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Traditional processing methods reduced phytate in cereal flour, improved nutritional, functional and rheological properties

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A B S T R A C T

The impact of traditional processing methods on the phytate, nutritional, functional and rheological quality of flours from sorghum, maize and millet were investigated. The grains were either spontaneously fermented, malted, roasted or unprocessed before separately milled into different flours. The phytate content, proximate, functional and pasting properties of processed grains were determined using standard methods. Phytate level reduced almost three-folds with malting, two-folds with fermentation and one-fold in roasted flour samples. Malting resulted in a 36% and 54% increase in sorghum and millet's crude protein content, respectively. The total energy for sorghum ranged from 387.00–393.00 kcal/100 g; that of maize ranged from 387.00–396.00 kcal/100 g, while millet ranged from 390.30–409.10 kcal/100 g. Processing methods significantly ($p < 0.001$) reduced bulk density, increased water holding capacity and oil absorption capacity of flours samples. Malting resulted in almost 88%, 93% and 69% decline in peak viscosity for sorghum, maize and millet flours, respectively. Again, malting recorded the highest final viscosity reduction: about 97% in sorghum, 98% in maize, and 85% in millet flours. Malting and fermentation resulted in a reduced level of phytate, improved nutritional and functional properties in the cereals investigated. This study provides relevant information on the processing methods that can reduce phytate (antinutrient), relatively high in most cereals consumed in Ghana.

Introduction

Cereal forms a significant staple food globally, and especially in low-income countries, including Ghana. Cereals such as millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and maize (*Zea mays*) are rich sources of energy, protein, dietary fiber, vitamins, minerals, and phytochemicals (Oghbaei & Prakash, 2016). They play a critical role in the human diet and may contribute significantly to the nutrient intake of many people.

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Aside from the vital role cereals play in our nutrition, cereals, together with legumes, have been implicated for their substantial levels of phytic acid or phytate. Phytate is an antinutrient that impairs the bioavailability of some minerals such as iron, calcium, copper and zinc [24]. Unfortunately, cereal grains are significant ingredient for complementary feeding in Ghana. Thus, bioavailability of essential micronutrients need to promote infant's growth and development is impaired (citation). In maize, sorghum and millet, which are generally recognized as monocots, phytate is present in the bran or aleurone layer [53] and must be removed or reduced significantly to increase mineral absorption from foods.

Pretreatment methods such as wet and dry heat have been reported to minimize antinutrients content in the bran of most cereals [28]. However, there have been varied opinions on the effect pretreatment conditions on the activity of endogenous phytase, an enzyme that degrades the phytate level in food crops during processing. For instance, Jongbloed and Kemme [27] reported that endogenous phytase activity declined in wheat and barley with processing at 70–80 °C. In another study Reale, Konietzny, Coppola, Sorrentino, and Greiner [52], also opined that lactic acid fermentation preceded by heat treatment resulted in the inactivation of the endogenous cereal (rye, wheat and oat) phytases leading to a complete loss of phytate degradation. On the contrary, Ma and Shan [32] reported a high endogenous phytase activity with processing at 100 °C.

Traditional processes such as fermentation and malting under controlled conditions have been used to improve several products' nutritional and organoleptic properties [35,44]. There have also been reports of these processes being able to minimize antinutrients and improve the bioavailability of nutrients [35,45]. For instance, fermentation provides an optimum pH for endogenous phytase activity in cereals [16] that helps degrade phytic acid that chelates minerals making them more available [41]. Malting, on the other hand, is reported to increase the activity of endogenous phytase in cereals, legumes, and oilseeds through de Novo synthesis and/or activation of inherent phytase [18]. In previous studies, malting [58], and fermentation [47], were reported to increase α-amylase activity in cereals and consequently decreases viscosity of cooked flours and also increased starch digestibility.

The study aimed at exploring the potential of traditional processing methods (Fermentation, malting, roasting) under controlled conditions on phytic acid, nutritional and functional properties of commonly grown cereals (sorghum, maize, and millet) in northern Ghana.

Materials and methods

Experimental design

The study employed a 3 × 4 factorial design. This study evaluated the effect on three (3) selected cereal grains: Red sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), and white maize (*Zea mays*), and four (4) traditional processing methods: Fermentation, malting, roasting and unprocessed (as control) on the phytate, nutritional, functional and rheological quality of processed flours

Sample preparation

The cereal grains sourced from the open market in Nyankpala, Northern Region, Ghana, were manually cleaned to remove foreign material, broken and spoilt seeds, dirt and other contaminants. The cereal grains were then packaged for further processing.

Fermentation

A kilogram of each of the cereal grains was washed in separate plastic bowls and wet-milled with a commercial miller. A dough (1 part of water: 2 parts of flour) was formed from the milled samples for each of the selected cereal flours. The formed dough was allowed to spontaneously ferment for 48 h in ambient conditions (27–31 °C; 72–78% relative humidity). The dough was then dried in the open air at ambient conditions, then milled again and sieved using a 154 μm sieve to obtain fine flour. The flour from each cereal grain was then packed in low-density polyethene bags and stored for further analysis.

Malting

Sample of each cereal grain, one (1) kilogram, was separately soaked in water for 16 h; the water was changed after the first 8 h. The soaked cereals were then removed from the water and spread on jute (fiber woven) sacks and then covered with another moist jute sack and allowed to germinate (80%, form hypocotyl) for 96 h in ambient conditions (27–31 °C; 72–78% relative humidity). During the germination process, 500 ml of water was sprinkled daily on each cereal grain. After 96 h the samples were air-dried at ambient conditions and then milled into flour with a commercial miller and sieved using a 154 μm sieve to obtain fine flour and packaged in low-density polyethene bags and stored for further analysis.

Roasting

A kilogram of each cereal grains was traditionally roasted (110–120 °C) using an aluminum pot and milled into flour with a commercial miller and sieved using a 154 μm sieve to obtain fine flour and packaged in low-density polyethene bags and stored for further analysis.

Unprocessed

One (1) kilogram of sorghum, maize and millet were weighed and milled into flour using a commercial miller and sieved using a 154 µm sieve to obtain fine flour and packaged in low-density polyethene bags and stored for further analysis.

All the processed samples were stored in a fridge (4 °C) during the analysis.

Phytic acid determination

The phytic acid content of the samples was determined as reported elsewhere [26] with slight modification. Four (4) grams of flour samples were soaked in 100 ml of 2% HCl for 3 h and filtered through Whatman (25 mm) channel filter paper. Aliquots of 25 ml of the filtrate in a conical flask were added to 5.00 ml of 0.30% ammonium thiocyanate as an indicator. About 53.5 ml of refined water was added to provide the ideal acidity. The mixture was titrated with standard iron (III) chloride solution to obtain a brownish yellow color which persisted for 5 min. The percent phytate was calculated with the equation below:

$$\%\ \text{phytate} = \frac{8.24\text{t} \times 100}{\text{wt of sample}}$$

$$\text{t} = \text{titrevalue}$$

Proximate composition

The methods described in the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC) International [12] were used to determine the moisture (AOAC 925.10) with some slight modification by drying the samples at 105 °C overnight for approximately 12 h instead of 24 h, crude protein (AOAC 960.52), Ash (923.03) and crude fat (AOAC 922.06). Total carbohydrate was computed by difference.

Total energy

The total energy contents of the flour samples from each selected cereal and processed with the traditional method investigated was determined using the Atwater general factor of 4–4–9 as described elsewhere [37].

Functional and pasting properties

Tapped bulk density (TBD)

The tapped bulk density was determined according to the method described by Abe-Inge et al. [1]. A 20 g sample was put into a 50-ml measuring cylinder. The cylinder was gently tapped on the benchtop 10 times from a height of 5 m from the ground. The bulk density was calculated as the weight per unit volume of the sample and computed as following:

$$\text{TBD g/ml} = \frac{\text{Weight of Sample}}{\text{The volume of the sample after tapping}}$$

Water and oil holding capacities

Water- and oil absorption capacities of samples were carried out as reported elsewhere by Elkhalifa, Schiffler, and Bernhardt [20]. Two (2) grams of each cereal flour sample was weighed into a pre-weighed centrifuge tube, and 20 ml of distilled water were added. For oil binding, 20 ml sunflower oil was added. Samples were vortexed and allowed to stand for 30 min at room temperature before centrifuged at 4000 rpm for 25 min. Excess water or oil was decanted by inverting the tubes over absorbent paper and samples were allowed to drain. The weights of water and bound oil samples were determined by difference.

Pasting properties

The pasting properties of all flour samples were analyzed using a Rapid Visco Analyzer instrument (Perten; RVA-4500; Australia) equipped with a thermocline software as previously reported [10]. Briefly, flour samples of known moisture content were directly weighed (3.5 g) into the canisters of the RVA and then 28.12 g of distilled water was added to reach a total weight of 31.62 g. The canister paddle was inserted and the whole canister was mounted on the RVA. The weight of distilled water added depended on the moisture content of the flour. The amount of distilled water added was based on the moisture content of the flour. The total run time was about 13 min. The viscosity was recorded as temperature increased from 50 °C to 95 °C during the heating phase and decreased from 95 °C back to 50 °C during the cooling phase. The rotation speed for the first 10 s was 960 rpm and 160 rpm for the rest of the run time. All measurements were done in triplicate.

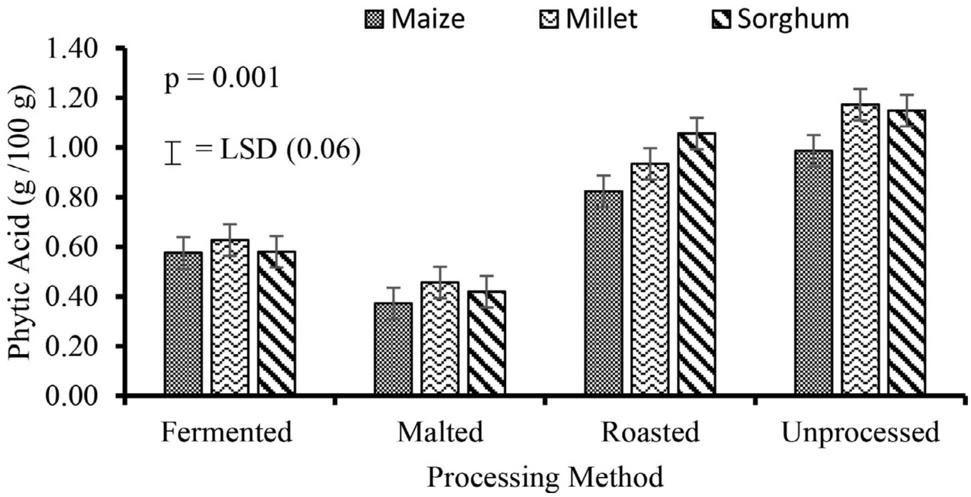

Fig. 1. Influence of processing method on phytate concentration of cereal grains Bar values are means; $n = 2$.

Statistical analysis

Data were subjected to analysis of variance using the general linear model for factorial experimental design in Genstat Release 18.2. (VSN International Ltd). The fisher's protected least significant difference was used to compare differences between means when the ANOVA result was significant ($p < 0.05$).

Results and discussion

Phytate

The phytic acid content in sorghum flour ranged from 0.42–1.15 g/100 g, while millet and maize ranged from 0.46–1.17 g/100 g and 0.37–0.99 g/100 g, respectively (Fig. 1). Traoré et al. [58] reported similar results on red sorghum. Maize flour recorded the lowest phytic acid content compared to sorghum and millet in roasting and unprocessed.

The phytic acid content of flours from malted and fermented treatments was similar among the grains investigated. Malting generally recorded the lowest phytate concentration in each of the cereal flours. Malting, fermentation, and roasting reduced the phytate concentration in all the different flour samples nearly three-folds, two-folds and one-fold, respectively. The current findings lend credence to previous studies by Egli et al. [18] who found that malting resulted in a decrease in the phytic acid content of most of the cereals investigated. Also, Kayodé, Hounhouigan, and Nout [29] also reported that almost 95% of the phytic acid content in sorghum was reduced with soaking, germination, boiling and fermentation. The reduction in the levels of phytate with malting could be attributed to the activities of endogenous phytase that is activated during germination as reported elsewhere [56]. During germination, phytins are degraded by endogenous phytase, releasing their P, myo-inositol and mineral contents for use by the growing sprout [49]. The noticeable reduction of phytic acid with fermentation in the cereal flours could be that the fermentation process provided optimum conditions for the activity of the endogenous phytase. The optimum pH for the endogenous phytase is reported to range from 4.5–5.5 [4,52,56]. Both malting and fermentation could be important processes in improving the bio-accessibility of micronutrients particularly iron and zinc in cereals with high phytic acid content.

Roasting seemed to have marginally reduced the phytic acid content in the cereal flours compared to fermentation and malting (Fig. 1). The findings seem unsurprising because heat processes such as roasting (70–80 °C) have been reported to inactivate endogenous phytase required to break down phytic acid in cereal grains [27]. Conversely, Ma and Shan [32] reported that phytase in cereals grains had strong heat stability as no phytase activity was lost at 70 °C heat processing for 1 h. The relatively high roasting temperature (110–120 °C) in this study could explain the differences between Ma and Shan [32] and our findings.

Proximate composition

The crude protein content of flours from the investigated cereals was significantly ($p < 0.001$) affected by the processing method. The data also showed that changes in crude protein due to the processing method varied considerably with the cereal type. For instance, malting resulted in a 36% and 54% increase in the protein content of sorghum and millet, respectively. The current findings agree with those of Mbithi-Mwikya, Van Camp, Yiru, and Huyghebaert [36] who reported a 29.5% increase in the protein content of malted millet. Loss of dry matter, particularly, carbohydrates through respiration during

Table 1
Cereal type and traditional processing method on the proximate composition of flours (Dry Matter Basis).

Cereal	Method	Chemical properties %Crude Protein	%Crude Ash	%Moisture	%Crude Fat	%Total CHO	Total Energy (kcal/100 g)
	Unprocessed	7.68 ± 0.537^{ab}	1.48 ± 0.014^{c}	3.06 ± 0.263^{bc}	2.26 ± 0.483^{a}	85.52 ± 0.539^{d}	393.20 ± 0.890^{bc}
Sorghum	Fermented	6.78 ± 1.342^{a}	1.69 ± 0.012^{ef}	3.88 ± 0.209^{cd}	2.18 ± 0.093^{a}	85.47 ± 1.133^{d}	388.60 ± 1.010^{c}
	Malted	10.45 ± 2.410^{bc}	1.34 ± 0.070^{b}	4.25 ± 0.225^{def}	2.60 ± 0.322^{a}	81.36 ± 2.35^{c}	390.60 ± 1.180^{ab}
	Roasted	8.21 ± 0.178^{ab}	1.59 ± 0.024^{de}	2.20 ± 0.211^{ab}	2.47 ± 0.283^{a}	85.54 ± 0.478^{d}	387.50 ± 2.840^{a}
	Unprocessed	8.13 ± 0.675^{ab}	1.29 ± 0.034^{b}	5.37 ± 0.459^{ef}	2.83 ± 0.103^{a}	82.39 ± 0.321^{c}	387.50 ± 2.360^{a}
Maize	Fermented	8.33 ± 0.953^{ab}	1.28 ± 0.020^{b}	4.58 ± 0.076^{def}	4.03 ± 0.016^{a}	81.77 ± 1.003^{c}	396.70 ± 0.290^{c}
	Malted	7.57 ± 0.570^{ab}	1.08 ± 0.016^{a}	6.03 ± 0.754 g	3.29 ± 0.159^{a}	82.03 ± 1.177^{c}	394.40 ± 3.790^{bc}
	Roasted	14.62 ± 0.549^{d}	1.09 ± 0.024^{a}	5.10 ± 0.763^{efg}	3.84 ± 0.147^{a}	75.36 ± 1.361^{a}	388.00 ± 2.410^{a}
	Unprocessed	7.93 ± 0.537^{ab}	1.51 ± 0.059^{cd}	4.69 ± 0.094^{def}	3.04 ± 0.189^{a}	82.82 ± 0.317^{c}	390.40 ± 0.532^{ab}
Millet	Fermented	8.60 ± 0.355^{ab}	1.73 ± 0.055^{f}	5.06 ± 0.191^{efg}	3.49 ± 0.636^{a}	81.12 ± 0.947^{bc}	390.30 ± 2.280^{ab}
	Malted	12.22 ± 1.327^{cd}	1.16 ± 0.019^{a}	4.00 ± 0.488^{cde}	3.35 ± 0.029^{a}	79.27 ± 1.044^{b}	396.10 ± 2.100^{c}
	Roasted	6.90 ± 0.800^{a}	1.63 ± 0.014^{ef}	1.28 ± 0.167^{a}	4.14 ± 0.957^{a}	86.05 ± 1.198^{d}	409.10 ± 5.280^{d}
p-value		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.068$	$p < 0.001$	$p < 0.001$

Values are means ± SD; $n = 3$. Means in the same column with different letters are significantly different ($p < 0.001$).

germination [36] has long been attributed to the apparent increase in proteins [46]. However, roasting resulted in a 13% decline in millet but a 6.9% and 80% increase in protein content of sorghum and maize, respectively. There have been varied reports on the effect of roasting on the protein content of food samples. For instance, roasting resulted in an increase in the protein content of pulses by 0.39–2.6% [13]. Conversely, Oboh, Ademiluyi, and Akindahunsi [43] also reported a decline in the protein content of roasted maize as in the case of this current study. The decline in protein content with heat processes could be attributed to protein denaturation and loss due to the participation of amino acids in non-enzymatic reactions [15].

Generally, the crude protein values were lower than the 16.70% minimum recommendations of FAO/WHO for complementary foods [60]. This implies that these flours have to be composited with protein-rich flours such as soybean if they are intended to be used for weaning food.

Crude ash that represents the total mineral content of samples was significantly ($p < 0.001$) influenced by the combined effect of processing method and cereal type (Table 1). Malting generally resulted in a decline in the crude ash content of all flours irrespective of the cereal type. Leaching out of solid matter during the pre-germination soaking process could be ascribed to the decline in the inorganic matter of the malted samples [30]. Fermentation and roasting resulted in a 14% and 7.4% increase in crude ash respectively in sorghum and about 15% and 8% increase in millet respectively. However, all processing methods resulted in a decline in crude ash content in maize flours (Table 1).

The moisture content of flour samples was generally low ranging from 1.28–6.03% as shown in Table 1. The moisture content varied significantly ($p < 0.001$) among the processing methods for each cereal type. The generally low (1.28–6.03%) moisture content of flours is important because; it reduces microbial activity and consequently results in stable shelf life.

The combined effect of cereal type and processing method had no marked ($p = 0.068$) effect on the crude fat content (Table 1). The current finding lends credence to those of Hingade, Chavan, Machewad, and Deshpande [23] who recently reported that malting had no significant effect on the fat content of wheat and barley. The crude fat content of the flour samples ranged from 2.18–4.03% higher than the 2.18–2.23% reported elsewhere [6] for processed millet.

The total carbohydrates content of processed sorghum, maize and millet presented in Table 1 shows that the interactive effect of cereal type and processing method significantly ($p < 0.001$) influenced the total carbohydrates content of the flours. The total carbohydrates of all the investigated cereals (sorghum, maize and millet) was slightly above 80% (Table 1), an indication that these cereals are rich in carbohydrates. For each cereal type, malting resulted in a decline in the total carbohydrates content except for millet flour. The decline in carbohydrates after malting could be due to the utilization of carbohydrates as an energy source during germination as earlier reported [39]. Furthermore, malting increase the enzymatic activity of α-amylase particularly in sorghum and millet [25].

From Table 1, the combined effect of cereal type and processing method had a significant ($p < 0.001$) influence on the total energy content of the flours. The total energy for sorghum ranged from 387.00–393.00 kcal/100 g; that of maize ranged from 387.00–396.00 kcal/100 g while millet ranged from 390.30–409.10 kcal/100 g. The influence of the traditional processing method on total energy content varied with the cereal type. While fermentation and malting resulted in a significant increase in the total energy content of maize flour, the reverse was the case for sorghum flour.

Functional properties

Tapped bulk density

The TBD, which is an indication of the highest attainable density with compression [30], was generally low for the flours from the cereals investigated. Averagely, sorghum had a significantly lower TBD of 0.648 g/ml, about 1.1 and 1.0 times lower than maize and millet, respectively. The low TBD values of the flours from the investigated cereal grains suggest that the volume of the flour in the package will not decrease excessively during storage or distribution.

Table 2
Cereal type and traditional processing method, and the functional properties of flour.

Cereal	Method	Functional Property		
		Tapped Bulk Density (g/ml)	Water Absorption Capacity (%)	Oil Absorption Capacity (%)
Sorghum	Unprocessed	0.704 ± 0.0001^{c}	198.524 ± 0.0004^{k}	208.871 ± 0.0001^{k}
	Fermented	0.685 ± 0.0002^{e}	247.934 ± 0.0001^{a}	254.528 ± 0.0001^{b}
	Malted	0.725 ± 0.0001^{b}	227.372 ± 0.0003^{f}	235.671 ± 0.0001^{f}
	Roasted	0.477 ± 0.0001^{f}	219.864 ± 0.0009^{h}	215.343 ± 0.0001^{i}
Maize	Unprocessed	0.735 ± 0.0001^{a}	218.364 ± 0.0003^{j}	250.727 ± 0.0001^{c}
	Fermented	0.705 ± 0.0003^{c}	161.776 ± 0.0001^{l}	240.134 ± 0.0004^{d}
	Malted	0.683 ± 0.0028e	233.936 ± 0.0008^{c}	235.671 ± 0.0003^{f}
	Roasted	0.724 ± 0.0006^{b}	220.035 ± 0.0057 g	214.758 ± 0.0001^{j}
Millet	Unprocessed	0.735 ± 0.0002^{a}	235.246 ± 0.0002^{b}	287.682 ± 0.0014^{a}
	Fermented	0.695 ± 0.0001^{d}	219.794 ± 0.0003^{i}	237.853 ± 0.0021^{e}
	Malted	0.694 ± 0.0001^{d}	227.372 ± 0.0014^{e}	232.421 ± 0.0001 g
	Roasted	0.704 ± 0.0002^{c}	231.698 ± 0.0001^{d}	218.772 ± 0.0003^{h}
p-value		< 0.001	< 0.001	< 0.001

Values are means ± SD; $n = 3$. Means in the same column with different letters are significantly different ($p < 0.001$).

All processing methods generally had a significant ($p < 0.001$) influence on the TBD of flours from the selected cereal grains except for malted sorghum flour that recorded an almost 3% increase (Table 2). On average, fermentation, malting and roasting respectively reduced the TBD of the flour samples by almost 4.1%, 6.4% and 12.6%, irrespective of the cereal type. The results corroborate previous studies by Adedeji et al. [3]; Alka, Neelam, and Shruti, [8] who reported that fermentation resulted in a reduction in tapped and loose bulk density. Similarly, Sreerama, Sashikala and Pratape [55] also reported that chemical and enzymatic pre-treated grains had lower TBD compared to the untreated. Fermentation for 24 h has also been reported to cause a decline in bulk density by 10% [20]. A lower bulk density is important for flours intended for complementary foods because samples could be prepared with a small amount of water yet provide the desired energy and nutrient density and semi-solid consistency that can be fed to infants as reported elsewhere [33,38].

Water absorption capacity (WAC)

WAC is an important processing parameter that has implications for viscosity [40]. It depicts the optimal amount of water that can be added to the flour before it becomes too sticky to process or utilize [19]. WAC indicates the amount of water available for gelatinization and lower WAC is desirable for making thinner gruels. The WAC of maize was significantly lower (208.53%; $p < 0.001$) than sorghum and millet. The lower WAC of maize could be due to its relatively low total carbohydrates (Starch) content as low WAC value indicates the compactness of the structure of starch polymers [2].

The WAC was generally affected ($p < 0.001$) by the traditional processing methods (Table 2). However, the effect of the traditional processing method largely depended on the type of cereal grain. For instance, processing methods increased the WAC of the sorghum flours. Similarly, all the maize flours recorded an increase in WAC except for fermented maize flour that recorded a 26% decline in WAC (Table 2). The increase in WAC could be ascribed to an increase in polar amino acid residues of proteins due to hydrolysis during the processing as reported elsewhere [42]. Conversely, all millet flour samples recorded a marginal decline in WAC with each of the traditional processing methods. The finding is similar to Elkhalifa et al. [20] who reported a significant (at least 7%) decline in WAC of sorghum flour with fermentation. [20]

Oil absorption capacity (OAC)

OAC represents the ability of the protein matrix in food to physically bind fat by capillary gravitation [57]. The data on OAC show that millet flour was significantly (244.18%; $p < 0.001$) higher; almost 1.04 and 1.06 times higher than maize and sorghum, respectively. The differences in OAC could be attributed to the differences in the amylose/amylopectin ratio and their chain length distribution [31]. OAC is reported not to only influence the oil retention in samples, but can also regulate some important sensory attributes such as flavor and mouthfeel [22].

Traditional processing methods markedly ($p < 0.001$) influenced the OAC of the flour samples. Fermentation, malting and roasting increased the OAC of sorghum flour. This finding lends support to Elkhalifa et al. [20] who reported a 7% increase in OAC of fermented sorghum flour. However, for the maize and millet flours, the traditional processing methods resulted in a decline in OAC. The finding does not support previous work that showed a marked increase in OAC of sorghum, pearl millet and maize flours after 36 h of fermentation [8]. The differences in fermentation time between the current study (48 h) and the previous study (36 h) may account for the differences observed.

Pasting properties

Peak viscosity

Among the cereal type investigated, millet recorded a significantly ($p < 0.001$; 673.75 cP) high peak viscosity relative to maize and sorghum. The differences in peak viscosity among flours could partly be due to differences in starch concentration as well as α-amylase activity in the cereals. Our data also show that peak viscosity was significantly ($p < 0.001$)

Table 3
Influence of cereal type and traditional processing method on the pasting properties of flour.

Cereal	Method	Pasting Property					
		Peak Viscosity (cP)	Trough (cP)	Breakdown Viscosity (cP)	Final Viscosity (cP)	Setback Viscosity (cP)	Peak Time (min)
Sorghum	Unprocessed	861.67 ± 7.37^{b}	843.33 ± 16.26^{a}	18.33 ± 9.02^{fg}	2845.00 ± 68.50^{a}	2001.67 ± 52.50^{a}	6.16 ± 0.34^{b}
	Fermented	865.33 ± 23.10^{b}	849.00 ± 23.40^{a}	16.33 ± 1.53 g^{h}	1749.67 ± 60.50^{b}	900.33 ± 37.30^{c}	6.87 ± 0.17^{a}
	Malted	103.67 ± 0.57^{h}	36.33 ± 2.08^{hi}	67.33 ± 2.52^{d}	84.67 ± 1.53^{hi}	48.33 ± 0.58 g	4.44 ± 0.08^{e}
	Roasted	228.33 ± 6.03 g	217.33 ± 6.35^{f}	11.00 ± 2.65 g^{h}	503.33 ± 7.64^{f}	286.00 ± 2.65^{e}	6.96 ± 0.08^{a}
Maize	Unprocessed	619.67 ± 29.00^{d}	596.67 ± 24.50^{d}	23.00 ± 5.20^{ef}	1602.00 ± 76.60^{c}	1005.33 ± 52.30^{b}	6.71 ± 0.21^{a}
	Fermented	792.33 ± 23.90^{c}	772.00 ± 25.90^{b}	20.33 ± 2.08f^{g}	1725.33 ± 41.00^{b}	953.33 ± 15.31^{bc}	7.00 ± 0.00^{a}
	Malted	46.67 ± 2.08^{i}	13.67 ± 1.53^{i}	33.00 ± 1.00^{e}	29.00 ± 2.65^{i}	15.33 ± 1.53 g	3.62 ± 0.04^{f}
	Roasted	88.00 ± 6.56^{h}	76.00 ± 5.00^{h}	12.00 ± 1.73^{h}	159.00 ± 10.540 g^{h}	83.00 ± 5.57 g	7.00 ± 0.00^{a}
Millet	Unprocessed	1034.00 ± 13.70^{a}	771.67 ± 12.86^{b}	262.00 ± 2.52^{a}	1774.67 ± 34.60^{b}	1003.00 ± 22.60^{b}	5.58 ± 0.04^{c}
	Fermented	898.67 ± 3.20^{b}	713.00 ± 5.29^{c}	185.67 ± 4.51^{c}	1256.33 ± 13.70^{d}	543.33 ± 17.60^{d}	5.45 ± 0.04^{c}
	Malted	317.00 ± 5.57^{f}	85.00 ± 3.61 g	232.00 ± 2.65^{b}	262.67 ± 8.74 g	177.67 ± 5.13^{f}	4.87 ± 0.00^{d}
	Roasted	445.33 ± 4.16^{e}	438.00 ± 4.58^{e}	7.33 ± 0.58^{h}	915.00 ± 12.12^{e}	477.00 ± 7.55^{d}	6.82 ± 0.17^{a}
p-value		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$

Values are means ± SD; $n = 3$. Means in the same column with different letters are significantly different ($p < 0.001$).

affected by the traditional processing methods (Table 3). Particularly, malting and roasting showed some remarkable reduction in the peak viscosity of the flour samples. Expectedly, malting resulted in almost 88%, 93% and 69% decline in peak viscosity for sorghum, maize and millet flours, respectively. The findings support Claver, Zhang, Li, Zhu, and Zhou [14] who reported lowered peak viscosity in malted sorghum flour. The reduction in peak viscosity with malting could be ascribed to the degradation of starch by the action of α-and β-amylase that are developed during the process. Ranganathan, Nunjundiah, and Bhattacharya, [51] reported a decreased peak viscosity with roasting and heat-moisture treatments. The decline in peak viscosity found in this study by roasting was about 74% in sorghum, 86% in maize and 57% in millet. The findings further lend support to Sharma, Gujral, and Rosell [54] who reported a 53–78% decline in peak viscosity of barley flour with roasting. The plausible reason for the low viscosity with roasting could be attributed to the partly gelatinized, damaged and loosely packed starch granules that hydrate easily preceding roasting as reported elsewhere [34]. It is noteworthy that the present finding contradicts those of Agume, Njintang, and Mbofung [5] who found a significant increase in peak viscosity of maize flour with roasting. Fermented flours recorded the highest peak viscosity in the cereals investigated except for millet. The increase in peak viscosity of maize with fermentation has been previously reported [7,11,21]; and alignment of amylose chains in the starch could explain this observation. Peak viscosity is important because it gives an indication of the water-holding capacity of the starch or mixture. It is often correlated with final product quality, and also provides an indication of the viscous load likely to be encountered by a mixing cooker

Trough viscosity

The trough is the lowest viscosity value at constant temperature and measures the ability of paste to resist breakdown during cooling. It is an important parameter to be considered during processing. The data on trough viscosity show that cereal type had a marked ($p < 0.001$) effect on the trough viscosity of flour samples with millet recording the highest (501.92 cP) and maize recording the least (364.58 cP) an indication of the resistance of swollen granules towards shear.

All the traditional processing methods resulted in a significant ($p < 0.001$) decrease in trough viscosity except for fermented maize and sorghum flour that recorded an almost 21% and 0.67% increase in trough viscosity, respectively (Table 3). Malting resulted in about 96%, 98% and 89% reduction in sorghum, maize and millet flours respectively. Our findings contradict Akinsola and co-workers (2018) who reported a significant increase in trough viscosity in malted maize-millet composite flour. Roasting, on the other hand, led to about a 74% decline in trough viscosity for the sorghum flour, 87% in maize flour and 43% in millet flour. Sharma and co-workers [54] earlier reported a decline in viscosity of barley flour with roasting. Trough viscosity is affected by amylose exudation rate, granule swelling, the formation of the amylose-lipid complex as well as competition between leached amylose and remaining granules for unbound water molecules [30].

Breakdown viscosity

Breakdown viscosity measures the degree of viscosity reduction during the heating process and it is an important indicator for pasting stability of flours during processing. Sorghum, maize and millet varied widely in terms of their breakdown viscosity with millet recording the highest (171.83 cP). This indicates that millet flour could be less stable during heat processing compared to sorghum and maize as higher breakdown viscosity is associated with poor heat stability [2,17]. Fermentation and roasting resulted in a significant ($p < 0.001$) decline in breakdown viscosity (Table 3). For example, roasting treatment resulted in an almost 40% decline in sorghum, 48% in maize and 97% in millet flours. This finding agrees with an earlier study by Wani et al. [59] who reported a drastic decline in breakdown viscosity by 48.1% and 51.9% with microwave and pan-roasting respectively. Apart from millet flour, malting resulted in increased breakdown viscosity. Higher breakdown viscosity with malting in maize- composited flour have previously been reported [7]. The lower breakdown viscosity values for the flours with fermentation or roasting is an indication that the pastes are more stable under hot conditions resulting from lower concentrations of starch in a sample. This ability of a sample to withstand high temperature and shear stress has been considered an important feature for many processes [50]

Final viscosity

The final viscosity differed significantly among the three kinds of cereal investigated with maize having the least final viscosity (878.83 cP). Differences in starch concentration as well as α-amylase activity [58] in the cereals could account for the differences in final viscosities. Final viscosity is the commonly used quality index for flour samples intended for use as complementary food as it provides vital information on the ability of the material to form a viscous paste or gel after cooking and cooling. Except for fermented maize flour, all the traditional processing methods resulted in a reduced final viscosity in all the selected cereals. Malting recorded the highest reduction of about 97% in sorghum, 98% in maize and 85% in millet. Our findings lend support to Claver and co-workers [14] who reported lower viscosity in malted sorghum flour. The decline in final viscosity could be attributed to the enzymatic activity of α- and β-amylases during malting. The α-amylase digest complex carbohydrates into dextrins and maltose resulting in reduced viscosity of thick cereal porridges without nutrient energy thinning. The reduced final viscosity of the flour associated with the traditional processing technologies implies that the flour, when composited to prepare complementary food, will form a low viscous paste rather than a thick gel on cooking and cooling [48].

Setback viscosity

The re-association between starch granules during cooling referred to as the setback viscosity, involves retrogradation, or re-ordering of the starch molecules [59]. This property has been reported to have a relation with the texture of various products. Sorghum had a significantly (809.08 cP; $p < 0.001$) higher setback relative to maize and millet. Higher setback viscosity is associated with a higher tendency of amylose to retrograde during cooling [61] leading to syneresis or weeping [9]. Setback viscosity of all flours from the various cereals was significantly ($p < 0.001$) reduced with the traditional processing methods (Table 3). The decline in setback viscosity in malted sorghum, maize and millet was 98%, 99% and 82%, respectively. Fermentation had the least influence as it resulted in only a 55% decline in sorghum, 5.2% in maize and 46% in millet. Akisola and co-workers [7] also reported lower setback viscosity in maize-millet composite flour with malting and fermentation. The low setback value of the flours irrespective of the cereal type indicates that flours processed using the traditional methods investigated could be composited to prepare gruels that will not be a cohesive.

Limitation

The method for phytic acid determination quantified all forms of inositol phosphates. This is a limitation because lower inositol phosphates do not form strong complexes with minerals and trace elements and thus have a less negative influence on iron and zinc bioavailability. Therefore, further study is required with a method that excludes lower inositol phosphates.

Conclusions

Malting and fermentation were effective in reducing phytic acid in sorghum, maize and millet. Traditional processing technologies varied considerably with the cereal type concerning the crude protein content. The processing technologies either had a similar energy content or increased the energy content of the maize and millet flours. The tapped bulk density of flour from the selected cereals was lower, a critical index to consider for flours intended for complementary foods as less water will be required during porridge preparation. . Except for fermented maize flour, all the traditional processing methods reduced final viscosity in all the selected cereals. Malting and fermentation reduced phytic acid level, improved nutritional and functional properties in the cereals investigated and should be encouraged at the household level.

Declaration of competing interest

The authors declare no conflict of interest.

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