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Original Research

Effect of natural fermentation on the physicochemical, functional and sensory properties of orange-fleshed sweet potato (*Ipomea batatas* L.) flour and gluten-free bread

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Abstract

The objective of this study was to evaluate the effect of natural fermentation on the physicochemical, functional and sensory properties of orange-fleshed sweet potato (*Ipomea batatas* L.) flour and bread.
The sweet potato strips were fermented for 0, 24, 48, 72 and 96 hours, oven dried at 60°C and milled to a flour.
The protein and fat content of the sweet potato flour (SPF) increased with an increase in fermentation time, while ash, crude fibre and carbohydrates decreased.
The SPF showed an increase in water absorption and a decrease in swelling power, solubility power and bulk density.
The moisture, protein and fat content of the bread increased with an increase in fermentation time of the SPF, while the crude fibre and carbohydrates decreased.
Physical and sensory properties of sweet potato bread showed an increase in softness scores and a decrease in height, volume, specific volume, bake loss, flavour, aroma and overall acceptance scores with an increase in fermentation time.
Results of this study show that it is feasible to produce bread from fermented sweet potatoes. However, some physical and sensory properties of the bread need to be optimized.

Keywords: Orange-fleshed sweet potato, gluten-free bread, sensory, nutritional, *Ipomea batatas*

Introduction

Sweet potato is the seventh most important food crop in the world, and fourth in tropical countries [1]. In comparison to other main staple food crops, sweet potatoes adapt to marginal conditions; they have a short production cycle, high nutritional value and superior sensory attributes in terms of flesh colour, taste and texture [2]. The yellow- and orange-fleshed sweet potato varieties are the most nutritious due to their high dietary fibre, β-carotene, ascorbic acid, minerals and polyphenolic compounds [3]. Furthermore, sweet potatoes produce the highest amount of edible energy per hectare per day [4].

Sweet potatoes can be eaten in fried, roasted and boiled forms [5]. The crop is also used to produce starch, pectin, lacto-juices and composite flours, which are reported to be rich in vitamins and minerals [5–7]. Thus, sweet potato flour (SPF) can be used to improve the nutritional value of many food products [8]. Moreover, SPF is a non-gluten flour, therefore it does not cause conditions such as coeliac disease [9].

Since the development of human civilizations, fermented beverages and foods have been staples for most people [10]. Fermentation of food, especially grains, improves starch and protein digestibility and bioavailability of minerals [11]. Fermentation also reduces levels of anti-nutrients such as phytic acid, saponins and polyphenols in cereals [12], and can modify sensory and quality parameters of foods [13].

Successive droughts compounded by economic shocks have resulted in decreased wheat production worldwide [14]. Thus, there is a need to find alternative food crops for bread production. However, the use of these non-wheat flours is limited due to their low baking quality and the poor sensory attributes of the baked products. It is possible that fermentation of these food crops can improve the physicochemical, functional and sensory properties of the flour and flour products.
The aim of this study was to investigate the effect of natural fermentation on the physicochemical, functional and sensory properties of orange-fleshed SPF and sweet potato bread (SPB).

Materials and methods

Preparation of fermented SPF

Sweet potatoes were washed, sliced into 4–5 mm strips and immersed in a mixture of 1% NaCl (1 l), 1% potassium metabisulphite (1 l) and 0.5% citric acid (1 l) for 30 min to prevent browning. The slices were then soaked in tap water and fermented for 24, 48, 72 and 96 hours. After fermentation, the slices were drained, dried at 65°C for 9 hours in a cabinet drier and milled into flour (<250 μm). The dried unfermented sweet potatoes were used as a control.

Nutritional composition of the sweet potato flour and bread

The moisture content, ash, crude fat, crude protein and crude fibre of the SPF and SPB were analysed according to modified Association of Official Analytical Chemists (AOAC) methods [15]. The carbohydrate content was the percentage of matter that remained after moisture, ash, crude fat and crude protein were determined.

Functional properties of SPF

Water absorption capacity (WAC)

One gramme of SPF in a pre-weighed centrifuge tube was mixed with 15 ml of distilled water. The mixture was vortexed for 2 min and centrifuged at 4000 rpm for 20 min. The clear supernatant was discarded; the bound water was determined by difference and expressed as the weight of water bound by 100 g of dry flour [16].

Bulk density

SPF samples (10 g) were weighed into a 50 ml measuring cylinder. The sample was packed by gently tapping the cylinder to a constant volume [17]. The volume of the compacted sample was recorded and the bulk density was calculated as:

$$Bulk\ density\ \left(\frac{g}{cm3}\right) = \frac{Weight\ of\ sample}{Volume\ of\ sample\ after\ tapping}$$

Swelling power and solubility

Swelling power and solubility were determined by the method described by McCormick *et al.* [18]. One gramme of sample was weighed into a 100 ml conical flask, mixed with 15 ml of distilled water and agitated for 5 min. The resultant slurry was heated in a water bath at 90°C for 40 min. The slurry was added to 7.5 ml distilled water in pre-weighed centrifuge tubes, and centrifuged at 2200 rpm for 20 min. After centrifugation, the supernatant was decanted into a pre-weighed pan and then dried at 100°C to a constant weight. The weight of the dried sediment was recorded, and solubility of the SPF was calculated as:

$$Solubility\ \% = \frac{Weight\ of\ dried\ sediment\ in\ supernatant}{weight\ of\ original\ sample} \times 100$$

The sediment obtained after decanting the supernatant was also weighed to determine the swelling power, calculated as:

$$Swelling\ power = \frac{Weight\ of\ sediment}{Weight\ of\ sample}$$

Preparation of fermented SPB

Ingredients listed in **Table 1** were mixed by hand to obtain a batter. The batter was placed into baking tins and proved in an incubator at 40°C for 1 hour. A cup of boiled water was the source of humidity during proving, thus the humidity in the incubator was not controlled. After proving, the batter was baked in an oven at 240°C for 20 min.

Table 1 Bread formulation

Ingredient	Quantity (g)
Sweet potato flour (SPF)*	100
Tapioca starch	100
Corn starch	100
Fat	40
Sugar	20
Salt	10
Yeast	3
Baking powder	0.01
Milk	27
Xanthan gum (XN)	13
Sodium stearoyl lactylate (SSL)	1
Vinegar	5
Water	340

*Unfermented or fermented for 0, 24, 48, 72 and 96 hours

Physical properties of the SPB

Bake loss

Aluminium foil tins and a pan (M1) were weighed. Also, aluminium foil tins containing the batter (M2) and baked loaves (M4) were weighed. Mass of the batter (M3) was found by subtracting M1 from M2 [19], and the percentage bake loss was calculated as:

$$\%\ Bake\ loss\ (moisture\ loss) = \frac{100}{M3} \times [M3 - M4]$$

Loaf volume and specific volume

The rapeseed displacement method [20] was used to measure volume and specific volume of the loaves. A 2 l glass beaker was standardized by filling the container with rapeseeds and a glass rod was used to remove excess seeds. The volume of seeds (V1) in the 2 l beaker was then measured using two 1 l measuring cylinders. SPB loaves were wrapped with 'cling film' plastic to maintain the shape and contours of the loaf. A loaf sample was then placed in the standardized 2 l glass beaker and rapeseeds were poured into the container, ensuring that there was no bridging or air pockets. The container was levelled and the volume of the seeds (V2) was measured using two 1 l measuring cylinders. The loaf volume (V3) in cm^3 was calculated as:

$$Loaf\ volume\ [V3] = V1 - V2$$

Loaf specific volume (SV) was calculated as:

$$Loaf\ SV = \frac{Loaf\ volume\ [V3][cm3]}{Loaf\ mass\ [g]}$$

Sensory evaluation of SPB

Fifty untrained students from the Department of Food, Nutrition and Family Sciences evaluated the SPB. The panelists evaluated the softness, flavour and overall acceptability of the bread on a nine-point scale that ranged from 1 (extremely dislike) to 9 (like extremely), according to Crisosto *et al.* [21].
SPB samples were coded with three-digit numbers and served in plastic plates in a booth.
After tasting of each SPB sample, distilled water was used to rinse the mouth.

Statistical analysis

The results reported in this study are given as means ± standard deviation. One-way analysis of variance (ANOVA) in GraphPad Prism was used to determine whether there were significant differences in physicochemical, functional or sensory properties of the SPF and bread. Means were separated by Tukey's post hoc test, with $p \le 0.05$ considered significant.

Results and discussion

Nutritional composition of SPF

The nutritional composition of the unfermented and fermented SPFs are shown in **Table 2**. There were insignificant ($p > 0.05$) changes in the moisture content of SPF with an increase in fermentation time. These results contradict those found by Igbabul *et al.* [22], who reported a significant increase in moisture content of cocoyam flour with an increase in fermentation time. In this study, low levels of moisture obtained for the fermented SPFs decrease their susceptibility to microbial spoilage.

The ash content of the SPF decreased significantly ($p \le 0.05$) with an increase in fermentation time. Similarly, Atti reported that the ash content of millet decreased with an increase in fermentation time [23]. In contrast, Sefa-Dedeh *et al.* observed that fermentation increased the ash content of fermented cowpea and maize [24]. Leaching of minerals into the fermenting medium possibly contributed to the decrease in ash content observed in this study [23].

With an increase in fermentation time, there was a significant ($p \le 0.05$) increase in

Table 2 Macronutrient content of sweet potato flour (SPF)

Parameter (g/100 g)	Fresh sweet potato	Control [1]	SPF24 [2]	SPF48	SPF72	SPF96
Moisture	71.83±1.4^{3}a	9.91±0.03^b	9.82±0.01^b	9.80±0.01^b	10.07±0.01^b	10.00±0.01^b
Ash	1.41±0.01^a	1.337±0.01^a	1.303±0.01^a	1.286±0.01^b	1.17±0.01^c	1.143±0.01^c
Protein	1.73±0.03^a	1.80±0.01^a	2.567±0.06^b	2.78±0.01^c	2.927±0.50^d	3.02±0.29^e
Fat	1.37±0.03^a	1.41±0.01^a	1.50±0.01^b	1.56±0.03^{bc}	1.61±0.01^{cd}	1.63±0.01^{de}
Crude fibre	4.07±0.06^a	3.99±0.01^a	3.85±0.05^a	3.72±0.10^b	3.65±0.05^c	3.58±0.03^d
Carbohydrate	19.59±0.32^a	82.13±0.04^b	81.17±0.04^c	80.55±0.21^d	78.70±0.04^e	80.69±0.01^f

[1] Unfermented SPF. [2] SPF fermented for n hours. In the same row, data with different superscripts are significantly different at $p \le 0.05$. The results are expressed as mean ± SD

the protein content of the SPF. Oshodi *et al.* [25] observed this trend for beniseed flour. The net synthesis of protein by microorganisms during fermentation and the structural proteins of fermentation bacteria probably contributed to the increase in protein of SPF [26, 27].

The fat content of the flours increased significantly ($p \leq 0.05$) with an increase in fermentation time. The results are consistent with those obtained by Igbabul *et al.* [22], who reported a significant increase (1 g/100 g to 2.61 g/100 g) in fat content of cocoyam with an increase in fermentation time. This increase in fat content can be attributed to the extensive breakdown of larger fat molecules to fatty acids due to the activity of lipolytic enzymes [27].

Crude fibre and carbohydrate contents of the SPFs decreased significantly ($p \leq 0.05$) with increasing fermentation time. According to Igbabul *et al.*, the crude fibre of cocoyam decreased from 0.73 to 0.19% with an increase in fermentation time [22]. The authors also reported an increase (66.53 to 71.57 g/100 g) in carbohydrate content of cocoyam with an increase in fermentation time. In this study, the decrease in fibre and carbohydrates can be attributed to the utilization of these nutrients by fermenting microorganisms as an energy source for metabolism and growth [28, 29].

Functional properties of SPF

Functional properties of the fermented and unfermented flours are shown in **Table 3**.

The water absorption of SPFs increased significantly ($p \leq 0.05$) with an increase in fermentation time, as shown in **Table 3**. In contrast, several authors reported a decrease in water absorption with fermentation time.

Alfaro *et al.* [30], Filli *et al.* [31] and James and Nwabueze [32] observed a decrease in water absorption with increasing fermentation time for extruded millet–soybean flour, soya bean flour and extruded African breadfruit flour mix.

High values of water absorption observed in this study imply that the SPFs can be incorporated into aqueous food formulations, especially those involving dough handling [33].

Results of this study show that the bulk density of the SPFs significantly decreased ($p \leq 0.05$) with an increase in fermentation time.

Similarly, Elkhalifa *et al.* [34] and Onimawo *et al.* [35] observed a decrease in the bulk density of bambara nut flour and sorghum flour with an increase in fermentation time. In contrast, Appiah *et al.* [36] reported that the bulk density of unfermented samples (0.46 g/cm^3) was significantly lower ($p \leq 0.05$) than that of the fermented flour (0.57 g/cm^3). Bulk density indicates the heaviness of flour [37] and is a key parameter that determines the ease of packaging and transportation of flours [38]. It also influences the strength and the amount of packaging material required and the mouth feel and texture of the resultant food products [39].

The swelling power and solubility of the SPFs decreased significantly ($p \leq 0.05$) with fermenta-

Table 3 Functional properties of sweet potato flour (SPF)

Parameter	Control	SPF24[1]	SPF48	SPF72	SPF96
Water absorption (%)	56.03±0.15^a	57.41±0.01^b	59.53±0.06^c	58.8±0.01^d	58.00±0.001^d
Bulk density (g/cm^3)	0.84±0.0045^a	0.827±0.02^a	0.72±0.01^b	0.67±0.02^c	0.63±0.01^d
Swelling power (ml/g)	3.61±0.01^a	3.54±0.04^b	3.46±0.02^c	3.38±0.01^d	3.15±0.05^e
Solubility power (%)	10.52±0.02^a	9.77±0.06^b	9.04±0.06^c	8.27±0.21^d	7.70±0.10^e

[1] SPF fermented for n hours. In the same row, data with different superscripts are significantly different at $p \leq 0.05$.
The results are expressed as mean ± SD

tion time. In contrast, Osungbaro *et al.* [40] reported an increase in solubility of cassava flour with an increase in fermentation time. The decreases observed in this study for the fermented samples could be due to modification of starch granules during fermentation, resulting in lower water uptake by the granules [41]. The higher swelling power and solubility of unfermented compared to fermented SPF was possibly due to a higher degree of intermolecular association and higher amylose content in the unfermented SPF [42]. Swelling power and solubility properties of flours can influence the loaf volume, loaf weight and water retention of baked products [43].

Nutritional composition of SPB

The nutritional composition of the SPB samples is shown in **Table 4**.

The moisture content of SPB samples ranged from 45.33 ± 0.58 g/100 g for the control bread to 48.98 ± 0.03 g/100 g for SPB96. The increase in protein and fat content of SPF during fermentation could have contributed to the increase in moisture of the bread, because proteins and fats immobilize and bind water in food products [44, 45].

In this study, the ash contents of the SPB samples were not significantly (p>0.05) different. This is possibly due to the fact that SPFs had the same amounts of ash (**Table 2**). Thus, these results show that other ingredients such as corn starch and tapioca starch did not significantly contribute to the ash content of the bread. SPB96 (6.9 ± 0.01 g/100 g) had the highest crude fat content, while the control had the lowest (5.96 ± 0.06 g/100 g). This variation is due to the higher fat content of the SPF96 compared to the control flour.

In this study, the addition of milk, shortenings and sodium stearyl lactylate increased the fat content of SPB. Protein content of the bread samples ranged from 2.52 ± 0.02 g/100 g for the control to 2.93 ± 0.06 g/100 g for SPB96. Milk used in the bread formulation is high in protein compared to SPF, thus the ingredient significantly contributed to the overall increase in protein content of all SPB samples. The carbohydrate and fibre contents of the SPB decreased significantly (p≤0.05) with an increase in fermentation time of SPF. This is attributed to the fact that the fibre and carbohydrate contents of the SPFs decreased with fermentation time, as shown in **Table 2**.

Physical properties of SPB

The control bread had the highest volume and specific volume (**Table 5**), while SPB96 had the lowest.

The volume of SPB samples decreased significantly (p≤0.05) with an increase in fermentation time of the SPF. Sciarini *et al.* [46] reported that gluten-free breads have specific volumes of approximately 2 cm^3/g, significantly lower than those of wheat products (4–7 cm^3/g). Alvarez-Jubete *et al.* [19] observed that gluten-

Table 4 Macronutrient content of sweet potato bread (SPB)

Parameter (g/100 g)	Control	SPB24*	SPB48	SPB72	SPB96
Moisture	45.33±0.58^a	47.81±0.1^b	48.24±0.01^c	48.78±0.03^c	49.06±0.03^d
Ash	1.50±0.01^a	1.49±0.01^a	1.48±0.01^a	1.46±0.001^a	1.45±0.01^a
Protein	2.52±0.02^a	2.75±0.02^a	2.81±0.01^a	2.87±0.02^b	2.93±0.06^b
Fat	5.96±0.06^a	6.01±0.01^a	6.04±0.001^b	6.08±0.01^b	6.9±0.01^d
Crude fibre	4.00±0.01^a	3.97±0.02^b	3.97±0.01^b	3.90±0.01^c	3.87±0.001^c
Carbohydrates	40.69±0.53^a	38.84±0.04^b	37.46±0.06^c	36.96±0.05^d	35.46±0.02^e

*Bread produced from sweet potato flour fermented for n hours. In the same row, data with different superscripts are significantly different at p≤0.05. The results are expressed as mean ± SD free flour requires more water to improve the volume and crumb structure of the resultant bread. The authors attributed this to the higher water retention capacity of fermented flour compared to unfermented flour. Specific volume is a key quality parameter for leavened product, hence it is important to improve this parameter and ultimately the overall quality of leavened products [47, 48].

Bake loss indicates the amount of moisture retained, thus the softness of the bread [49]. The bake loss ranged from 40.18 ± 0.01% for SPB96 to 42.89 ± 0.065% for the control bread. Results of this study show that the bake loss decreased significantly ($p \leq 0.05$) with an increase in fermentation time of SPF, probably due to the increase in protein and fat content of SPF [19]. Proteins and fats restrict gas diffusion, and minimize vapour loss because of their strong water holding capacities [50].

Also, emulsifiers such as sodium stearoyl lactylate in the bread formulation (**Table 1**) can contribute to the plasticity of the crust, thereby reducing moisture loss from the bread. Loaves with a low bake loss or a greater moisture retention have low staling rates and a soft crumb, but are more susceptible to mould manifestation [49].

Sensory evaluation scores of the SPB

Sensory scores of the SPB are shown in **Table 6**. The control bread had the lowest softness scores, while SPB96 had the highest. The control bread had lower softness scores than the other bread samples, and this can be attributed to the low moisture content of the control bread, as shown in **Table 4** [48].

The levels of proteins, fats and carbohydrates and their interactions, as well as differences in the capacity of these macromolecules to retain moisture, greatly influence texture attributes such as the softness or firmness of gluten-free breads [51].

Table 5 Physical properties of sweet potato bread (SPB)

Parameter	Control	SPB24*	SPB48	SPB72	SPB96
Volume (cm^3)	1972.19±0.564^a	1925.21±0.693^a	1848.29±0.506^b	1791.69±1.051^c	1683.94±0.655^d
Height (cm)	7.897±0.015^a	7.523±0.032^b	7.08±0.026^c	6.943±0.04^d	6.777±0.025^e
Specific loaf volume (cm^3/g)	2.944±0.005^a	2.87±0.01^b	2.757±0.049^c	2.67±0.01^d	2.51±0.01^e
Bake loss (%)	42.89±0.065^a	42.03±0.012^a	41.35±0.01^b	40.78±0.02^c	40.18±0.01^c

*Bread produced from sweet potato flour fermented for n hours. In the same row, data with different superscripts are significantly different at $p \leq 0.05$. The results are expressed as mean ± SD

Table 6 Sensory evaluation scores of the sweet potato bread

Parameter	Control	SPB24*	SPB48	SPB72	SPB96
Softness	6.5±0.048^a	6.33±0.2^a	7.29±0.57^b	7.34±0.0068^b	7.35±0.0312^b
Flavour	8.6±0.002^a	7.3±0.04^b	7.1±0.001^b	6.3±0.0054^c	6.1±0.0033^c
Aroma	8.7±0.58^a	8.23±0.002^b	7.63±0.02^c	7.26±0.01^d	6.9±0.6^e
Overall acceptance	7.8±0.03^a	7.1±0.05^b	6.5±0.2^c	6.0±0.03^d	5.6±0.2^e

*Bread produced from sweet potato flour fermented for n hours. In the same row, data with different superscripts are significantly different at $p \leq 0.05$. The results are expressed as mean ± SD

Flavour scores ranged from 6.1 ± 0.0033 for SPB96 to 8.6 ± 0.002 for the control bread; aroma scores ranged from 8.7 ± 0.58 for the control to 6.9 ± 0.6 for SPB96.

Flavour scores of SPB24, SPB48, SPB72 and SPB96 showed insignificant (p>0.05) differences. On the other hand, aroma scores of SPB24, SPB48, SPB72 and SPB96 showed significant (p≤0.05) differences. In this study, the lower flavour and aroma scores of SPB24, SPB48, SPB72 and SPB96 compared to the control were probably due to the sour taste of compounds that include organic acids and alcohols produced during fermentation of the sweet potatoes [52]. These compounds possibly masked odorants such as 2-acetyl-1-pyrroline, methional, 2,3-butanedione and [E,E]-2,4-nonadienal [53–55] in the bread. They are mainly produced during baking, but are also influenced by fermentation conditions and dough ingredients [56, 57].

There were significant (p≤0.05) differences in the overall acceptability scores of the bread samples. The control bread had the highest overall acceptability scores, while SPB96 had the lowest. The acceptability scores of SPB samples were highly correlated with flavour and aroma scores, and showed low correlation with softness scores.

Therefore, the flavour and aroma attributes greatly influenced the acceptance of the bread. Also, physical characteristics such as volume, specific volume and height of bread can influence acceptability scores.

In this study, SPB24, SPB48, SPB72 and SPB96 had lower volume, specific volume and height than the control, and consequently lower overall acceptability scores.

Similarly, de Morais *et al.* [58] observed that most consumers prefer gluten-free breads with high specific volume. Furthermore, gluten-free breads are rated lowly because of their crumbly texture, poor colour and other quality defects that include flavour and aroma [59].

Conclusions

The macronutrient content results of SPF showed an increase in fat and protein, while carbohydrates, ash and crude fibre decreased after fermentation of the SPF. Fermentation increased the water absorption capacity of the flour, while a decrease was observed in bulk density, solubility power and swelling power. The nutritional and functional properties of the fermented SPF greatly influenced quality of the SPB. The bake loss, volume and specific volume decreased with an increase in fermentation time. Also, the sensory attributes (aroma, softness and flavour) decreased with an increase in fermentation time, and consequently the overall acceptability scores were low.

Author contributions The authors confirm contributions to the paper as follows: study conception and design: Shumba TC, Chipurura B and Benhura C; data collection: Shumba TC; analysis and interpretation of results: Shumba TC, Benhura C and Chipurura B; draft manuscript preparation: Shumba TC, Benhura C and Chipurura B.

Ethical standards No studies using human or animal subjects were performed by any of the authors for this article.

Conflict of Interest The authors declare that they have no conflicts of interest.

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