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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Effect of *Piliostigma thonningii* fruit pulp addition on nutritional, functional, and sensorial properties of maize flour blends

Armistice Chawafambira[1*]

ABSTRACT: *Piliostigma thonningii* (monkey bread fruit) is an underutilised indigenous fruit of southern Africa. *P. thonningii* pulp flour of concentrations 15%, 25%, 35%, 50%, 65%, and 80% (w/w) was blended with maize flour (MF). Nutritional, functional, and sensory properties of maize flour and flour blends (MBF+MF) were determined using standard methods. Results showed a significant increase in least gelation concentration (6–10%), emulsion activity (44.8–55.3%), emulsion stability (40.2–52.1%), swelling capacity (2.12–5.23 g/ml), swelling index (0.5–1.98), oil absorption capacity (1.12–3.1 ml/g), water absorption capacity (191.2–270%) and decrease in bulk density (0.73–0.4 g/ml) and least gelatinization temperature (63.6–52.1°C) with increase in the addition of MBF at different percentage weights. Protein content increased from 10.2% to 14.8%, crude fibre increased from 3.5% to 4.8%, ash increased from 2.1% to 3.0%, and carbohydrates decreased from 74.0% to 66.3%. Iron and calcium content increased from 2.11 to 3.11 mg/100 g and 8.12 to 9.12 mg/100 g, respectively. The food gel prepared with 25% MBF/75% MF was most preferred with respect to colour, texture, flavour and overall acceptability. The flour has the potential to supply over 30% and 80% of the recommended dietary allowance for iron and carbohydrates in children's diets.

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PUBLIC INTEREST STATEMENT

Indigenous fruit trees (IFTs) are abundant in forests of Southern Africa and play an important role as sustainable food sources in times of droughts. Wild fruits have been found to supplement human diets. Fruits are important in providing essential micronutrients and functionality in many foods. However, there is limited scientific knowledge on the importance of using wild fruit in food blends and their effects on nutritional, functional and sensory properties. Furthermore, most diets in Sub-Saharan Africa are mainly dominated by local staple foods rich in carbohydrates. There are high rates of food insecurity and malnutrition in Sub-Saharan Africa resulting from limited access to food. Processing technologies have been developed and initiated to add value increase utilisation of wild fruits. The utilisation of wild fruits in food processing has great potential to improve functionality, nutrition, sensorial properties of many food consumed by most rural populations in sub-Saharan Africa.

Subjects: Nutrition; Food Additives & Ingredients; Food Chemistry; Food Engineering

Keywords: Piliostigma thonningii; flour blend; swelling capacity; oil absorption capacity; least gelatinisation temperature; least gelation concentration; sensory quality

1. Introduction

Indigenous fruit trees (IFTs) are abundant in forests and act as a sustainable food source during times of food shortages by supplementing human diets (Chawafambira, Sedibe, Mpofu, Achilonu et al., 2020a). *Piliostigma thonningii* is an underutilised IFT native to tropical Africa and is well adapted to the miombo woodlands (Orwa et al., 2009). *P. thonningii* fruit tree belongs to the genus *Piliostigma* of the family Fabaceae and the subfamily Caesalpinioideae (Brummitt et al., 2007; Orwa et al., 2009). In southern Africa, the fruit tree is found widespread in Namibia, Botswana, Mozambique, Zimbabwe and South Africa (Plant For A Future (PFAF), 2020). In Zimbabwe, the fruit tree grows well in semi-dry and dry regions in forests.

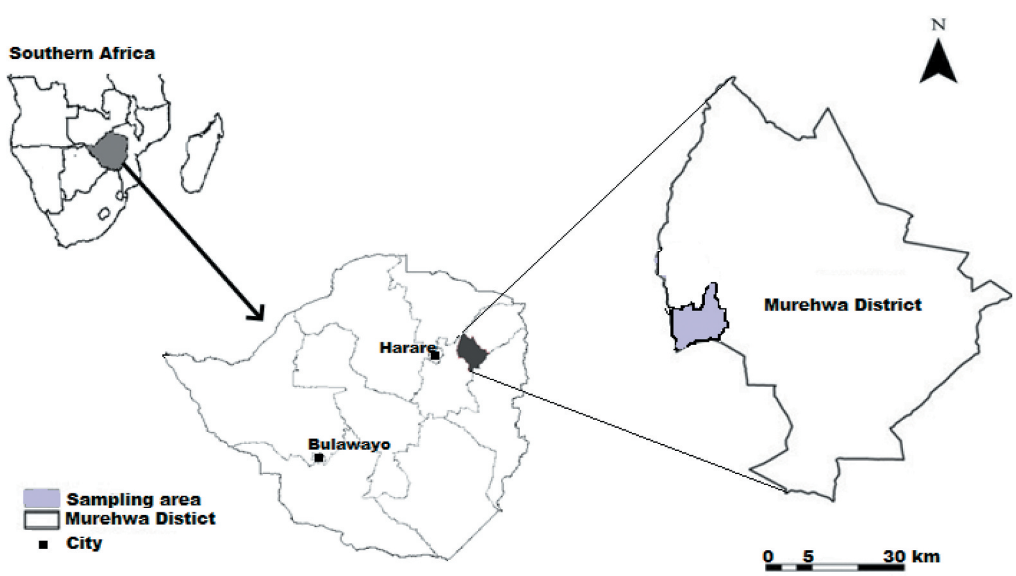
The tree produced fruits which ripens during March to October (Orwa et al., 2009), and is known by different names as monkey bread in English; *mchekeche, msegese mchikichi* in Swahili; and *musekesa, mutukutu, muchekecha* in Shona. The fruit is hairy, hard, and contains flattish pods that become rusty brown, woody, twisted and often splits when fully mature and ripened (Bombardelli et al., 1994). The fruit pulp that surrounds the seeds is eaten raw mainly by children and has a sweet flavour (Bombardelli et al., 1994). Nutritionally, *P. thonningii* fruit is a rich source of proteins, organic acids, vitamins, fiber, essential oils, starch, and calcium oxalates (Mandibaya & Chihora, 1999). *P. thonningii* fruits contain (g/100 g edible portion) water 9.8, crude protein 15, crude fat 3.2, dietary fibre 8.8, ash 4.3, and carbohydrate 58.9. Its nutritional content is relatively high as compared with *Adansonia digitata* (Malvaceae) fruits which contain (g/100 g) protein 2.3, fat 0.7, and water 10 (Abdel et al., 2011: Chawafambira, Sedibe, Mpofu, Achilonu et al., 2020a). The mineral content of the fruit is high in calcium (360 mg/100 g) and iron (40 mg/100 g) (Irvine, 1961) as compared to other indigenous fruits of southern Africa such as *Uapaca kirkiana* (Phyllanthaceae) and *Tamarindis indica* (Fabaceae) (Chawafambira, Sedibe, Mpofu, Achilonu et al., 2020b: Soloviev et al., 2004). The fruit contains rich phytochemicals and these include tannins, flavonoids, alkaloids, kaurane, diterpenes, saponins, and terpenes (Nwaehujor et al., 2015). *P. thonningii* is mostly used as a traditional medicinal plant in Africa (Neuwinger, 2000). Crude extracts of *P. thonningii* were reported to possess antibacterial and antioxidant (Nwaehujor et al., 2015), antilipidemic (Asuzu & Nwaehujor, 2013), and anti-inflammatory (Ibewuike et al., 1997) properties.

In Sub-Saharan Africa, diets for infants and adults mainly consist of local staple foods made from carbohydrate-rich plants such as cereals, cassava, and potato tubers. However, previous studies have reported that most cereals are limiting in essential amino acids such as tryptophan and threonine but are rich in lysine (Onweluzo & Nnamuchi, 2009), and indigenous fruits are rich in proteins, vitamins, minerals, and organic acids. Utilisation of indigenous fruits in food blends has the potential to improve economic and social conditions, as well as provide food security to the local population in an area (Deb et al., 2013).

Functional properties are the important physicochemical characteristics that indicate the complex interaction between the composition, structure and molecular conformation of food components and their nature of association and measurement (Siddiq et al., 2009). Despite the benefits that can be derived from *P. thonningii* fruit, little is known about the functional potential of its dry powdery fruit pulp as food. Therefore, this study was aimed at evaluating the effect of *P. thonningii* fruit pulp addition on the nutritional, functional potential and sensory quality in maize flour blends used in processing of a non-fermented food gel.

Figure 1. Ripe *Piliostigma thonningii* fruits and seeds.

Figure 2. Sampling area of *Piliostigma thonningii* fruits in Murehwa, Zimbabwe.



2. Materials and methods

2.1. Fruit collection

Ripe *P. thonningii* fruits (Figure 1) were collected from forest trees in Murehwa, a semi-dry communal area located 17.65°S and 31.77°E in agro-farming region 4 and has luvic arenosols soils (Figure 2). Permission to carry out the study was granted by local leaders (councillors) in the study area. Information about the research was explained to prospective participants. Questions concerning the study from the prospective participants were answered and an assessment was conducted check if the participants had comprehended the information. Consent forms were obtained from participants who volunteered to participate in the study. Fruit trees were chosen randomly using stratified sampling method. Samples of 100 ripe fruits were randomly collected from different parts of the tree. The collected fruits were transported in clean polythene bags and were stored at room temperature (25°C) in a laboratory.

2.2. Sample preparation

Ripe dry *P. thonningii* fruits were opened and seeds removed. The outer fruit coat was then removed. White dried maize grains obtained from a local rural market in Murehwa were cleaned of extraneous materials. The dry *P. thonningii* fruit pulp and maize grains were both milled in a laboratory mill (Model RLA, 201–80,014; Hammer mill, UK) and passed through a sieve with a size 420 μm (Model. HL 20; Gallenkamp and Co Ltd) to obtain fine maize and *P. thonningii* pulp flour. The milled flours were then stored in an airtight polythene plastic (0.77 mm thickness) at 25°C.

2.3. Blending ratios

P. thonningii pulp flour samples of concentrations: 15, 25, 35, 50, 65, 80% (w/w) were blended with maize flour for 3 minutes using a blender (Model Km201, Kenwood, Birmingham, UK). The flour samples were packed in polyethylene bags (0.77 mm thick) and sealed. A control sample had 100% (w/w) maize flour.

2.4. Functional properties of flour blends

2.4.1. Bulk density

Bulk density analysis was determined using a method adopted from Appiah et al. (2011) The flour samples were placed in a 50 ml beaker and their weight was measured using an analytical balance (B204-S, MK II, Mettler Toledo, Switzerland). Water was poured in the same beaker and its volume was recorded. The bulk density was calculated as follows:

$$\text{Bulky density}\left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{Weight of sample(g)}}{\text{Volume of water(ml)}} \tag{1}$$

2.4.2. Least Gelation Concentration (LGC)

The gelation property analysis was determined according to a method adopted from Adebowale et al. (2005) Flour samples weighing 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20% (w/v) were prepared in 10 ml of distilled water and heated in a shaking water bath (Lab Companion 37 L, Jeio Tech, Korea) at 100°C for 1 h. The samples were cooled under running tap water and kept at 5 ± 1°C for 2 h. The LGC was the one at which the sample did not fall down or slip when the test tube was inverted.

2.4.3. Least gelatinisation temperature (LGT)

A sample of flour blend weighing 1 g was mixed with 10 ml distilled water in a 20 ml screw capped tube. The samples were heated in a water bath until a solid gel began to form. The temperature at which complete gel formation (when a solid gel is formed and that does not flow when a test tube or vial is inverted) occurs was recorded as the gelatinization temperature.

2.4.4. Swelling Index (SI)
The swelling index was determined using a method adopted from Chandra et al. (2015). A 5 g flour sample was mixed with 30 ml distilled water in a 50 ml graduated cylinder. The mixture in the cylinder was then swirled and allowed to stand for 4 h while a change in volume (swelling) was observed. The level of swelling was determined as follows:

$$\text{Swelling Index} = \frac{(\text{volume after soaking} - \text{volume before soaking})}{\text{weight of sample}} \tag{2}$$

2.4.5. Swelling capacity
The gel obtained from swelling index was used in calculating swelling capacity as follows:

$$\text{Swelling capacity}(\%) = \frac{\text{weight of gel}}{\text{weight of sample}} \times 100 \tag{3}$$

2.4.6. Oil Absorption Capacity (OAC)
The oil absorption capacity analysis was conducted according to a method adopted from Chandra et al. (2015). One gram of sample was mixed with 10 ml soyabean oil and allowed to stand at 30 ± 2°C for 30 min and centrifuged (LMC-3000, Biosan, Riga, Latvia) at 2000 × *g* for 30 min. The OAC was determined as follows:

$$\text{OAC}(\%) = \left(\frac{W_2 - W_1}{W_0}\right) \times 100 \tag{4}$$

where W_0 is the weight of the sample, W_1 is the weight of the centrifuge tube plus the sample and W_2 is the weight of the centrifuge tube plus sediments.

2.4.7. Water Absorption Capacity (WAC)
WAC was determined by mixing a 2 g flour sample with distilled water (20 mL) and allowed to stand for 30 min. The mixture was then centrifuged (LMC-3000, Biosan, Riga, Latvia) at 2000 × *g* for 25 min. The sediments were weighed after complete removal of the supernatant. WAC was calculated as follows:

$$\text{WAC}(\%) = \left(\frac{W_2 - W_1}{W_0}\right) \times 100 \tag{5}$$

where W_0 is the weight of the sample, W_1 is the weight of the centrifuge tube plus the sample and W_2 is the weight of the centrifuge tube plus sediments.

2.4.8. Emulsion activity and stability
Emulsion activity (EA) and stability were determined by the method adopted from Siddiq et al. (2009). Two grams of maize and/or flour blends were mixed with 20 ml distilled water in a test tube and 20 ml refined soybean oil was then added. The mixture was shaken vigorously for 5 minutes. The resulting emulsion was placed into 50 ml centrifuge tubes centrifuged (LMC-3000, Biosan, Riga, Latvia) at 2000 × *g* for 30 minutes. The emulsion activity was expressed as a percentage of the ratio of the height of the emulsion layer to the height of the liquid layer. In determining the emulsion stability, the emulsion in a 50 ml centrifuge tubes was heated at 80°C in a water bath (Lab Companion 37 L, Jeio Tech, Korea) for 30 min, cooling to 23°C and then centrifuged (LMC-3000, Biosan, Riga, Latvia) at 2000 × g for 30 min. The emulsion stability was expressed as a percentage of the ratio of the height of the emulsion layer to the height of the liquid layer.

2.5. Nutritional analysis
Proximate analysis on moisture content using (AOAC method 925.45), crude protein using Kjeldahl (AOAC method 991.20), crude fibre using enzymatic gravimetric method (AOAC method 985.29), crude fat using Soxhlet method (AOAC 989.05), mineral content using Inductively Coupled Plasma–Optical Emission Spectrometer (ICP-OES) (Agilent 5100, Agilent Technologies, Santa Clara, California, USA), and ash content using dry ashing (AOAC method 938.08) were determined

Table 1. Functional properties of MF, MBF, and flour blends (MBF+MF)

Functional Properties		MBF:MF (%, w/w)							
	100:0	0: 100	15:85	25:75	35:65	50:50	65:35	80:20	p-value
BD (g/ml)	0.38 ± 0.01 [c]	0.73 ± 0.01[a]	0.67 ± 0.01[a]	0.64 ± 0.01[a]	0.57 ± 0.01[b]	0.52 ± 0.01[b]	0.48 ± 0.02 [c]	0.40 ± 0.01 [c]	<0.001
LGC (%)	5[a]	6[a]	7[ab]	8[b]	8[b]	9[bc]	10 [c]	10 [c]	0.012
EA (%)	41.2 ± 0.01[a]	44.8 ± 0.02[a]	48.1 ± 0.02[b]	50.2 ± 0.04 [c]	50.6 ± 0.05 [c]	55.3 ± 0.01[d]	48.2 ± 0.06[b]	46.4 ± 0.07[ab]	0.014
ES (%)	36.1 ± 0.01[a]	40.2 ± 0.04[a]	45.2 ± 0.01[b]	50.3 ± 0.02 [c]	50.8 ± 0.06 [c]	52.1 ± 0.01 [c]	48.6 ± 0.02[b]	49.1 ± 0.05[b]	0.021
LGT (°C)	47.2 ± 2.1[b]	63.6 ± 2.49[d]	58.5 ± 1.12 [c]	51.6 ± 1.69 [c]	45.5 ± 1.01[b]	41.2 ± 1.34[b]	35.3 ± 1.36[a]	39.4 ± 2.23[a]	0.023
SC (g/ml)	3.81 ± 0.02[b]	2.12 ± 0.08[a]	2.62 ± 0.02[a]	3.45 ± 0.08[b]	3.81 ± 0.03[b]	4.12 ± 0.01[b]	4.62 ± 0.05[b]	5.23 ± 0.04 [c]	0.018
SI	0.42 ± 0.01[a]	0.50 ± 0.08[a]	0.68 ± 0.02[a]	0.84 ± 0.06 [c]	0.96 ± 0.04 [c]	1.16 ± 0.04 [c]	1.83 ± 0.06[d]	1.98 ± 0.05[d]	<0.001
OAC (ml/g)	0.9 ± 0.2[a]	1.12 ± 0.09 [c]	1.52 ± 0.21 [c]	1.75 ± 0.47[b]	2.12 ± 0.31[b]	2.63 ± 0.35[a]	2.92 ± 0.41[a]	3.1 ± 0.12[a]	0.0001
WAC (%)	224.1 ± 2.4 [c]	191.2 ± 4.60[d]	210.4 ± 6.56 [c]	228.1 ± 1.08 [c]	242.3 ± 5.02[b]	255.1 ± 6.06[b]	261.2 ± 7.04[a]	270 ± 4.07[a]	0.013

MF: maize flour; MBF: monkey bread flour; BD: bulk density; WAC: water absorption capacity; OAC: oil absorption capacity; SC: swelling capacity; LGC: least gelation concentration; SI: swelling index; LGT: least gelation temperature; ES: emulsion stability; EA: emulsion activity

Mean ± standard deviations are reported. Means with different superscripts ([a, b, c, d]) in a row are significantly different at $p < 0.05$.

according to standard methods by the Association of Official Analytical Chemists (AOAC, 2000). Total carbohydrate was determined by difference method. The total energy content was calculated using Atwater factors (4 kcal/g for protein, 9 kcal/g for fat, and 4 kcal/g for total carbohydrate).

2.6. Preparation of maize-based food gel

The performance of the flour blends in food processing was determined by preparing a non-fermented food gel (porridge). A formulation for a nonfermented food gel mix was developed according to a formula by Gitau et al. (2019) with modifications. Sucrose and salt were used in addition to the original formula. The control formulation had 100% MF. The food gel (porridge) samples were prepared by mixing 250 g of flour mix in 400 ml of cold water in a stainless-steel pot before further addition of 450 ml of boiling water. The mixture was cooked at 100°C under continuous stirring until it was gelatinised and was then left to boil for 25 minutes.

2.7. Sensory analysis

Sensory evaluation was done using 30 target consumers that were randomly selected from households in rural Murehwa area. Each of the 30 untrained panelist was served with 35 g of the food gel sample. The panellists determined the product's overall acceptance and scored their responses on a 6-point structured hedonic scale (6 = excellent, 5 = very good, 4 = good, 3 = fair, 2 = poor and 1 = very poor). Product attributes that were analysed were taste, texture, colour, aroma and appearance. The flour blend that produced a food gel with the best sensorial attributes was estimated on its % contribution in diet on the recommended daily allowances of nutrients per 100 g consumption of different age groups.

2.8. Statistical analysis

The results of functional, nutritional, and sensory properties were expressed as the mean ± standard deviation (SD), and all experiments were conducted in triplicates. The least significant differences (LSD) test was used to determine significant differences at $p < 0.05$. A one-way analysis of variance for F-test was conducted at $p < 0.05$ significance level using the SPSS package version 18.0 (Coakes and Ong, John Wiley & Sons, Queensland, Australia)

3. Results and discussion

3.1. Functional characteristics

3.1.1. Bulk density

The functional properties of MF, MBF, and flour blends (MBF + MF) are represented in Table 1. The bulk density of flour refers to the density measurement given without any effect of compression (Chandra et al., 2015). Bulk density was 0.73 ± 0.01 g/ml for MF and reduced from 0.67 ± 0.01 to 0.40 ± 0.01 g/ml with an increase in monkey bread flour (Table 1). The decrease in bulk density was significantly different at $p < 0.05$. This suggests that *P. thonningii* pulp flour has a low bulk density which can be correlated to its low carbohydrate content. Kubor and Onimawo, (2003) reported a high bulk density in maize flour. Furthermore, a study by Chandra (2015) reported high bulk densities of 0.76 ± 0.01, 0.91 ± 0.01 and 0.77 ± 0.01 in wheat, rice and potato flours, respectively. This can explain that carbohydrates-rich food materials have high bulk densities due to the packing of long-chain sugars into starch molecules. The flours had a particle size of 0.42 mm (420 μm) and moisture content of 8%. These properties could have affected the bulk density as reported by Chandra et al. (2015).

The low bulk density (0.40 ± 0.01 g/ml) of the flour makes it a possible ingredient in the preparation of complementary foods (Akpata & Akubor, 1999). Kubor and Onimawo (2003) also recommended the use of low bulk density flours in making weaning foods. This is because the flour had a low starch content. Starch is a key nutritional component in cereals responsible for low bulk density and is important in child nutrition. There is a correlation between bulk density of food and nutrition. The loss in bulk density in the flour could have resulted from the breakdown of large

Table 2. Heat gelation properties of MF and flour blends (MBF + MF)

Flour concentrations (%, w/v)										
MBF: MF	2	4	6	8	10	12	14	16	18	20
0:100	+	+	+	+	+	+	+	+	+	+
15:85	–	–	±	+	+	+	+	+	+	+
25:75	±	±	+	+	+	+	+	+	+	+
35:65	–	–	±	±	±	+	+	+	+	+
50:50	–	±	+	+	+	+	+	+	+	+
65:35	–	–	±	±	+	+	+	+	+	+
80:20	–	–	±	±	±	+	+	+	+	+

–, no gel; ±, weak gel; +, good gel.

organic molecules (proteins and carbohydrates) as water enters the starch granules (Desalegn, 2015). This results in an increase in protein and carbohydrate digestibility, thereby providing a nutrient dense diet to infants and young children, especially those with undeveloped digestive systems (Nnam, 2000; Onimawo & Egbekun, 1998; Osundahunsi & Aworh, 2002).

Onuoha et al. (2014) also reported that low bulk density food materials will provide adequate caloric and nutrient intake for infants and children that meets their energy and nutrient requirements. A low bulk density flour has good physical attributes in terms of transportation and storage since the flour could be transported and distributed easily (Agunbiade & Sanni, 2001)

3.1.2. Least gelation concentration

The LGC is the ability of the flour to form gels that can provide a structural matrix for holding water and water-soluble compounds such as sugars and flavours (Chandra, 2015). The LGC results indicated an increase in the least gelation concentration in the flour blends (Table 1). MF formed the gel quickly at the very lowest concentration (6 g/100 ml). The least heat gelation of MBF/MF blends ranged between 6% and 8% (w/v) (Table 2). These results were in agreement with Kubor and Onimawo, (2003) who noted an LGC of 8% (w/v) in maize flour. The MBF/MF blends formed a gel from 7 g/100 ml up to 10 g/100 ml. The gelation capacity of flours is affected by protein gelation and starch gelatinisation processes and their physical competition for water (Kaushal et al., 2012). Akintayo et al. (2004) reported that the lower the LGC of the flour, the better the gelating ability of the protein ingredient and the swelling ability (Kaushal et al., 2012).

This protein gelation process is significantly influenced by the addition of MBF due to the presence of sulfhydryl groups in proteins. Proteins found in MBF contain sulfhydryl groups which are exposed and induce the hydrophobic nature of the flour blend, thereby improving gel formation (Chandra et al., 2015). The variations observed in the gelling ability may be ascribed to the presence of carbohydrates, proteins, and lipids at different concentrations and their interactions cause significant effects on the functional properties of the flour (Jude-Ojei et al., 2017).

3.1.3. Least gelation temperature

The least gelation temperature refers to the temperature point at which starch gelatinise and start to form a gel (Sahay & Singh, 1996). The highest gelation temperature was observed for maize flour (63.6 ± 2.49°C). There was a decrease in gelatinisation temperature with an increase in addition of monkey bread flour as shown inTable 1. Flour blend with 15% MBF had the highest gelatinisation temperature of 58.5 ± 1.12°C among all flour blends and the lowest gelatinisation temperature was noted in 80% MBF (39.4 ± 2.23°C). The decrease in gelatinisation temperature in flour blends was significantly different at $p < 0.05$. The decrease in the gelatinisation temperature could be attributed to the effect of starch molecules. MBF flour contains a low content of carbohydrates but an increase in addition of MBF would have a net increase in the total carbohydrate content when added to MF. This net increase in carbohydrates would reduce the gelatinisation temperature of the flour as observed in this study.

Starch is a polysaccharide comprising amylose and amylopectin in its structure and their ratios is important in the gelatinisation process. This explanation is supported by Bhat and Srithsr (2008), who reported that an increase in starch content lowers the gelation temperature and is important in reducing cooking time.

3.1.4. Swelling capacity

Swelling capacity (SC) is a measurement of the ability of starch molecules to absorb water and swell and in this study it ranged from 2.62 ± 0.02 to 5.23 ± 0.04 g/ml in flour blends. There was a significant difference in the swelling capacity of the flours at $p < 0.05$. Chinma et al. (2015) reported that the increase in swelling capacity could be ascribed to an increase in the hydration of starch molecules in the flour. SC is important in food processing and it improves the structure of foods especially baked products (Jude-Ojei et al., 2017).

The swelling ability of flour is influenced by the amount of proteins which tends to decrease the surface tension of water in the food matrix (Jude-Ojei et al., 2017). Furthermore, Crosbie and Ross (2004) noted that the degree of swelling depends on the availability of water, temperature, type of starch, particle sizes, level of starch damage during thermal and mechanical processes and other carbohydrates such as pectin, hemicelluloses and celluloses.

3.1.5. Oil absorption capacity

The oil absorption capacity ranged from 1.52 ± 0.21 to 3.1 ± 0.12 ml/g in the flour blends. Maize flour had an oil absorption of 1.12 ml/g. OAC was significantly different at $p < 0.05$. Amandikwa et al. (2015) reported a low oil absorption capacity of 0.88 ml/g in wheat flour. The OAC increased with increase in MBF concentration in the flour blends (Table 1). This could be explained by the presence of a non-polar side chain, which tends to bind the hydrocarbon side chain of the oil in the flour (Chandra et al., 2015).

Water and oil-binding capacity of protein is dependent on intrinsic factors such as amino acid configuration, protein structure and surface polarity (Chandra et al., 2015). More so, proteins affect the OAC because they consist of both hydrophilic and hydrophobic parts. The high OAC suggested the improved hydrophobic character of proteins in the flour blends. Jitngarmkusol et al. (2008) and Singh (2001) reported that non-polar amino acid side chains might form hydrophobic interaction with hydrocarbon chains of fats and oils. This interaction can also occur as a result of the physical binding of fats through capillary action. Furthermore, *P. thonningii* pulp flour could be used in food formulations where an improvement in oil absorption capacity is required.

Lipids have technological importance especially in imparting good flavour and soft texture to food. In addition, oil absorption in food products enhances mouth feel and improves flavour retention (Chandra et al., 2015). The OAC property of MBF/MF blend can be beneficial in food processing because it could be used as a functional ingredient.

3.1.6. Water absorption capacity

The water absorption capacity increased while oil absorption capacity decreased with increased amounts of MBF in the blends (Table 1). WAC refers to the ability of a food product to be associated with limited water (Singh, 2001). WAC of maize flour was (191.2 ± 4.60%) and ranged from 210.4 ± 6.56 to 270 ± 4.07% in the flour blends. The increase in the WAC was significantly different at $p < 0.05$. The results indicated that WAC increased with the addition of *P. thonningii* pulp flour at different concentrations. Amandikwa et al. (2015) noted a WAC of 1.50 ml/g in wheat flour. Furthermore, Chandra et al. (2015) and Akubor and Onimawo (2003) reported a WAC for wheat and maize flour as 140% ± 12.25% and 197%, respectively. The observed increase in WAC results

Table 3. Nutritional composition and energy value of MF, MBF, and flour blends (MBF + MF)

Nutrient	MBF:MF (%, w/w)								
	100:0	**0: 100**	**15:85**	**25:75**	**35:65**	**50:50**	**65:35**	**80:20**	**p-value**
Moisture content	8.1 ± 0.05 ^{c}	7.6 ± 0.07^{b}	8.1 ± 0. 02 ^{c}	8.0 ± 0.05 ^{c}	8.4 ± 0.01 ^{c}	7.7 ± 0.08^{b}	6.6 ± 0.04^{a}	6.2 ± 0.03^{a}	0.021
Crude protein %	18.2 ± 0.01^{d}	10.2 ± 0.04^{a}	12.4 ± 0.05^{b}	13.8 ± 0.01^{b}	14.8 ± 0.04 ^{c}	14.3 ± 0.02 ^{c}	13.0 ± 0.06^{b}	12.7 ± 0.08^{b}	0.031
Ash %	4.2 ± 0.02^{d}	2.1 ± 0.01^{a}	2.4 ± 0.01^{a}	2.6 ± 0.06^{b}	2.7 ± 0.02^{b}	3.0 ± 0.01 ^{c}	2.8 ± 0.01^{b}	2.6 ± 0.10^{b}	0.041
Crude fat %	3.2 ± 0.01^{a}	3.5 ± 0.02^{a}	4.2 ± 0.21^{b}	4.5 ± 0.03^{b}	4.7 ± 0.01^{b}	4.8 ± 0.03^{b}	4.1 ± 0.11^{b}	3.8 ± 0.04^{a}	0.026
Crude fibre %	3.5 ± 0.02 ^{c}	2.3 ± 0.01^{a}	2.7 ± 0.12^{b}	2.9 ± 0.20^{b}	3.1 ± 0.13 ^{c}	3.3 ± 0.14 ^{c}	2.5 ± 0.20^{b}	2.4 ± 0.10^{a}	0.017
Carbohydrate %	62.8 ± 0.01^{a}	74.3 ± 0.02 ^{c}	70.2 ± 0.10^{b}	68.2 ± 0.24^{a}	66.3 ± 0.10^{a}	66.9 ± 0.12^{a}	71 ± 0.20^{b}	72.3 ± 0.10^{b}	0.029
Energy (cal/100 g)	352.8 ± 1.1^{a}	369.5 ± 0.42^{b}	368.2 ± 2.49^{b}	368.5 ± 1.27^{b}	366.7 ± 0.65^{b}	368 ± 0.83^{b}	372.9 ± 2.03 ^{c}	374.2 ± 1.08 ^{c}	0.04

Mean ± standard deviations are reported. Means with different superscripts ($^{a, b, c, d}$) in a row are significantly different at $p < 0.05$.

could be ascribed to the increase in amylose leaching, solubility and loss of starch crystalline structure of the flour blends (Chandra et al., 2015).

Moreover, a high WAC suggests the presence of more hydrophilic components such as polysaccharides in the flour. This is supported by the high fibre content of the *P. thonningii* fruit. The low WAC in maize flour could be attributed to the maize grains having less polar amino acids (Chandra et al., 2015; Kaushal et al., 2012). Proteins are hydrophilic and hydrophobic in nature meaning they have the ability to interact with water molecules in foods. Seena and Sridhar (2005) reported that high water absorption capacity would cause high water retention and no protein dissolution, thus increasing the viscosity of the gel. More so, Traynham et al. (2007) supported this and reported that WAC is dependent on the ability of polysaccharides and/or protein matrix to absorb, retain, and physically entrap water against the force of gravity. The WAC could also have been affected by particle size, amylose/amylopectin ratio and molecular organisation of the proteins and fats in flour (Adegunwa et al., 2011).

A good WAC of the flour blends might prove useful when using the flour for good viscosity in products such as gravies and soups. Niba et al. (2002) stated that WAC is important in bulking and consistency of many food products as well as in baking. The observed increase in WAC results in this study could also be attributed to differences in total protein concentration, their degree of water interaction and conformational properties (Butt & Batool, 2010).

3.1.7. Emulsion activity and stability

MF had an EA and ES of 44.8 ± 0.02 and 40.2 ± 0.04, respectively. Maize germ proteins have been reported to improve not only emulsifying capacity but also emulsion stability which in turn can improve texture, thus forming stable gels (Siddiq et al., 2009). EA of the flour blends ranged between 46.4 ± 0.07 and 55.3 ± 0.01%. Proteins being the surface active agents can form and stabilize the emulsion by creating electrostatic repulsion on the oil droplet surface (Kaushal et al., 2012). Lawton and Wilson (2003) noted that emulsion activity is dependent on the shape, charge and hydrophobicity of the protein molecules, neutrality of dipoles and hydration of polar groups.

ES and EA of the flour blends were found to be increasing. This increase could be explained by the formation of highly cohesive films in the flour due to the absorption of rigid globular protein molecules that resist mechanical deformation during the milling process (Lawton & Wilson, 2003). Furthermore, high soluble proteins tend to form a protective barrier around fat droplets thus inhibiting them from clustering together and hence resulting in a relatively high emulsion property (Siddiq et al. (2009); Lawton and Wilson (2003) The flour blends have a potential to be used as an ingredient in baking and can act as a stabilizing agent in the colloidal foods because of its relatively high ES and EA.

3.1.8. Nutritional composition

The nutritional composition of MF, MBF, and its flour blends is shown in Table 3. Moisture content ranged from 6.2 ± 0.03 to 8.4 ± 0.01 in the flour blends. The moisture content was significantly different at $p < 0.05$. Singh et al. (2005) reported that low moisture content of flour improves its storage stability by preventing the growth of moulds and limits the occurrence of biochemical reactions.

The crude protein content increased with the addition of monkey bread flour. Crude protein was highest in flour blends with 50%, w/w MBF (14.3% ± 0.02%) and lowest in 80%, w/w MBF (12.7% ± 0.08%). Crude protein was significantly different at $p < 0.05$. This could be ascribed to the protein content in *P. thonningii* fruits which are leguminous plants in nature. *P. thonningii* fruits contain a protein content of 20.25% (Hemen et al., 2012) and this could support the increase in protein content in flour blends. Furthermore, a study by Yetunde et al. (2009) reported that legume plants will result in synergistic effects of protein complement on cereal blends because they contain more protein. The ash content increased with the addition of monkey bread flour in the blends. Flour blend with 50% MBF had a high ash content of 3.0 ± 0.01% among other blends. The increase in ash content suggests the high mineral content of *P. thonningii* fruit. Indigenous fruits of

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Table 4. Mineral contents of MF, MBF, and flour blends (MBF+ MF)

Nutrient (mg/ 100 g)	MBF:MF (%, w/w)								
	100:0	0:100	15:85	25:75	35:65	50:50	65:35	80:20	p-value
Sodium	4.4 ± 0.5^{a}	4.32 ± 0.04^{a}	4.51 ± 0.01^{a}	4.80 ± 0.02^{a}	4.95 ± 0.05^{b}	4.60 ± 0.03^{a}	4.92 ± 0.01^{b}	5.12 ± 0.02^{b}	0.032
Potassium	410.5 ± 1.21^{d}	325.4 ± 2.08^{a}	355 ± 1.23^{b}	386.1 ± 2.12^{c}	398.5 ± 3.01^{d}	365.5 ± 2.20^{b}	401.2 ± 1.56^{d}	378.6 ± 3.23^{c}	<0.01
Iron	4.1 ± 0.2^{d}	2.11 ± 0.15^{a}	1.86 ± 0.21^{a}	2.20 ± 0.11^{b}	2.31 ± 0.25^{c}	2.8 ± 0.12^{c}	3.11 ± 0.10^{d}	2.42 ± 0.18^{c}	0.012
Calcium	7.8 ± 0.1^{b}	8.12 ± 0.10^{b}	6.20 ± 0.10^{a}	8.35 ± 0.20^{b}	8.80 ± 0.12^{bc}	9.0 ± 0.1^{c}	8.70 ± 0.30^{bc}	9.12 ± 0.15^{c}	0.038
Phosphorus	278.4 ± 5.23^{a}	286.4 ± 1.45^{a}	295.1 ± 1.10^{b}	301.2 ± 0.15^{b}	310.1 ± 1.20^{c}	290.2 ± 1.45^{ab}	323.5 ± 1.35^{c}	365.1 ± 2.10^{d}	0.012
Magnesium	90.1 ± 4.21^{d}	78.5 ± 5.10^{c}	66.4 ± 2.21^{a}	81.5 ± 2.10^{c}	83.1 ± 1.05^{c}	88.2 ± 2.5^{d}	79.5 ± 1.36^{bc}	77.6 ± 1.4^{b}	0.041
Zinc	0.89 ± 0.12^{a}	1.32 ± 0.13^{a}	1.10 ± 0.2^{a}	1.71 ± 0.1^{b}	1.86 ± 0.05^{cd}	1.78 ± 0.02^{c}	1.88 ± 0.20^{d}	1.57 ± 0.3^{b}	0.026
Copper	0.72 ± 0.05^{a}	0.15 ± 0.04^{a}	0.11 ± 0.01^{a}	0.14 ± 0.02^{a}	0.17 ± 0.01^{a}	0.22 ± 0.02^{b}	0.25 ± 0.02^{b}	0.28 ± 0.01^{b}	0.016

Mean ± standard deviations are reported. Means with different superscripts ($^{a, b, c, d}$) in a row are significantly different at $p < 0.05$.

Table 5. Mean sensory scores of non-fermented food gel prepared from MF and flour blends (MBF+MF)

Sensory Attributes					
Porridge MBF:MF	**Taste**	**Colour**	**Texture**	**Flavour**	**Overall Acceptability**
0:100	3.7 ± 0.01^{a}	3.8 ± 0.05^{a}	3.7 ± 0.06^{a}	3.8 ± 0.01^{a}	4.0 ± 0.05^{b}
15:85	3.5 ± 0.11^{a}	3.9 ± 0.02^{a}	3.8 ± 0.02^{a}	4.0 ± 0.01^{b}	4.1 ± 0.05^{c}
25:75	3.6 ± 0.05^{a}	4.0 ± 0.02^{a}	4.2 ± 0.05^{c}	4.1 ± 0.10^{b}	4.3 ± 0.12^{d}
35:65	3.7 ± 0.01^{a}	3.8 ± 0.21^{a}	3.9 ± 0.10^{b}	3.9 ± 0.10^{b}	4.0 ± 0.11^{c}
50:50	3.6 ± 0.06^{a}	3.9 ± 0.10^{a}	4.0 ± 0.26^{c}	4.0 ± 0.10^{b}	3.8 ± 0.10^{a}
65:35	3.5 ± 0.15^{a}	3.7 ± 0.05^{b}	3.9 ± 0.14^{b}	3.9 ± 0.15^{b}	3.7 ± 0.12^{a}
80:20	3.6 ± 0.02^{a}	3.8 ± 0.01^{b}	3.9 ± 0.01^{b}	4.1 ± 0.03^{b}	3.9 ± 0.15^{b}
p-value	0.112	0.065	0.002	0.031	0.021

1 = Very poor and 6 = excellent.

Mean ± standard deviations are reported. Means with different superscripts ($^{a, b, c, d}$) in a column are significantly different at $p < 0.05$.

southern Africa have been found to be rich sources of minerals (Chawafambira, Sedibe, Mpofu, Achilonu et al., 2020a).

The dietary fibre content was high in flour blends with 50% MBF (3.3 ± 0.14%). The increase in fibre content was significantly different at $p < 0.05$. The results could be explained by a relatively high fibre content in *P. thonningii* fruits. Dietary fiber refers to the edible carbohydrate monomers that naturally occur in foods with more than 10 monomeric units that cannot be hydrolysed by endogenous enzymes in the ileum of human (Joint FAO/WHO Food Standards Programme Commission, 2016). Dietary fibre intake has been found to be beneficial in reducing the risk of heart disease (Oppong et al., 2015), hypertension (Anderson, 2004), stroke (Whelton et al., 2005), obesity (Watzl et al., 2005), and potentially boost the immune system (Schley & Field, 2002).

The fat content was significantly different at $p < 0.05$ in all flour blends. The fat content range was 3.8–4.8% in the flour blends and is generally low. This might be due to the science that cereals and legumes store energy in the form of starch rather than lipids (Iwe et al., 2016). Esua et al. (2016) reported a low-fat content of 1.42% in *P. thonningii*. Reebe et al. (2000) indicated that low-fat content of flour is beneficial in ensuring longer shelf life and product stability as compared to high fat foods because the fat contains unsaturated fatty acids which are potentially susceptible to oxidative rancidity. The carbohydrate content was lowest in a blend with 35% MBF (66.3 ± 0.10%). This might be attributed to an increase in protein and fibre contents. This was in agreement with Jimoh and Olatidoye (2009) who reported a decrease in carbohydrate content of maize flour with an increase in the addition of soybean flour in the blends. The energy values were in the recommended range by FAO and WHO (2009).

The mineral content results are shown in Table 4. From the mineral content data, it is evident that the flours can be used as important sources of iron (2.11 − 3.11 mg/100 g), calcium (6.2–9.12 mg/100 g), potassium (325.4–401.2 mg/100 g), magnesium (66.4–88.2 mg/100 g), and zinc (1.10–1.88 mg/100 g). Esua et al. (2016) observed a calcium, iron, and manganese content of 4.31 ± 0.03 mg/100 g, 78.1 ± 23.2 mg/100 g, and 0.1 mg/100 g, respectively, in *P. thonningii* fruits. Equally, Chawafambira, Sedibe, Mpofu, Achilonu et al. (2020a) reported some positive correlations between iron content with calcium, zinc and copper in *U. kirkiana* fruit pulp. Moreover, the flour has the potential to improve mineral nutrition upon consumption. However, in terms of nutrition, it is therefore important and necessary to measure the bioaccessibility and/or bioavailability of these minerals (Chawafambira, Sedibe, Mpofu, Achilonu et al., 2020b). Iwe et al. (2016) stated that

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Table 6. Flour blend composition with recommended dietary allowance (RDA) and adequate intake (AI) for children (1–9 yrs), children (9–13 yrs), adolescents (14–18 yrs) and pregnant women (all ages)

		Carbohydrates	Protein	Fibre	Zn	Fe	Mg	Ca
		g/day	g/day	g/day	mg/day	mg/day	mg/day	mg/day
Flour blend (25% MBF + 75% MF) composition		**68.2****	**13.8****	**2.9****	**1.71*****	**2.20*****	**81.5*****	**8.35*****
RDA children (1–9 yrs)	Man	80[b]	25[b]	10[a]	5[b]	7[b]	130[b]	1000[b]
	Women	80[b]	25[b]	10[a]	5[b]	7[b]	130[b]	1000[b]
% Contribution in children diet		**85**	**55**	**29**	**34**	**31**	**62**	**0.8**
RDA children (9–13 yrs)	Man	130 [b]	34 [b]	12 [a]	8 [b]	8 [b]	240 [b]	1300 [b]
	Women	130 [b]	34 [b]	12 [a]	8 [b]	8 [b]	240 [b]	1300 [b]
% Contribution in children diet		**52**	**40**	**24**	**21**	**27**	**34**	**0.6**
RDA adolescents (14–18 yrs)	Man	130 [b]	55 [b]	16 [a]	11 [b]	11 [b]	410 [b]	1300 [b]
	Women	130 [b]	52 [b]	17 [a]	9 [b]	15 [b]	360 [b]	1300 [b]
% Contribution in adolescents diet		**52**	**25**	**17**	**11**	**15**	**20**	**0.6**
RDA pregnant women	All ages	175 [b]	41 [b]	28 [a]	12 [b]	27 [b]	350 [b]	1000 [b]
% Contribution in pregnant women diet		**39**	**34**	**10**	**14**	**8**	**23**	**0.8**

[a]Adequate intake (AI) values (Food and Nutrition Board (1997, 2001). [b] Recommended dietary allowances (RDA) values (Food and Nutrition Board, 2005). ** Unit of measurement = g/100 g. ***Unit of measurement = mg/100 g.

minerals are essential nutrients which work in many essential metabolic functions and are part of molecules such as adenosine triphosphate (ATP), deoxyribonucleic acid (DNA) and haemoglobin.

3.1.9. Sensory analysis

The mean sensory scores of the non-fermented food gels are shown in Table 5. There were no significant ($p > 0.05$) differences in taste, colour and flavour among the food gels. However, the texture and overall acceptability mean scores for the food gel differed significantly a $p < 0.05$. The mean sensory scores or colour did not differ significantly up to 50% addition level of MBF for the food gel. The non-fermented food gel prepared from 75% MF and 25% MBF was most preferred with respect to colour, texture, flavour, and overall acceptability. The calculations on % contributions indicated that flour blend comprising 25% MBF can deliver more than 80% and 50% of RDA for carbohydrates in age groups 1–9 years and 9–13, 14–18 years, respectively. Also, the flour has the potential to deliver more than 30% and 60% of the RDA for iron and magnesium in the age group 1–9 years, respectively (Table 6). Nutritionally, the data further support the importance of the flour as a good source of carbohydrates and magnesium.

4. Conclusion

The functional properties of MF and flour blends with MBF such as LGC, emulsion activity, emulsion stability, swelling capacity, swelling index, oil absorption capacity and water absorption capacity increased with increase in the incorporation of MBF. The addition of MBF to MF increased the protein, crude fibre and ash content but reduced the carbohydrate content. Essential minerals (iron and calcium) increased with the addition of MBF at different percentage level in the flour blends. Blending of MBF with MF results in an increase in protein, fat, ash and fibre contents in the flour blends. The food gel produced with 25% w/w MBF/MF flour blend was most liked and accepted by panelists. Higher level of MBF above 50%, conversely, reduced the overall acceptability and the sensory quality attributes of the food gel. The addition of *P. thonningii* pulp flour to maize flour would therefore be advantageous in producing a nutritious food gel that has the potential to meet RDA for essential nutrients and help to mitigate malnutrition problems in children in Zimbabwe. However, the amino acid profile and mineral bioaccessibility, which are crucial for understanding the protein quality and mineral nutrition of the MBF/MF flour blended food gels, should be explored further.

Conflicts of Interest
The authors declare there is no conflict of interest.

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