried out according to AACC method. Fresh ghee residue was procured from the model dairy plant of ICAR-NDRI, Karnal (Haryana). Ground sugar, skim milk powder (SMP), whey protein concentrate (WPC), cake gel, salt, baking powder, ammonium bicarbonate, sodium bicarbonate, and ammonium iron citrate were procured from the local market. The vanilla flavour was procured from International Flavours and Fragrance India Pvt. Ltd., Chennai.

2.2. Ghee Residue Powder Preparation. Fresh GR (Figure 1(a)) was used to prepare GRP (Figure 1(b)) according to the method mentioned by Thalor [25]. GR used in this study had a total solid of 28.19%, fat of 8.19%, protein of 12.18%, ash of 1.49%, and lactose of 6.32% on a wet basis.

2.3. Muffin Batter Preparation. Flour (24%), baking powder (1.2%), WPC (6%), and SMP (2%) were sieved together using a 12-micron mesh size sieve and were put aside. Shortening (16%) was taken in a Hobart mixer, and creaming was done at medium speed (418 rpm) for 3 minutes. Then, ground sugar (24%) was added and creamed at a medium speed for 4 minutes. The sugar crystal helps in air incorporation; hence, the density of the cream reduces which can be judged by the whitening of the mix. 0.5% cake gel was added to the above mix and creamed for 2 minutes. At low speed (218 rpm), sieved dry ingredients were added in 4-5 individual portions to prevent deaeration and to achieve uniform mixing. Finally, flavour (0.3%) and water (26%) were blended at low speed. The above-prepared batter is

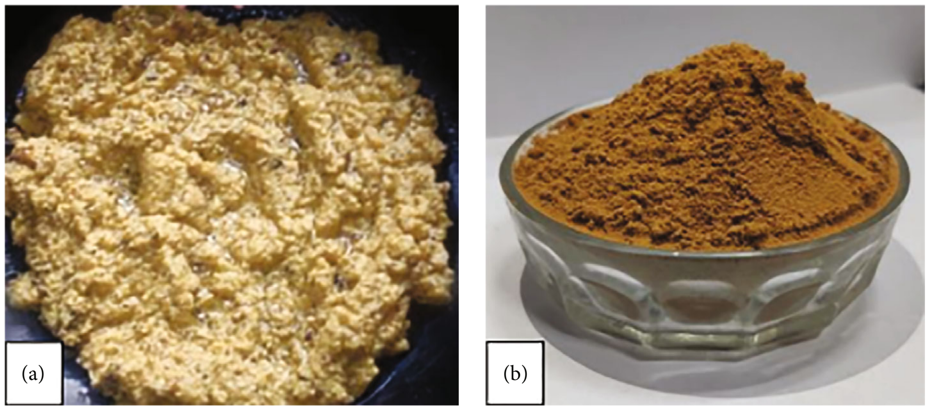

FIGURE 1: (a) Ghee residue and (b) Ghee residue powder.

control and labelled as W. In this study, RWF was replaced with composite flour, and bakery fat was substituted with ghee residue at 0%, 10%, 15%, and 20%, and they were labelled as WB, WB25, WB50, WB75, and WB100, respectively. The batter was filled into muffin moulds which were precovered with the muffin cover and was baked at 180°C for 18 minutes in the conventional oven.

2.4. GR and GRP Analysis. Total solid of GRP was analysed by gravimetric method as per Food Safety Standard Authority of India (FSSAI) [26], fat was extracted using Soxhlet apparatus as per FSSAI [26], protein was analysed by micro-Kjeldahl method as per FSSAI [26], and ash [27] and lactose were analysed by subtraction method.

2.5. Rheological Parameters. Rheological properties of batter were analysed by Anton Paar-MCR 52 Rheometer (Anton Paar, GmbH, Germany), equipped with PP50 (50 mm diameter) parallel plate geometry. During the rheological determinations, a special amenity was given to maintain samples with the same thermomechanical history before testing. Accordingly, the batters were all kept at 25 ± 1.0°C for 1 h after preparation before the rheological test. The batter sample was placed on the bottom Peltier plate and to remove the developed residual stress while loading, a 5 min resting time was given after loading the sample. Then, the top plate was lowered to a 1 mm gap, and the extra batter was trimmed, and the residue on the bottom plate was cleaned up. The exposed edge of the batter sample was covered with a thin layer of liquid paraffin to avoid moisture loss during experiments. The oscillatory amplitude sweep test was conducted at a strain (0.01-100%) and constant frequency (1 Hz) for each batter to obtain a viscoelastic range. All rheological experiments were performed in triplicate.

2.5.1. Flow Properties of Batter. A continuous ramp was applied, and the apparent viscosity was measured as a function of shear rate over the 1.0–1000 s^{-1} range, taking 100 points linearly in time at 25°C. Changes in viscosity were measured with temperature by applying a shear rate of 1 s^{-1} from 25 to 90°C at a heating time of 2°C/min.

2.5.2. Viscoelastic Properties of Batter. Temperature dependence linear viscoelastic behaviour of batter was studied by applying a temperature sweep at 1 Hz from 25 to 85°C at a heating rate of 2°C/min [28]. Storage modulus (G') and loss modulus (G'') were measured continuously as a function of temperature throughout the test. To simulate the effect of heating in the batter structure, a temperature sweep was performed from 25°C to 95°C at a heating rate of 2.0°C/min and a strain amplitude of 0.05%. The strain applied was selected to guarantee the existence of a linear viscoelastic response. Liquid paraffin was applied to the exposed surfaces of the sample. Three replicates from different batches of each formula were measured. Evolution of viscosity with temperature was studied by applying a shear rate of 1 s^{-1} from 25 to 90°C at a heating time of 2°C/minute.

2.6. Specific Gravity (SG) of the Batter. The SG of the raw batter was measured with a small cup of known volume [28]. It was determined gravimetrically by dividing the weight of this known volume of batter by the weight of an equal volume of water. The measurements were made in triplicate.

2.7. Weight Loss. The *muffins* were numbered by marking the underside of the mould and were weighed before (W_2) and after baking followed by one hour of cooling (W_1). The weight loss upon baking was calculated as in

$$\text{Weight loss} = \frac{(W_2 - W_1)}{W_1} \times 100. \quad (1)$$

2.8. Colour Values and Water Activity. A tristimulus spectrophotometer Hunter Lab model Colour Flex® (MiniScan XE plus, Hunter Associates Laboratory Inc., Reston, Virginia, U.S.A.) and the software (version 4.10) were used to measure the colour batter, and the results were expressed in terms of the CIELAB system. Additionally, the total colour difference (ΔE) was calculated using the following formula:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}, \quad (2)$$

where $\Delta L*$, $\Delta a*$, and $\Delta b*$ are differences in the $L*$, $a*$, and $b*$ values between the batter and the product, respectively. The water activity meter of Aqua Lab (Model Series

Table 1: Effect on colour and specific gravity of muffin batter upon fat substitution with GRP.

Batter sample	$L*$	$a*$	$b*$	Specific gravity (cm^3/g)
W	$68.90^{f} \pm 0.26$	$0.08^{a} \pm 0.01$	$24.34^{b} \pm 0.10$	$0.99^{a} \pm 0.02$
WB	$63.32^{e} \pm 0.28$	$1.06^{b} \pm 0.09$	$23.62^{a} \pm 0.08$	$1.05^{c} \pm 0.01$
WB25	$60.37^{d} \pm 0.14$	$4.02^{c} \pm 0.12$	$23.32^{a} \pm 0.10$	$0.99^{a} \pm 0.01$
WB50	$56.58^{c} \pm 1.95$	$4.94^{d} \pm 0.06$	$24.56^{b} \pm 0.11$	$1.04^{bc} \pm 0.01$
WB75	$53.24^{b} \pm 0.90$	$7.86^{e} \pm 0.10$	$27.79^{d} \pm 0.04$	$1.02^{ab} \pm 0.00$
WB100	$50.73^{a} \pm 0.28$	$8.32^{f} \pm 0.05$	$26.20^{c} \pm 0.20$	$1.03^{bc} \pm 0.02$

Data are represented as mean ± S.D ($n = 3$). Values with different superscript letters in different rows of a column differ significantly ($p < 0.05$).

3 TE) supplied by M/s Decagon Devices, WA, USA, was used for the determination of the water activity of batter. The instrument was calibrated with charcoal, and then, the sample readings were taken in triplicate.

2.9. Texture Analysis of Muffin. Textural properties of muffins were measured using TA-HD plus texture analyser (Stable Micro System, USA) provided with Texture Exponent 32 program software. A load cell of 50 kg and a speed of 0.5 mm/s were used for testing. The test was carried out on a Heavy Duty Platform (HDP/90) using a stainless steel probe (75 dia. compression platen -p/75). Analysis was carried out by two compression cycles using the probe. The muffins were cut horizontally at the height of the mould, the upper half was discarded, and the 2.5 cm high lower halves were removed from the mould. A double compression test was performed with a height of 1.25 cm (50% compression) with a 75 mm diameter and 5 s waiting time between the two cycles. The parameters obtained from the curves were hardness, springiness, cohesiveness, gumminess, and chewiness.

2.10. Sensory Evaluation. The GRP-added muffin samples were analysed for sensory parameters and evaluated by an expert panel of 10 judges on a 9-point hedonic scale, wherein a score of 1 represented "dislike extremely" and a score of 9 represented "like extremely." The panelists were asked to score on the following parameters: (a) colour and appearance, (b) body and texture, (c) flavour, (d) sweetness, and (e) overall acceptability.

2.11. Statistical Analysis. The data obtained from the experiments were recorded as mean ± standard deviation and subjected to statistical analysis to arrive at valid and meaningful influences. Data was analysed using one-way ANOVA. The Tukey (HSD) test calculated the least significant differences, and the significance at $p < 0.05$ was determined. These analyses were performed using SPSS for Windows Version 26.0.

3. Results and Discussion

3.1. Chemical Composition of GRP. GRP had a fat content of $46.09 \pm 0.44\%$, protein of $31.18 \pm 0.13\%$, lactose of $16.55 \pm 0.45\%$, and ash of $4.91 \pm 0.03\%$. Thalor [25] has mentioned a similar composition for the manufactured GRP samples. Due to a lack of literature, it was not able to compare with similar materials.

3.2. Physical Parameters of Batters. Table 1 depicts the physical parameters of the batters. The lightness of wheat batter (W) was 68.90 and WB was 63.32, and by replacing WPC with the GRP, the lightness of the batter decreased from 63.32 to 50.73. Higher $L*$ values in W batter is due to the whiter colour of RWF. When RWF was replaced with 50% of PMF, the redness value increased to 1.06 and $L*$ decreased to 63.32, which is due to the dull colour of PMF. Furthermore, when WPC is substituted with GRP, the redness value increases from 4.02 to 8.32 significantly ($p < 0.05$). The decrease in $L*$ value and increase in $a*$ and $b*$ are associated with the strong yellow-orange colour of the GRP. The yellowness value of W batter was 24.34, and when it was substituted with pearl millet flour, the yellowness decreased to 23.62; when WPC was replaced with GRP, the yellowness began to increase from 23.32 to 26.20.

The amount of air incorporated in the batter is indirectly indicated by the specific gravity of the batter [29]. This attribute eventually leads to the desirable spongy, fluffy, and high-volume product. The specific gravity of the RWF batter (W) was lower; however, when pearl millet was substituted for RWF, the specific gravity increased to 1.05 cm^3/g, and further, the specific gravity was increased when WPC was replaced with ghee residual powder. According to Lindarte Artunduaga and Gutiérrez [30], the smaller the specific gravity of the batter, the higher amount of air will be incorporated during baking. WB25 batter showed a similar specific gravity as W batter. The increase in specific gravity shows the higher batter density and lesser air incorporation. Agrahar-Murugkar et al. [9] reported similar results of specific gravity for gluten-free eggless cake.

3.3. Flow Properties of Muffin Batter

3.3.1. Viscosity as a Function of Shear Rate. Viscosity plays an important role in aerated batters during baking. The final quality like sponginess, bubble size, air cell, height, and volume of muffins depends on the initial viscosity as well as the evolution of apparent viscosity during baking. In Table 2, the wheat batter (W) had the highest viscosity among the batters, as well as the lowest specific gravity. That indicates better foam stability, air incorporation, and retention. But the viscosity decreased when RWF was replaced with PMF. The obtained result could be related to the system's dilution of RWF protein, which is a key component for mixing structure development [31]. Further replacement of WPC with

Table 2: Viscosity of the muffin batters.

	W	WB	WB25	WB50	WB75	WB100
Viscosity (Pa·s)	$13.83^{b} \pm 1.87$	$9.04^{a} \pm 1.83$	$9.22^{a} \pm 1.51$	$7.08^{a} \pm 1.87$	$8.24^{a} \pm 0.54$	$10.71^{ab} \pm 1.43$

Data are represented as mean ± S.D ($n = 3$). Values with different superscript letters in different columns of a row differ significantly ($p < 0.05$).

GRP increased the viscosity, which is due to the increase in protein content of GRP upon replacement.

The apparent viscosity was measured as a function of shear rate in the range of 0.1–1000 s^{-1} with 100 points at 25°C. Figure 2 demonstrates the apparent viscosity vs. shear rate for muffin batters made with different levels of WPC substitution with GRP. With the application of the shear rate, all batters showed shear thinning behaviour [28].

3.3.2. Viscosity as a Function of Temperature. The viscosity of the muffin batter was examined over a temperature range of 25 to 90°C (Figure 3) to approximate the gelatinization temperature of the batter during baking. The viscosity of the batters reduced with increasing temperature. The viscosity began to rise after 80°C, indicating the commencement of starch gelatinization. A decrease in the end product volume has been linked to lower batter viscosity during heating [32]. During the heating process, higher viscosities reduce coalescence, migration, and loss of air cells before the batter sets. Higher viscosity during heating would allow the batters to retain a better form by expanding air nuclei and resisting starch granule settling, resulting in improved cake volume and crumb grain [28]. The substitution of PMF and GRP in a batter caused a reduction in viscosity during the initial heating stage, which may be probably due to the dilution of gluten protein. Gluten provides a unique viscoelasticity; hence, it is used extensively in the preparation of bakery products [33]. The low viscosity in a batter indicates less air incorporation, and the resultant product will be of low volume. Shaabani et al. [34] obtained a similar result of low viscosity for gluten-free muffin prepared from millet flour.

3.3.3. Viscoelastic Properties of Different Batters during Heating. The linear viscoelastic characteristics of the muffin batter were examined over a temperature sweep from 25 to 85°C to approximate the structural changes in the batter during baking. But temperature in rheometer was not the same as in the oven (180°C for 18 min), and this test was done to distinguish the series of structural changes that occur during heating. G' indicates the storage modulus (elastic behaviour), G'' indicates the loss modulus (viscous behaviour), and tan δ indicates an overall viscoelastic response of the material [35]. The G', G'', and tangent δ were plotted against the temperature by keeping the constant frequency (1 Hz) as shown in Figures 4 and 5. Both the G' and the G'' were dropped when the temperature rose from 25 to 85°C. However, when the temperature was raised to 30°C, both moduli were increased. Matos et al. [36] noticed a similar tendency, where they associated that this effect could be possibly due to protein-protein interactions. The results obtained were in agreement with the observations of Baixauli et al. [28]. The storage modulus of all the batters was greater than the loss modulus, indicating soft gel behaviour. When compared to all other batters, WB75 and WB100 showed lower storage modulus, indicating that the batter was too liquid in nature. We can see from Figure 4 that the sudden decrease of G' from 28°C to 40°C due to the melting of fat and an increase in tg δ (Figure 5) over this temperature indicate the decrease in batter viscoelasticity. A smooth decrease in G' is observed from 40°C to 51°C whereas tg δ is stable at this temperature range. This may be due to the production of carbon dioxide as it diffuses into the occluded air in the batter. Hence, the batter density

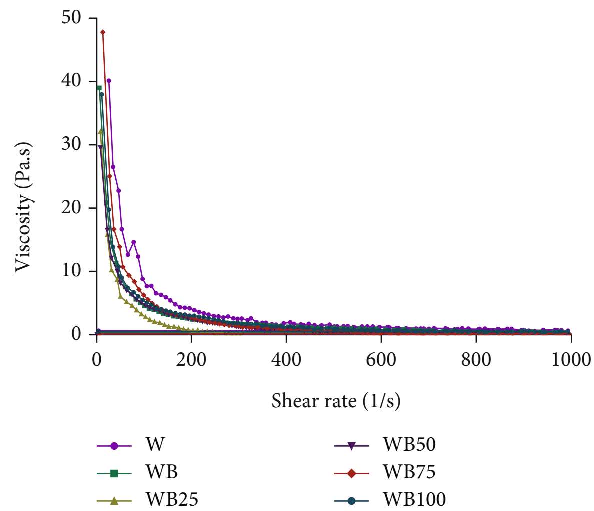

Figure 2: Influence of substituting WPC with different levels of GRP on the flow properties of a muffin batter at 25°C.

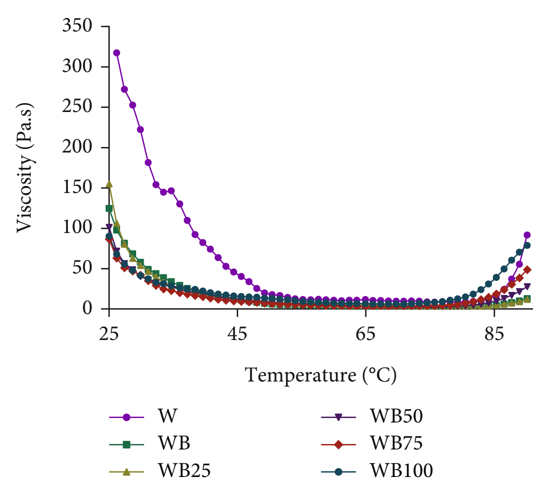

Figure 3: Evolution of viscosity during heating.

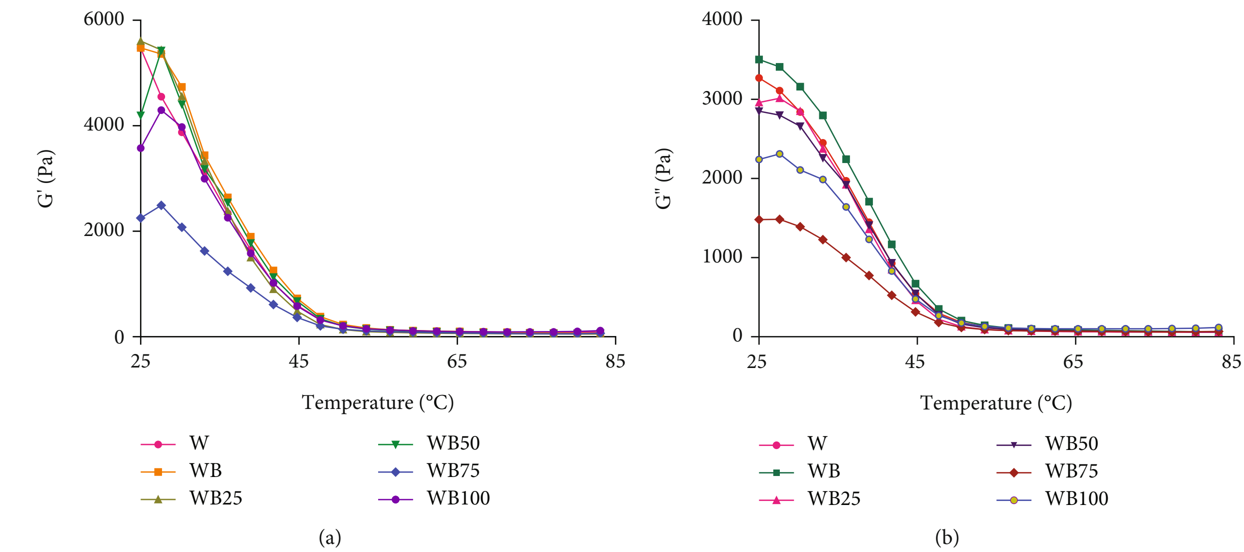

Figure 4: Influence of GRP levels in the muffin batter on the evolution of G' and G'' with temperature. Heating rate: 0.032°C/s. Strain wave amplitude: 0.05 (W, WB, WB25, WB50, WB75, and WB100). Frequency: 1 Hz (a) Storage modulus and (b) Loss modulus.

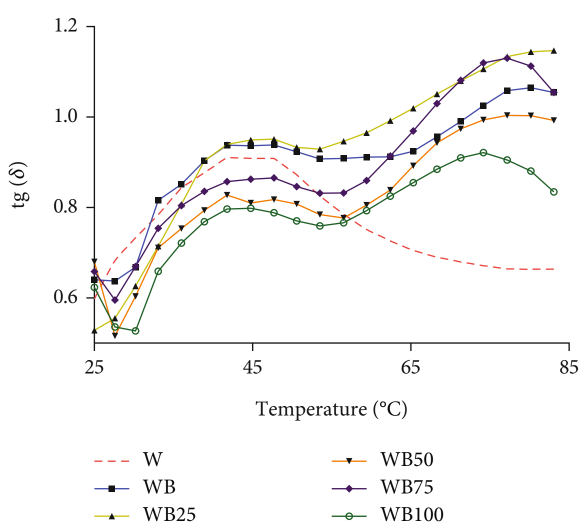

Figure 5: Influence of GRP levels in the muffin batter on the evolution of loss of tangent values (tg δ) with temperature. Heating rate: 0.032°C/s. Strain wave amplitude: 0.05 (W, WB, WB25, WB50, WB75, and WB100). Frequency: 1 Hz.

is reduced. A similar observation was also reported by Martínez-Cervera et al. [37]. The G' continues to decrease thereafter till 85°C, but tg δ increased showing the viscous property of the batter.

It was stated that lower tan δ values for RWF-based batter indicate a batter that was more elastic, stronger, and time-stable [38]. The consistency of the batter determines the ultimate quality of the muffins. Lower batter viscosities during heating have been associated with lower volume of final products [32]. Figure 5 shows that, except for the wheat flour batter (W), all other batters had a greater tangent delta, indicating that they behaved viscously at 85°C, which is undesirable. Furthermore, Herranz et al. [38] also mentioned that the higher tan delta values (tg δ near to 1) indicated that the protein was not heat stable. In this regard, substituting PMF for RWF dilutes the gluten protein, and substituting whey protein concentrate for GRP caused the batter to behave highly viscous even at higher temperatures.

3.4. Proximate Analysis of Muffin. The proximate composition of the muffin is given in Table 3, as the highest moisture was retained in the WB75 muffin and the lowest in the pearl millet (WB) muffin. The fat levels were increased when WPC was replaced with GRP due to the presence of high fat in GRP. Protein content was found to be decreased with the replacement, and this could be due to low protein content in GRP when compared to WPC. Ash was also found to be increasing with an increase in the degree of WPC substitution with GRP. These results obtained were in accordance with Sharoba [39] who reported on pearl millet flour-based cake. The acid-insoluble ash ranged from 0.07 to 0.10, and lower values were obtained for WB batter, and W and WB25 had similar values, and upon GRP substitution, the values increased due to higher ash content (4.91%) of GRP.

3.5. Crumb Colour and Water Activity of Eggless Pearl Millet-Based Muffin. The instrumental values for lightness ($L*$) and colour ($a*$, $b*$ values) for muffin samples are shown in Table 4. When RWF was substituted with PMF, the $L*$ values were reduced from 67.55 (W) to 53.21 (WB), which could be due to the contribution of dullness from PMF. Umashankar et al. [40] also reported similar findings. The lightness of the crumb was further reduced when WPC was replaced with GRP. The redness of muffins ranged from 0.71 to 10.66, and it increased when the amount of GRP was increased. With GRP substitution, yellowness increased up to a level of 50% replacement and then significantly decreased ($p < 0.05$). The strongest colour of GRP increased $a*$ and $b*$ values and decreased the $L*$ value. ΔE represents the colour difference value between batter and the

Table 3: Effect of different levels of GRP on the proximate values of eggless pearl millet-based muffin.

Batter sample	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Acid-insoluble ash
W	$24.14^{ab} \pm 1.82$	$18.69^{c} \pm 0.52$	$9.68^{f} \pm 0.03$	$0.89^{a} \pm 0.03$	$0.07^{ab} \pm 0.00$
WB	$20.77^{a} \pm 0.52$	$16.68^{a} \pm 1.15$	8.94d ± 0.05	$0.96^{ab} \pm 0.01$	$0.06^{a} \pm 0.01$
WB25	$23.78^{ab} \pm 0.49$	$17.45^{b} \pm 0.35$	$9.22^{e} \pm 0.03$	$1.00^{ab} \pm 0.01$	$0.07^{b} \pm 0.00$
WB50	$24.01^{ab} \pm 1.19$	$18.76^{c} \pm 0.51$	$8.09^{c} \pm 0.03$	$1.07^{bc} \pm 0.06$	$0.08^{c} \pm 0.01$
WB75	$25.31^{b} \pm 1.49$	$20.12^{d} \pm 0.48$	$7.64^{b} \pm 0.10$	$1.18^{c} \pm 0.05$	$0.09^{d} \pm 0.01$
WB100	$24.10^{ab} \pm 1.60$	$20.37^{d} \pm 0.08$	$6.68^{a} \pm 0.05$	$1.20^{c} \pm 0.08$	$0.10^{e} \pm 0.00$

Data are represented as mean ± S.D ($n = 3$). Values with different superscript letters in different rows of a column differ significantly ($p < 0.05$).

Table 4: Effect on colour and water activity of muffin upon WPC substitution with GRP.

Batter sample	$L*$	$a*$	$b*$	ΔE	a_w
W	$67.55^{f} \pm 0.13$	$0.71^{a} \pm 0.09$	$20.72^{bc} \pm 0.16$	$3.90^{a} \pm 0.12$	$0.903^{ab} \pm 0.002$
WB	$53.21^{e} \pm 0.12$	$1.41^{b} \pm 0.04$	$20.07^{b} \pm 0.22$	$10.72^{b} \pm 0.28$	$0.904^{ab} \pm 0.013$
WB25	$41.58^{d} \pm 0.29$	$5.13^{c} \pm 0.09$	25.54c ± 0.26	$18.94^{d} \pm 0.22$	$0.891^{a} \pm 0.011$
WB50	$39.38^{c} \pm 0.56$	$6.27^{d} \pm 0.06$	$21.07^{a} \pm 0.27$	$17.14^{c} \pm 0.59$	$0.908^{ab} \pm 0.014$
WB75	$34.95^{b} \pm 0.48$	$7.11^{e} \pm 0.12$	$20.01^{b} \pm 0.41$	$19.89^{de} \pm 0.36$	$0.914^{b} \pm 0.015$
WB100	$32.36^{a} \pm 0.28$	$10.66^{f} \pm 0.06$	$16.28^{a} \pm 0.35$	$21.01^{e} \pm 0.55$	$0.902^{ab} \pm 0.012$

Data are represented as mean ± S.D ($n = 3$). Values with different superscript letters in different rows of a column differ significantly ($p < 0.05$).

product. Table 4 clearly says that muffin made with RWF had lowest changes compared to other batters. As when RWF is replaced 50% with PMF, ΔE value increased significantly ($p < 0.05$) to 10.72. Further, GRP substitution impacted drastic difference in the colour difference value of all the batter. With increase in GRP level, ΔE values increased significantly ($p < 0.05$). WB75 had the highest water activity, while WB25 had the lowest. The determination of water activity is crucial to ensure the shelf life of muffins and consumer acceptability.

3.6. Physical Properties of Muffin. Table 5 shows the physical properties of muffins. The weight loss of a muffin prepared using RWF (W) was ~12.14%, and then, the weight loss was reduced to ~11.91% when RWF was substituted with pearl millet flour, although the difference was statistically insignificant ($p < 0.05$). According to De La Hera et al. [41], moisture loss was greater in flours with lower gluten concentration due to a lack of water binding capacity, and Thalor [25] reported that the water binding capacity of GRP is around 2.2 g/g of protein. So, we can conclude that the moisture retention in the WPC-replaced muffins may be impacted by the presence of GRP. When RWF was replaced with PMF, the volume of the WB muffin was lowered to ~51.47 cm^3. This could be due to lower levels of gluten protein. When WPC is replaced with GRP, the volume of the muffins decreases, either due to a higher specific gravity value or fewer air cells incorporated and inadequate air bubble retention capacity of the muffin batter [29]. According to Gomez et al. [42], the volume of a muffin can also depend on the amino acid composition of the flour and the amount of protein. So from the above inference, we can say upon substitution, the volume keeps decreasing due to lower amount of protein.

Table 5: Effect of substitution of GRP on physical properties of muffin.

Batter sample	Weight loss (%)	Volume (cm^3)
W	$12.14^{a} \pm 0.65$	$56.19^{c} \pm 8.56$
WB	$11.91^{a} \pm 0.09$	$51.47^{bc} \pm 3.37$
WB25	$13.35^{bc} \pm 0.38$	$42.19^{a} \pm 5.35$
WB50	$12.63^{ab} \pm 0.79$	$44.48^{ab} \pm 3.79$
WB75	$12.74^{abc} \pm 0.58$	$45.17^{ab} \pm 4.01$
WB100	$13.68^{c} \pm 0.50$	$36.84^{a} \pm 0.50$

Data are represented as mean ± S.D ($n = 6$). Values with different superscript letters in different rows of a column differ significantly ($p < 0.05$).

3.7. Textural Properties of Muffin. Table 6 shows the effect of GRP on the textural quality of eggless pearl millet-based muffins. All textural qualities reduced quietly; when RWF was replaced with PMF except springiness, the former had highest compared to earlier one. Gumminess in WB muffin is decreased ($p < 0.05$), due to the decrease in gluten content in WB compared to W muffin. All textural qualities fell drastically when WPC was replaced with GRP, except the hardness of WB25. The muffins were less elastic due to a decrease in cohesiveness, springiness, and resilience. Lower resilience denotes that the muffins were less spongy, as they take a

Table 6: Effect of substitution of GRP on textural properties of muffin.

Textural characteristics	W	WB	WB25	WB50	WB75	WB100
Adhesiveness (g·s)	-0.85 ± 0.41	-0.66 ± 0.29	-1.17 ± 0.27	-1.86 ± 1.96	-2.00 ± 1.29	-1.28 ± 0.55
Springiness (mm)	$0.56^{cd} \pm 0.07$	$0.59^{d} \pm 0.05$	$0.50^{bc} \pm 0.03$	$0.46^{b} \pm 0.03$	$0.32^{a} \pm 0.01$	$0.25^{a} \pm 0.01$
Cohesiveness	$0.48^{d} \pm 0.04$	$0.39^{c} \pm 0.05$	$0.34^{bc} \pm 0.01$	$0.31^{b} \pm 0.03$	$0.19^{a} \pm 0.02$	$0.17^{a} \pm 0.00$
Gumminess (N)	$1.59^{d} \pm 0.1$	$1.12^{bc} \pm 0.42$	$1.51^{cd} \pm 0.10$	$0.83^{ab} \pm 0.16$	$0.52^{a} \pm 0.08$	$0.40^{a} \pm 019$
Chewiness (N·mm)	$0.90^{b} \pm 0.17$	$0.68^{b} \pm 0.28$	$0.75^{b} \pm 0.07$	$0.38^{a} \pm 0.01$	$0.06^{a} \pm 0.01$	$0.10^{a} \pm 0.05$
Resilience	$0.17^{c} \pm 0.02$	$0.14^{c} \pm 0.02$	$0.11^{b} \pm 0.01$	$0.10^{b} \pm 0.01$	$0.06^{a} \pm 0.01$	$0.05^{a} \pm 0.00$
Hardness (N)	$3.31^{c} \pm 0.21$	$3.15^{c} \pm 0.29$	$4.43^{d} \pm 0.29$	$2.62^{b} \pm 0.28$	$2.63^{b} \pm 0.21$	$1.82^{a} \pm 0.23$

Data are represented as mean ± S.D ($n = 5$). Values with different superscript letters in different columns of a row differ significantly ($p < 0.05$).

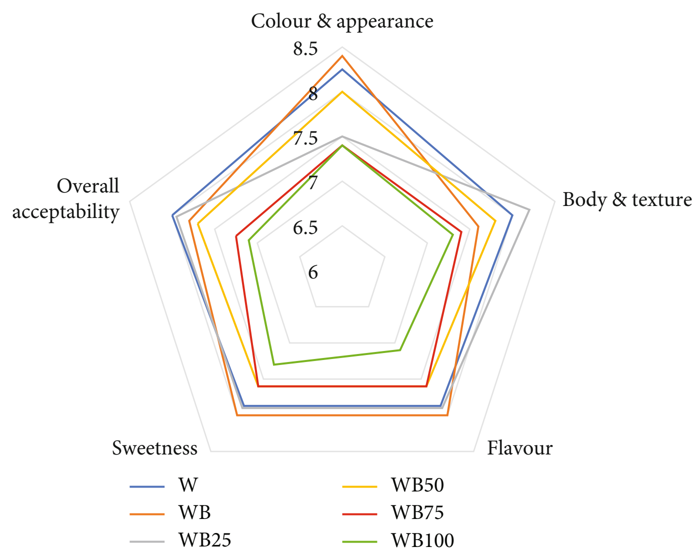

Figure 6: Radar diagram of sensory score of a muffins.

Figure 7: Longitudinal section view of muffins.

longer duration to recover after compression [43]. Generally, denser material means less air-incorporated batter, showing low resilient values. The resilient value of instrumental texture values is easily comparable to the specific gravity of batter, confirming the weak foam stability of GRP batters. Springiness is related to fresh, aerated products; hence, high springiness values indicate good muffin quality [44]. The data in the table clearly shows that the higher replacement of WPC deteriorates the textural properties of the muffin. The hardness of muffins from GRP had lower values due to GRP's low water binding capacity. Chewiness refers to how hard to chew a sample between the jaws to be ready for swallowing. The GRP batters are significantly ($p < 0.05$) different from W and WB except for WB25. The values are dramatically decreased for GRP batters. Replacement of RWF reduced the chewiness in PMF added muffin (WB).

3.8. Sensory Evaluation of Muffin. Figure 6 depicts the sensory scores of muffins. The W-coded batter sample got the highest score of colour and appealing quality. This muffin secured the highest score in terms of colour and appearance, taste and texture, and overall acceptability. The RWF muffin had very fine cells and a smooth, fluffy texture (Figure 7). The sensory evaluation revealed a difference in the mean scores of sensory. The score (7.80) of WB muffin decreased with the replacement of RWF with PMF. However, the score of flavour and sweetness in WB muffins recorded the highest compared to muffins made from exclusively RWF. A similar trend was observed by Mallasiy et al. [45], and the overall acceptability of bound cake decreased with the replacement of RWF with PMF. Further, the GRP substitution decreased the score of colour with an increase in GRP. The decrease in colour value is associated with the dull yellow colour of PMF and the strong yellow-orange colour of the GRP. The flour replacement caused the low loaf volume in the muffins, and a further decrease in loaf volume was observed when WPC was replaced with GRP. The flavour and sweetness of the WB muffin were slightly enhanced when RWF was replaced with pearl millet flour, but not drastically. Again, GRP substitution caused a reduction in the flavour and sweetness score. All sensory attributes were decreased when WPC was replaced with GRP. The body of the muffin collapsed when more than half of the WPC was replaced with GRP, while WB75 and WB100 had surface cracking in the crust, rendering them unsuitable for muffin production. The GRP was only able to replace up to 50% of the WPC. Vinay [46] got the highest overall acceptability score for millet biscuits made from 50% RWF and 50% PMF.

4. Conclusions

The manufactured GRP had protein of 31% and fat of 46.09%, which can act as a functional and flavouring food ingredient. The GRP having a strong orange-yellow colour might be used as a colour source. Upon substitution of RWF with PMF in batter increased the specific gravity of batter, further GRP substitution caused the high specific gravity batter and the colour values of the batters considerably decreased. Rheological data showed that the shear thinning behaviour of all batter samples and substitution of GRP caused the reduction in the viscosity of batters. In the flow properties, the commencement of starch gelatinization was approximated and the commencement started somewhere around 85°C; the higher gelatinization temperature was obtained due to the high sugar content in the batter. All batter samples behaved like soft gel, and in all batters, the storage modulus was higher compared to the loss modulus. Higher $a*$ and $b*$ values were obtained for GRP-substituted muffin. Considerable weight loss and 8.4% reduction in volume of muffins were obtained in PMF-substituted muffins. Further, 34.43% reduction occurred in GRP-added muffins. Poor textural quality parameters were obtained for GRP and PMF muffins compared to control W batter. Overall results showed that GRP can only substitute 25% of WPC; thereafter, poor-quality muffins are obtained; hence, we conclude that GRP alone cannot function as an emulsifying agent to replace both egg and WPC. Maillard's products present in the GRP mimic the colour of cocoa powder and contribute to antioxidant and may act as antioxidants as well.

Data Availability

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

Ethical Approval

All participants engaged in the sensory evaluations were experienced panel members who underwent thorough training and possessed a comprehensive understanding of the study's objectives, procedures, and potential risks. Prior to conducting any tests, explicit consent was obtained from each participant. The study was executed under standardized environmental conditions, and the outcomes were meticulously and transparently documented. Approval from the National Dairy Research Institute in Karnal was secured before commencing the study, with the following assigned approval ID: NDRI/DT/RES/4652-13. The selected methodology demonstrated a high level of competitiveness.

Conflicts of Interest

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

Authors' Contributions

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

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