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Research article

Leavening capacity, physicochemical and textural properties of wheat dough enriched with non-commercial unripe banana flours

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Abstract: Banana is a highly nutrient-dense, widely produced and consumed tropical fruit. *Luvhele* and *mabonde* non-commercial unripe banana cultivars were used to produce the flour and substituted the wheat flour at four levels (10%, 20%, 30% and 40%) for dough production. The water and oil holding capacity of the blended flour samples and the pH, titratable acidity, leavening capacity, proximate composition and texture of the dough were determined. Incorporation of *Luvhele* and *Mabonde* flour improved the blended flours' water and oil holding capacity. At 0 min and level 40%, the pH of the dough sample decreased from 5.79 (control) to 5.27 in both banana cultivars. The volume of the dough decreased from 195.00 mL (control) at 30 min to 128.33 mL (*luvhele*) and 125.00 mL (*mabonde*), respectively. The proximate composition of the blended dough increased in terms of ash, fiber, fat and carbohydrate. However, a decrease in protein and moisture contents at $p < 0.05$ was also observed. The hardness of the dough increased significantly with increased amounts of unripe banana flour substitutions. On the other hand, the control sample recorded a high cohesiveness (1.22). Doughs added with *mabonde* flour recorded high adhesion. The results of this work demonstrate that non-commercial unripe banana flour can be used as an alternative functional component for baked products with improved nutritional value.

Keywords: banana; dough volume; pH; proximate composition; and textural properties

1. Introduction

Banana is an elongated, edible fruit of the genus Musa of the family *Musaceae* [1]. After citrus, the banana is the second most cultivated fruit, accounting for around 16% of global fruit production [2]. Banana is among the most important commercial subtropical fruits grown in South Africa for sale in local markets or for home consumption [3]. *Luvhele* and *Mabonde* banana varieties (Musa species) are grown in the Limpopo province, South Africa. They are classified as non-commercial or indigenous varieties as they are seldom grown for trade or export but are cultivated by smallholder farmers in home gardens for consumption [4]. Green bananas are rich in fiber, minerals (zinc, magnesium, phosphorus, potassium), vitamins (ascorbic acid, provitamin A, vitamin B_6), phenolic compounds, resistant starch and pectin, which are satiating, aid digestion and reduce blood sugar levels [5,6].

Consumption of fresh unripe bananas is rare amongst populations compared to ripe bananas due to their undesirable taste. During ripening, mature bananas are subjected to mechanical damage and spoilage, making storage and transportation complex [1]. According to Babu *et al.* [7], about one-fifth of the total unripe bananas produced are wasted, and the rejected bananas are usually discarded. Bananas are characterized by high starch/resistant starch content at the green ripening stage, which attracts the industry's interest in developing new food products [8]. Subsequently, an innovative approach to utilising green bananas is to dry the fruit and process it into banana flour. This increases the value of banana plants by decreasing waste and losses in the manufacturing chain, increasing sustainability, and utilizing some nutrients lost during ripening [9,10]. The use of unripe banana flour is important as an alternative raw material for the processing of healthy functional products. Moreover, a combination of unripe banana flour and other gluten-free flours have been promoted for use in starchy foods such as bread, pasta, biscuits and cakes [11,12].

The dough is a complex mixture of flour and ingredients such as water, yeast, salt and other components that transform wheat into bread and other items such as biscuits and rolls [13]. Gluten is a protein in wheat *(Triticum spp.*), which forms an elastic dough when mixed with water and handled mechanically, giving leavened bread its distinctive and desirable texture [14]. The amount of energy input during mixing creates the characteristics of the dough with the proper balance of elasticity and viscosity properties, traps the gas and can pass through various bread-making stages (sheeting, shaping, etc.) [15].

Due to size, appearance defects and lack of market for locally produced, over 20% of banana production is not sold, resulting in increased losses [3]. Given the high rate of banana losses across the supply chain, using unripe bananas at an early stage could be a potential approach for reducing the postharvest loss of bananas. Drying and processing unripe bananas into flour can produce a storable ingredient incorporated with other alternative flour to make cereal-based products such as pasta, bread, rolls and cakes. Unripe banana flour can also be marketed as gluten-free flour, an alternative for people with gluten allergies. There is little data regarding the utilization of non-commercial unripe banana flour in bakery products. Mashau *et al*. [16] investigated the impact of two unripe non-commercial banana cultivars (l*uvhele* and *mabonde*) on biscuits' physical, antioxidant and sensory properties. Results showed that the inclusion of both unripe banana flours increased physical characteristics such as weight, diameter, thickness and antioxidant properties of the biscuits. Nevertheless, consumers preferred biscuits added with up to 10% unripe banana flour. The novelty of this research arises from the usage of unripe *luvhele* and *mabonde* banana flours in the preparation of wheat dough and reporting the results for the very first time. We aimed to determine the leavening capacity, textural and physicochemical characteristics of wheat dough added with non-commercial unripe banana flours at different ratios. The results of this study are expected to help improve the utilization of non-commercial banana cultivars in food products.

2. Materials and methods

2.1. Raw materials

Unripe non-commercial banana varieties of *luvhele* and *mabonde* (Musa species) were obtained from household farms around Ngovhela village, Thohoyandou, South Africa. Yeast, wheat flour, salt, sugar and fat were purchased from a local shop. Chemicals were purchased from Merck, Midrand, South Africa and were of analytical grade.

2.2. Unripe banana flour preparation

The fruits (l*uvhele* and *mabonde*) were washed thoroughly, peeled by hand, cut into small slices with a knife and immediately immersed in a 10 g/L citric acid solution (to prevent oxidative browning) for 10 min [17]. After 2 min, the mixture (organic acid pre-treatment and sliced pulp) was drained. A forced-air oven was used to dry banana pulp at 70 ℃ for 24 h. Dried pulp was milled using Salton stainless steel jug blender and sieved using a 250 µm sieve until fine-milled flour was obtained. The flour was packed in polythene plastic and stored at 4 ℃ for dough-making.

2.3. Formulations for dough production using blended flours and other ingredients

The brown bread wheat and banana flours were mixed at a ratio of 100:0; 90:10; 80:20; 70:30; and 60:40, as shown in Table 1. Brown bread wheat flour served as a control. The resultant dough was prepared using the straight dough method [18]. All the ingredients were weighed and placed in a bowl for mixing and kneading (flour, salt, water, sugar, yeast, etc.). Baking pans smeared with vegetable oil were used to place different dough samples and allowed to ferment at 30 ℃ for 90 min while covered with a damp cloth, resulting in gas generation and gluten development. Three batches of dough were produced on different days and stored in polythene plastic bags at 4 ℃ for further analysis.

Table 1. Recipe formulation for dough production.

Ingredients	A	B	C	D	E
Brown bread Wheat flour (g)	100	90	80	70	60
Banana flour (g)	0	10	20	30	40
Salt (g)	2.5	2.5	2.5	2.5	2.5
Fat (g)	2	2	2	2	2
Yeast (g)	2.5	2.5	2.5	2.5	2.5
Sugar (g)	2	2	2	2	2
Water (mL)	65	65	65	65	65

2.4. *Determination of water and oil absorption capacity of the flour*

The control and blended flour's water and oil holding capacity were measured, as explained by Anyasi *et al.* [4]. In 15 mL centrifuge tubes, one gram of each flour sample was weighed. About 10 mL of distilled water was added to each sample and mixed for 2 min using a vortex. The samples were then allowed to rest for 30 min at room temperature. The mixtures were centrifuged for 20 min at 3000 rpm. The sediment-filled centrifuge tube was weighed after the supernatant was decanted.

About one gram of mixed flour was weighed in 15 mL centrifuge tubes for oil holding capacity. Ten millilitres of cooking oil were poured into each sample and mixed for 2 min. The mixtures were allowed to rest for 30 min at room temperature before being centrifuged for 20 min at 3000 rpm. After that, each supernatant was put into a 10 mL graduated cylinder, and the volume was measured.

2.5. *The leavening capacity of the dough*

The kneaded dough samples were transferred to a measuring cylinder at 100 mL and incubated. The leavening behavior of the dough samples was measured after 30, 60 and 90 min of incubation by contrasting the initial volume to the volume observed after each incubation interval [19].

2.6. *pH and total titratable acidity of the dough*

During fermentation times of 0, 30, 60 and 90 min, the dough samples' pH and total titratable acidity (TTA) were measured. Each dough sample's pH was measured using a Crison digital pH meter (Crison instrument, South Africa). To determine the TTA of each sample, 10 g of dough was mixed with 90 mL of distilled water in a beaker to homogenise it. Once all the dough had dissolved, 100 g of the sample was titrated with 0.1M NaOH to a pH of 8.3. The amount of acid produced was calculated in volume (mL) [19].

2.7. *Proximate composition of the dough*

The AOAC method [20] was used to measure the proximate composition of the dough samples. The hot air-drying method No 925.10 was used to measure the moisture content. The micro-Kjeldahl method was used to determine the crude protein. Soxhlet extraction method No 920.39 was used to determine the fat content of dough samples. The ash content was measured using a muffle furnace at 550 ℃ using method No 923.03. Fiber Tech method No 962.09 was used to measure the crude fiber. The carbohydrate percentage was calculated using the percentages of moisture, ash, fat, fiber and protein method using the following formula.

$$Carbohydrate = 100 - (\%Moisture + \%Protein + \%Ash + \%fat + \%Crude\ fiber) \quad (1)$$

2.8. *Color analysis of the dough*

Color coordinate values L* (lightness/darkness), a* (redness/greenness) and b* (yellowness/blueness) were recorded for dough samples using a Hunter Lab Scan XE Spectrophotometer CIELAB [9]. The formulae below were used to calculate hue and Chroma from these coordinates.

$$Hue\ (H°) = \tan^{-1}\left\{\frac{b*}{a*}\right\} \tag{2}$$

$$Chroma = \sqrt{(a*)^2 + (a*)^2} \tag{3}$$

2.9. Textural properties of the dough

A method of Devi *et al.* [21] was used to measure the texture of the dough. The texture analyzer (TAXT2i Stable Micro Systems, Surrey, UK) was used to measure the dough's hardness, adhesiveness and cohesiveness.

2.10. Statistical analysis

The experiment was replicated on different days and analyzed in triplicate. One-way analysis of variance (ANOVA) was used to perform the statistical analysis (using SPSS) software (version 26.0, IBM SPSS, Armonk, NY, USA). Duncan’s multiple range test was used to compare means for treatments. The significance test was set at $p < 0.05$.

3. Results and discussions

3.1. Oil and water absorption capacity of the blended flour

Figure 1 shows the control and blended flour's water and oil absorption capacity. The water absorption capacity (WAC) indicates the magnitude occupied by starch granules after swelling more than water [22]. The WAC of wheat and blended flour samples showed a significant difference at $p < 0.05$. A high WAC value was observed in the flour sample with 40% *luvhele* (2.69 g/g), while the control sample had a lower WAC of 1.58 g/g. The amount of protein, degree of interaction with water and conformational characteristics might be responsible for the observed variations in blended and control flour samples [23]. Moreover, banana flour is rich in dietary fiber, which enabled it to entrap more water than wheat flour [24]. The high WAC of wheat flour added with 40% *luvhele* flour might be associated with greater hydroxyl groups in its fiber structure, facilitating increased hydrogen bonding and greater interactions with water [25]. Higher WAC of the dough added with 40% *luvhele* flour means that excessive milling of the flour and sieving resulted in the modification of protein structure. Nevertheless, a higher WAC of wheat flour added with 40% *luvhele* flour means that bakery products incorporated with it may retain a softer texture, affecting quality characteristics such as crispiness and general acceptability. Patel *et al*. [26] indicated that lubrication and moisture retention are the two most valuable characteristics of bakery fat needed to develop various types of dough recipes. The high WAC of blended flour samples demonstrated these characteristics of bakery fat. All blended flours showed favorable WAC, thus making them a functional ingredient in producing baked goods or ready-to-eat foods. Ho *et al.* [27] obtained similar data of increased WAC for wheat-green banana flour blends to prepare steamed bread.

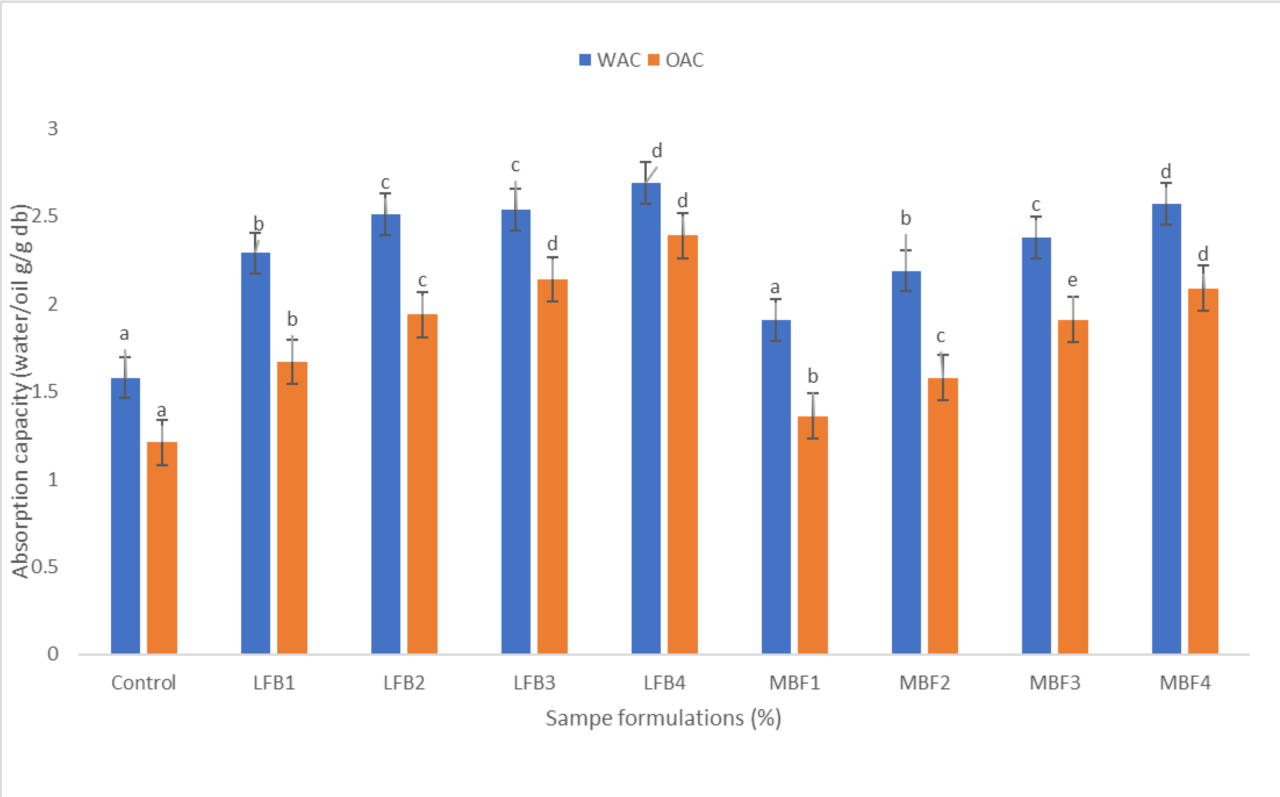

Figure 1. Water and oil absorption capacity of blended flours. Values are means ± standard deviations of three independent trials. Different letters within columns denote significant differences ($p \leq 0.05$). Control = 100% wheat flour, LFB1-4 = Wheat dough with 10, 20, 30 and 40% *luvhele* banana flour, MBF1-4 = Wheat dough with 10, 20, 30 and 40% *mabonde* banana flour. WAC = Water absorption capacity, OAC = Oil absorption capacity.

The capacity of food material to absorb oil is measured by its oil absorption capacity (OAC). The OAC showed a significant increase ($p < 0.05$) ranging from 1.21 to 2.39 g/g in *luvhele* and 1.36 to 2.09 g/g in *mabonde* blended flours. The hydrophobic nature of the protein in 40% *luvhele* blended flours could account for the high OAC. Ohizua *et al*. [28] reported that protein availability makes more non-polar amino acids to be exposed to fat, increasing the flour's hydrophobicity and facilitating high oil absorption. Moreover, the addition of fat during flour preparation might have contributed to the high AOC of blended flours because it served as an emulsifier. The emulsifier consists of both lipophilic and hydrophilic characteristics; thus, it provided a chance to react at the water-oil interphase.

The amphiphilic part took part in producing the complex structure with protein and starch since there was increasing emulsion ability [29]. In general, the role of emulsifiers in the baking industry is to improve the strength of the dough and water absorption rate. The mechanisms of emulsifiers to improve the characteristics of the dough are attributed to their capacity to bind to glutens and to form complexes with starch [30,31]. Emulsifiers bind the protein hydrophobic surface to promote aggregation of glutens in the dough. On the other hand, low OAC in the control sample might be because of more polar groups on the protein surface interacting with oil molecules [14]. The high OAC of the blended flours make them useful ingredients in products that require flavor retention, enhanced palatability, and shelf life extension, especially in baked products where oil absorption is beneficial [32].

3.2. *The leavening capacity of blended wheat and banana dough*

The dough volume significantly decreased ($p < 0.05$) with increasing levels of unripe banana flour substitutions during all fermentation times (30 min, 60 min and 90 min) (Table 2). This could be due to the reduced wheat flour content in each successive dough sample, which resulted in a corresponding decrease in wheat gluten levels and ultimately led to a proportional reduction in dough volume. The low dough volume might be attributed to the addition of unripe *luvhele* and *mabonde* flours, which increased starch and caused a minor decrease in gluten, affecting optimal gluten matrix formation during mixing and fermentation and decreasing the dough's elasticity [33,34]. When gluten is present in low amounts, it can lead to the generation of weaker gluten networks that decrease the ability of the dough to retain carbon dioxide [35]. This results in less stable dough and can lead to undesirable texture and overall quality of baked products. Dube et al. [36] reported that an increased in WAC of composite flour samples (Figure 1) decreased water-gluten interactions, making dough volume to decrease with increased blended flour levels. Moreover, dietary fiber in the dough samples added with *luvhele* and *mabonde* flours might have reduced starch swelling, potentially leading to decreased dough volume [37]. Moreover, dietary fiber could have hindered the development of gluten by cutting through gluten strands, preventing the generation of a viscoelastic network, which resulted in weak dough [38]. A significant decrease in the leavening capacity of dough added with 30 and 40% *luvhele* and *mabonde* flour might be because when the amount of gluten proteins was low, the proteins in the banana flour composition competed with wheat proteins to absorb water while mixing the ingredients [39]. According to the results obtained, the addition of up to 20% unripe banana flour led to a dough with a good leavening capacity, because gluten proteins aggregated and retained gases formed during the dough fermentation [40]. On the other hand, Aboaba and Obakpolor [41] reported that the inclusion of 20% cassava flour decreased dough volume during leavening.

Table 2. The leavening capacity of composite dough (volume in mL).

Sample	0 min	30 min	60 min	90 min
Control	99.67 ± 0.58^{a}	195.00 ± 5.00^{d}	250.00 ± 5.00^{e}	296.67 ± 5.78^{e}
LBF1	100.00 ± 0.00^{a}	178.33 ± 2.89^{c}	230.00 ± 5.00^{d}	246.67 ± 2.89^{d}
LBF2	100.00 ± 0.00^{a}	173.33 ± 2.89^{c}	195.00 ± 5.00^{c}	235.00 ± 10.00^{c}
LBF3	100.00 ± 0.00^{a}	160.00 ± 5.00^{b}	183.33 ± 5.78^{b}	230.00 ± 5.00^{b}
LBF4	100.00 ± 0.00^{a}	128.33 ± 5.77^{a}	135.00 ± 5.00^{a}	145.00 ± 5.00^{a}
MBF1	100.00 ± 0.00^{a}	176.67 ± 2.89^{c}	228.33 ± 2.89^{d}	240.00 ± 8.66^{c}
MBF2	100.00 ± 0.00^{a}	168.33 ± 2.89^{c}	191.67 ± 2.89^{c}	230.00 ± 5.00^{bc}
MBF3	100.00 ± 0.00^{a}	158.33 ± 7.64^{b}	178.33 ± 2.89^{b}	225.00 ± 5.00^{b}
MBF4	100.00 ± 0.00^{a}	125.00 ± 0.00^{a}	131.67 ± 2.89^{a}	143.33 ± 2.89^{a}

Values are means ± standard deviations of three independent trials. Values followed by different letters within columns denote significant differences ($p \le 0.05$). Control = 100% wheat flour, LBF1-4 = Wheat dough with 10, 20, 30 and 40% *luvhele* banana flour, MBF1-4 = Wheat dough with 10, 20, 30 and 40% *mabonde* banana flour.

A high amount of gluten in the control dough sample resulted in a more elastic texture that allowed it to retain carbon dioxide gas better and form structured dough during leavening (30–60 min) [42]. Gluten is a protein that forms structures in flour and is accountable for the dough's elasticity. The primary proteins in gluten, gliadins and glutenin are responsible for the elasticity and viscosity of dough.

Moreover, the capacity of gluten to generate a strong network in the control dough sample could be linked to the formation of intermolecular disulfide bonding between glutenin polypeptides and the creation of extended chain polymers [43].

3.3. Blended dough titratable acidity and pH

The dough pH decreased significantly with increasing levels of unripe banana flour substitutions during all fermentation times, as shown in Table 3. This was observed particularly after dough production time (0), with increased *luvhele* and *mabonde* levels of up to 40%, the pH of the dough decreased from 5.79 to 5.27, respectively. After a fermentation time of 90 min, the pH of the control dough decreased from 5.30 to 4.36 (40% *luvhele* flour) and 4.38 (40% *mabonde* flour). The low pH as the blended dough begins to ferment might be attributed to acid production (acetic and lactic acid) by the proliferation of microorganisms related to yeast in the dough [44]. This resulted in a sourdough, contributing to the final product's flavor, shelf life, rheological properties and color [45]. The dough incorporated with *luvhele* was the least acidic compared with *mabonde* cultivar flour. In baking, pH control is critical for inhibiting spoilage by different mold species.

Table 3. pH and titratable acidity of the banana and wheat blended dough.

Banana flour %	Time 0		Time 30		Time 60		Time 90	
	pH	Acidity	pH	Acidity	pH	Acidity	pH	Acidity
Control	5.79 ± 0.01^{e}	0.18 ± 0.02^{a}	5.64 ± 0.02^{e}	0.21 ± 0.01^{a}	5.51 ± 0.02^{e}	0.22 ± 0.04^{a}	5.30 ± 0.01^{e}	0.25 ± 0.02^{a}
LBF1	5.57 ± 0.01^{d}	0.22 ± 0.02^{b}	5.14 ± 0.02^{d}	0.21 ± 0.04^{ab}	5.07 ± 0.02^{d}	0.25 ± 0.01^{ab}	5.01 ± 0.02^{d}	0.26 ± 0.01^{ab}
LBF2	5.48 ± 0.01^{c}	0.24 ± 0.02^{b}	5.06 ± 0.01^{c}	0.25 ± 0.02^{bc}	4.78 ± 0.01^{c}	0.27 ± 0.02^{b}	4.71 ± 0.03^{c}	0.27 ± 0.01^{ab}
LBF3	5.34 ± 0.02^{b}	0.25 ± 0.03^{b}	4.65 ± 0.03^{b}	0.26 ± 0.15^{bc}	4.60 ± 0.02^{b}	0.28 ± 0.01^{b}	4.57 ± 0.01^{b}	0.29 ± 0.02^{b}
LBF4	5.27 ± 0.03^{a}	0.26 ± 0.01^{b}	4.47 ± 0.06^{a}	0.28 ± 0.02^{c}	4.47 ± 0.01^{a}	0.35 ± 0.02^{c}	4.36 ± 0.01^{a}	0.38 ± 0.01^{c}
MBF1	5.49 ± 0.03^{d}	0.18 ± 0.01^{a}	5.11 ± 0.03^{d}	0.22 ± 0.02^{ab}	5.05 ± 0.02^{d}	0.23 ± 0.01^{a}	5.03 ± 0.03^{a}	0.26 ± 0.01^{ab}
MBF2	5.44 ± 0.02^{c}	0.19 ± 0.01^{a}	4.89 ± 0.00^{c}	0.23 ± 0.01^{ab}	4.73 ± 0.05^{c}	0.24 ± 0.01^{ab}	4.74 ± 0.04^{c}	0.27 ± 0.01^{ab}
MBF3	5.33 ± 0.02^{b}	0.22 ± 0.01^{b}	4.56 ± 0.01^{b}	0.24 ± 0.01^{bc}	4.49 ± 0.05^{b}	0.25 ± 0.01^{ab}	4.55 ± 0.04^{b}	0.28 ± 0.02^{b}
MBF4	5.27 ± 0.03^{a}	0.26 ± 0.01^{b}	4.41 ± 0.03^{a}	0.29 ± 0.01^{c}	4.40 ± 0.01^{a}	0.32 ± 0.02^{c}	4.38 ± 0.04^{a}	0.37 ± 0.03^{c}

Values are means ± standard deviations of three independent trials. Values followed by different letters within columns denote significant differences ($p \leq 0.05$). Control = 100% wheat flour, LBF1-4 = Wheat dough with 10, 20, 30 and 40% *luvhele* banana flour, MBF1-4 = Wheat dough with 10, 20, 30 and 40% *mabonde* banana flour.

Total titratable acidity (TTA) indicates the level of acidity present in a given food sample. There was a significant rise ($p < 0.05$) in the TTA of dough added with unripe banana flour during incubation.

However, no significant difference was observed between the doughs added with *luvhele* and *mabonde* flours. The activities of yeast and lactic acid-producing bacteria might be attributed to the rise in TTA of the blended dough samples since they degraded carbohydrates resulting in the acidification of the dough [46]. Moreover, Borsuk *et al.* [47] indicated that the rise in TTA during the incubation period of the dough could be due to carbon dioxide gas dissolving into bicarbonate ions, acidifying the dough. The progressive increase of TTA and low pH during the incubation period has been previously reported for wheat dough added with prickly pear peel flour [19]. Moreover, Mashau *et al.* [48] observed low pH and a rise in TTA of the dough enhanced with Bambara groundnut flour.

3.4. Proximate composition of the wheat dough added with unripe banana flour

Table 4 depicts the proximate composition of control and dough added with unripe banana flour. Compared to all samples, the dough sample with 40% *luvhele* flour had a high ash content of 2.52%. In general, the ash content of the blended dough samples significantly increased, which was mainly caused by high amounts of dietary fiber in both banana flours. The variation in ash content of the dough samples could be attributed to differences in the mineral contents of the banana cultivars because of agricultural practices and climate change [49]. High ash content in dough samples incorporated with *luvhele* flour indicated the high presence of mineral components [9]. Banana is rich in minerals such as phosphorus, magnesium and potassium; hence the ash content significantly increased ($p < 0.05$) with an increase in unripe banana flour amounts [10]. This showed that blended dough samples are a rich source of these minerals compared to the control dough. Moreover, this demonstrated that blending wheat flour with other food crops, such as bananas, is important since it is rich in minerals. Kumar *et al.* [50] reported an ash content of 2.50% for unripe banana flour. Moreover, Khoza *et al*. [22] observed the ash content varying from 2.46–3.50% for four green banana cultivars grown in South Africa.

Table 4. Proximate composition of wheat dough incorporated with banana flour (dry basis).

Sample	Ash (%)	Moisture (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate
Control	1.28 ± 0.07^{a}	37.32 ± 1.10^{e}	5.42 ± 0.96^{f}	2.40 ± 0.96^{a}	1.15 ± 0.07^{a}	52.39 ± 1.09^{a}
LBF1	2.22 ± 0.02^{b}	35.24 ± 0.01^{d}	5.21 ± 0.03^{e}	2.63 ± 0.03^{b}	1.24 ± 0.01^{b}	54.75 ± 0.20^{b}
LBF2	2.39 ± 0.09^{d}	33.93 ± 0.11^{c}	4.41 ± 0.05^{d}	2.83 ± 0.05^{d}	1.34 ± 0.02^{c}	55.01 ± 0.12^{b}
LBF3	2.37 ± 0.01^{d}	33.45 ± 0.06^{b}	4.22 ± 0.36^{c}	2.93 ± 0.04^{e}	1.55 ± 0.07^{d}	55.47 ± 0.10^{b}
LBF4	2.52 ± 0.15^{g}	32.17 ± 0.29^{b}	4.10 ± 0.02^{b}	2.99 ± 0.02^{f}	1.73 ± 0.10^{f}	56.48 ± 0.37^{c}
MBF1	2.31 ± 0.03^{c}	35.30 ± 0.08^{e}	5.18 ± 0.01^{e}	2.58 ± 0.04^{b}	1.18 ± 0.03^{ab}	53.44 ± 0.10^{a}
MBF2	2.37 ± 0.05^{d}	34.10 ± 0.06^{d}	4.39 ± 0.06^{d}	2.69 ± 0.03^{c}	1.25 ± 0.02^{b}	55.21 ± 0.13^{b}
MBF3	2.45 ± 0.05^{e}	32.19 ± 0.07^{b}	4.17 ± 0.05^{b}	2.78 ± 0.04^{d}	1.53 ± 0.03^{d}	56.82 ± 0.07^{c}
MBF4	2.48 ± 0.24^{f}	31.06 ± 0.16^{a}	4.02 ± 0.04^{a}	2.90 ± 0.02^{e}	1.68 ± 0.04^{e}	57.75 ± 0.22^{d}

Values are means ± standard deviations of three independent trials. Values followed by different letters within columns denote significant differences ($p \leq 0.05$). Control = 100% wheat flour, LBF1-4 = Wheat dough with 10, 20, 30 and 40% *luvhele* banana flour, MBF1-4 = Wheat dough with 10, 20, 30 and 40% *mabonde* banana flour.

The dough samples (S1) incorporated with unripe banana flour showed lower moisture content than the control sample, and the gradual decrease in moisture content might be due to the contribution of solids content from unripe banana flour. The dough sample added with 40% mabonde flour had the lowest moisture content (31.06%), indicating that the baked product would be microbiologically stable and have a longer shelf life [51]. Moreover, the moisture content in bakery products is crucial as it can significantly impact their quality. For instance, a reduced moisture content of the composite dough will contribute to bread with a hard texture.

The dough samples' protein content decreased with the increased level of unripe banana flour, with the control dough sample having a higher protein content of 5.42%. The low protein content of unripe banana might be attributed to the decreased in protein content of the blended dough. Khoza *et al.* [22] reported that different unripe banana cultivars' protein content ranges from 3.60 to 4.12%. Protein is a reactive food component that can interact with other food constituents, such as fats, sugars and other compounds, generating complex structures that could potentially impact the solubility and digestibility of the food component [52].

The fat content increased significantly with increasing amounts of unripe banana flour, varying from 2.40 to 2.99% in *luvhele* and 2.58 to 2.90% in *mabonde* dough samples. The control dough sample had a low-fat content of 2.40%. Khoozani *et al.* [53] reported the fat content of unripe banana flour with values ranging from 0.92–0.93%. The increase in fat content might be due to adding fat during dough preparation. Moreover, Rahman *et al*. [54] indicated that incorporating unripe banana flour in wheat flour increases the fat content. The functionality of the dough might be affected by the interaction between fats and starch or protein when the blended dough samples have a substantial increase in fat content [41].

The fiber content of the dough samples significantly increased ($p < 0.05$) with increasing levels of unripe banana flour substitutions ranging from 1.15 to 1.73% (*luvhele*) and from 1.18 to 1.68% (*mabonde*), respectively. This could be because unripe bananas are naturally rich in dietary fiber [55]. The dietary fiber of unripe banana flour ranges from 6.0 to 15.5% [56]. The crude fiber indicates a variable dietary fiber fraction, mainly cellulose, hemicellulose components and lignin. The high dietary fiber in blended dough samples was relevant since foods rich in dietary fiber improve nutrition and human health by decreasing constipation.

The dough samples incorporated with unripe banana flour showed high carbohydrate content values of 56.48 and 57.75% for *luvhele* and *mabonde* banana cultivars. A low carbohydrate content of 52.39% was observed in the control sample. The high carbohydrate content observed on dough samples with increased levels of unripe banana flour was due to unripe bananas' high dietary fiber content [57]. The high content of resistant starch (approximately 40.9 to 58.5%) in unripe banana flour might have also contributed to the high carbohydrate content of the blended dough samples [56].

3.5. Color profile of composite dough

Table 5 shows the color profile of the dough; the lightness decreased significantly with an increase in unripe banana flour levels ranging from 23.00 to 19.76 in *luvhele* and 22.65 to 21.88 in *mabonde* dough samples. The control dough sample recorded the highest L* value of 23.00 compared to all other dough samples. The decrease in L* value was because of the oven-drying method used during banana flour processing which resulted in a yield of dark banana flour [58]. According to Ekafitri *et al.* [59], cultivar maturity can significantly impact the final L* value. Furthermore, enzymes such as polyphenol oxidase available in banana fruits might have contributed to the brown color of the banana flour. A similar trend of decreasing L* value was reported by Zuwariah and Aziah [58] whereby wheat flour was substituted with modified banana flour at different levels.

The a* values increased with the increase in unripe banana flour levels. The *mabonde* added dough sample had the highest a* value of 4.05, and the lowest significant value was observed in the control sample at 2.18. The color data obtained also indicated the increase in the yellowness (b*) value due to the addition of unripe banana flour. The dough with 40% *mabonde* flour recorded a high b* value at 11.79, followed by the dough with 40% *luvhele* flour at 10.88, with the control recording the lowest b* value at 8.48.

Table 5. Color of blended dough samples.

Samples	L*	a*	b*	Chroma	Hue Angle
Control	23.00 ± 0.59[f]	2.18 ± 0.07[a]	8.48 ± 0.07[a]	8.76 ± 0.08[a]	75.56 ± 0.40[e]
LBF1	22.58 ± 0.06[e]	2.54 ± 0.06[b]	8.80 ± 0.13[b]	9.16 ± 0.14[b]	73.92 ± 0.22[c]
LBF2	20.63 ± 0.11[e]	2.85 ± 0.08[e]	9.04 ± 0.05[c]	9.48 ± 0.04[c]	72.49 ± 0.50[b]
LBF3	20.23 ± 0.06[d]	3.23 ± 0.11[f]	9.37 ± 0.19[d]	9.91 ± 0.19[d]	70..95 ± 0.70[a]
LBF4	19.76 ± 0.02[a]	3.75 ± 0.12[h]	10.88 ± 0.04[i]	11.50 ± 0.03[g]	70.97 ± 0.60[a]
MBF1	22.65 ± 0.04[e]	2.64 ± 0.14[c]	9.53 ± 0.22[e]	9.89 ± 0.24[d]	74.50 ± 0.54[d]
MBF2	22.64 ± 0.02[e]	2.74 ± 0.22[d]	9.91 ± 0.15[f]	10.29 ± 0.08[e]	74.54 ± 1.41[d]
MBF3	22.23 ± 0.04[d]	3.54 ± 0.09[i]	10.31 ± 0.21[g]	10.90 ± 0.23[f]	71.02 ± 0.28[a]
MBF4	21.88 ± 0.09[c]	4.05 ± 0.14[c]	11.79 ± 0.05[h]	12.36 ± 0.13[h]	71.04 ± 0.60[a]

Values are means ± standard deviations of three independent trials. Values followed by different letters within columns denote significant differences ($p \leq 0.05$). Control = 100% wheat flour, LBF1-4 = Wheat dough with 10, 20, 30 and 40% *luvhele* banana flour, MBF1-4 = Wheat dough with 10, 20, 30 and 40% *mabonde* banana flour.

The high b* value of the blended dough samples might be attributed to the presence of various phenolic compounds and xanthophylls in unripe banana flour [9]. Furthermore, because the carbohydrate in unripe banana flour is primarily starch, fermentation might have occurred during the preparation stage, increasing dough yellowness [60].

Chroma* values in doughs incorporated with unripe banana flour ranged from 8.96 to 11.50 in *luvhele* and 9.89 to 12.36 in *mabonde*. Chroma* increased with the increase in unripe banana flour level. The higher the Chroma values, the higher the color intensity of dough samples, as humans perceive. According to Reis *et al.* [61], an increase in C* is directly related to a higher pigment level in food. The hue angle values of dough samples ranged from 73.92° to 70.49° (*luvhele*) and 74.50° to 71.04° in *mabonde*, with the control having the highest at 75.56°. A similar decrease in the hue angle of wheat dough added with banana flour was also reported by Zuwariah and Aziah [58].

3.6. Texture profile of wheat-unripe banana flour blended dough

Table 6 shows the texture profile of dough added with unripe banana flour. The hardness increased significantly ($p < 0.05$) with increased unripe banana flour substitutions ranging from 520.01 to 816.01 g in *luvhele* and 505.83 to 654.26 g in *mabonde* dough samples. The inclusion of unripe banana flour contributed to a more compact dough with a denser structure. The increase in the dough hardness after increasing banana flour might be due to the high WAC in blended flours (Figure 1), which promoted partial dehydration of gluten, incomplete gelatinization of starch and trans-conformational changes in the structure of dough [62]. Incorporating unripe banana flour in wheat dough improved the fiber content (Table 5), influencing the dough's rheological characteristics. The stability of dough can be enhanced by certain types of soluble fiber fractions, such as arabinoxylans, due to their ability to form chain-like structures with other macromolecules [63]. Consequently, this might have contributed to the high hardness of the dough. Moreover, the interconnection between fiber, protein and gluten could have strengthened the gluten network, further contributing to the density and hardness of the dough. Khoozani *et al*. [9] obtained similar data whereby the incorporation of whole green banana flour increased the hardness of wheat dough.

Cohesiveness refers to the degree to which a food material can be altered in shape prior to breaking. The control sample recorded a high cohesiveness value of 1.22. This could be attributed to wheat flour's small particle size and greater surface area. Flour or starch with a fine particle size can absorb more water during mixing, resulting in a more cohesive dough [64]. On the other hand, blended dough samples had low cohesiveness values indicating that they were more vulnerable to rupture [65]. The low cohesiveness in the blended dough was probably attributed to low gluten content since banana flour does not contain it. Parafati *et al*. [19] observed a similar trend whereby the incorporation of 10% prickly pear peel flour reduced the cohesiveness of the dough.

From the results, doughs added with *mabonde* flour recorded high adhesion compared to the control sample while there was no significant difference between control and dough added with *luvhele* flour. Dough samples added with 30 and 40% mabonde flour recorded a high adhesiveness value of -0.16. Altuna *et al*. [66] reported that amylose content and the high dietary fiber in banana flour improved the adhesiveness of the dough because of their hydrophilic sites. Generally, the blended dough samples had higher WAC, as shown in Figure 1. Thus, increasing the amount of unripe banana flour in the formulation improved the WAC, thereby increasing the adhesiveness of the dough, especially the one added with *mabonde* flour.

Table 6. Textural properties of blended dough samples.

Samples	Hardness (g)	Cohesiveness	Adhesiveness
Control	485.41 ± 22.96^a	1.22 ± 0.23^d	-0.35 ± 0.23^d
LBF1	520.01 ± 74.40^c	1.03 ± 0.12^c	-0.22 ± 0.11^c
LBF2	689.22 ± 42.29^b	0.95 ± 0.01^b	-0.42 ± 0.13^b
LBF3	723.48 ± 42.29^f	0.83 ± 0.14^a	-0.48 ± 0.02^a
LBF4	816.01 ± 86.09^g	0.81 ± 0.34^a	-0.63 ± 0.05^a
MBF1	455.83 ± 18.61^b	1.06 ± 0.09^c	-0.17 ± 0.06^c
MBF2	512.98 ± 23.45^c	1.01 ± 0.09^c	-0.17 ± 0.02^c
MBF3	626.80 ± 20.42^d	0.98 ± 0.13^b	-0.16 ± 0.12^b
MBF4	654.26 ± 69.97^e	0.97 ± 0.03^b	-0.16 ± 0.02^b

Values are means ± standard deviations of three independent trials. Values followed by different letters within columns denote significant differences ($p \leq 0.05$). Control = 100% wheat flour, LBF1-4 = Wheat dough with 10, 20, 30 and 40% *luvhele* banana flour, MBF1-4 = Wheat dough with 10, 20, 30 and 40% *mabonde* banana flour.

The low cohesiveness of dough added with 30 and 40% *luvhele* might be due to the dietary fiber, which acted as a barrier against migration of water and could have inhibited the starch swelling, resulting in low adhesiveness [67]. Results are similar to Khoozani *et al*. [9] who observed low adhesiveness after the dough was enhanced with whole green banana flour.

4. Conclusions

The inclusion of *luvhele* and *mabonde* flours improved the oil and water absorption capacity of wheat flour and made the dough to be acidic. Moreover, there was an increase in ash, fiber, fat and carbohydrate contents of the blended dough samples. Incorporation of the unripe banana flours increased the redness, yellowness and chroma of the dough samples. Moreover, the hardness of the dough samples was increased with the inclusion of unripe banana flours. Based on the results of the leavening capacity, the addition of unripe *luvhele* and *mabonde* flours in the wheat dough is acceptable at 20%. Therefore, further studies on the effect of *luvhele* and *mabonde* flours on the quality characteristics of bread need to be carried out.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

No conflict of interest to declare by the authors.

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