Changes in nutritional and physico-chemical properties of pearl millet (*Pennisetum glaucum*) Ex-Borno variety flour as a result of malting

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Abstract The effect of malting periods on the nutritional composition and physico-chemical properties of flour from pearl millet (Ex-Borno) variety was evaluated. Grains were steeped at 25 °C for 24 h and germinated for different durations (12, 24, 36, 48, 60, 72, 84 and 96 h) before kilning at 55 °C for 18 h. The kilned seeds were devegetated, milled, sieved and analysed for their proximate composition, amino acid composition, total phenolic content, functional and pasting properties. The carbohydrate, fat and total phenolic contents of the pearl millet flour samples decreased while protein content increased with increased malting periods. Leucine was the dominant amino acid in the flour and 48 h-malted flour had the highest total amino acid (6.72). Peak viscosity significantly decreased as the malting period increased. Solubility index, pasting temperature and phenolic content of the flours ranged from 5.13 to 17.24%, 69.05 to 89.5 °C and 130.20 to 169.90 mg/

100 g, respectively. Malting offers a means of improving the nutritional profile of Ex-Borno pearl millet flour with an increased protein and fibre and reduced fat content. Malting also enhanced the functional and pasting properties of the flour.

Keywords Pearl millet · Malting · Amino acid · Phenolics · Pasting properties

Introduction

Millet is one of the oldest known foods consumed by humans and used for domestic purposes. Millet is an underutilized, but versatile crop whose inclusion in diets can improve nutritional qualities. Its protein content is about 11% (dry weight basis) and it has high B-vitamins, phosphorus, iron and fibre contents. Millet is a significant cereal crop in Africa and semi-arid tropics of Asia especially in Niger, Nigeria and India, and 97% of world millet productions are from developing countries (Mc Donough et al. 2000). There are about nine different species of millet across sub Saharan Africa, and the widely cultivated ones include foxtail millet (*Setaria italic*), proso millet (*Panicum miliaceum*), pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*). A significant number of nutritious food products can be derived from *Pennisetum glaucum* and there is progressive interest in pearl millet cultivation due to technological prospects of its utilization for industrial applications, since it is readily available. Also, pearl millet has been recognized to be adaptable to variabilities in climatic conditions (Chivenge et al. 2015). In Nigeria, the Ex-Borno variety of *Pennisetum glaucum* is among the highly recognized, recommended, improved and locally available breeds (Ojediran et al. 2010).

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The physico-chemical composition of food grains is influenced by various processing technologies. Such technologies can be of advantage if they offer the potential of improving the nutritional value of food products made from the grains (Saleh et al. 2013). One of such is malting, which is a controlled germination process characterized by the production of enzymes capable of triggering the hydrolysis of starch and other food components of a grain (Kent 1994). As indicated in the studies of Coulibaly et al. (2012), malting facilitates the activities of hydrolytic enzymes, enhances the breakdown of starch and proteins into their simpler forms, thereby reducing dry matter and enhancing food metabolism. Ogbonna et al. (2012) evaluated the effect of different malting conditions on the antinutritional and nutritional properties of sorghum grist. In their study, malting enhanced the nutritional status of sorghum grist with consequent decrease in some of its antinutritional factors (oxalate, trypsin inhibitor, tannin and phytate). Maidala et al. (2016) also observed an improvement in the nutrients of sorghum as malting period increased from 24 to 92 h.

Malting of pearl millet can be explored as a means of improving its utilization. However, only few studies have addressed the effect of malting on pearl millet properties. Pelembe et al. (2002) studied the effect of different malting conditions on some quality parameters (α - and β -amylase activity, diastatic power, malting loss and free α -amino nitrogen) of two pearl millet varieties. Also, Laxmi et al. (2015) investigated the influence of malting on the nutrients of foxtail millet. To the best of our knowledge, this is the first study on the effect of different malting periods on the physico-chemical and nutritional properties of pearl millet (Ex-Borno variety).

Materials and methods

Materials

Pearl millet (Ex-Borno) variety grains were obtained from Abeokuta, Nigeria and conveyed to the laboratory. They were inspected visually for extraneous objects, sorted, placed in air-tight containers and kept in a cool and dry place.

Sample preparation

In this study, three main malting operations were involved: steeping, germination and kilning. Pearl millet grains of 1 kg with an initial moisture content of 12% were steeped in sterile distilled water for 24 h to achieve a moisture content of about 46% to facilitate sprouting. The steeping water was replaced every 4 h to avoid the buildup of

organic compounds, phosphates and microorganisms. Excess water was drained off from the grains and they were kept at ambient temperature ($25 \pm 2^\circ\text{C}$) in the dark, on a sterilized multilayer muslin cloth. The grains were watered and turned thrice daily to provide uniform germination and aeration and prevent roots from joining together. Samples were taken for 4 days at 12 h interval (12, 24, 36, 48, 60, 72, 84, and 96 h). This was based on preliminary studies which showed that the sprouts were twice the length of the seedlings at day 4. Samples taken from the lot for each germination period were kilned in a hot air oven (PSO-415, Mercury, India) at 55°C for 18 h to reduce the moisture level of grains, arrest growth and internal alterations and initiate colour and flavour development of the malt. Thereafter, they were milled into flour using a hammer mill (Henan Allways, China) and passed through a $500\ \mu\text{m}$ sieve to get malted pearl millet flour. Unmalted pearl millet grains milled into flour were used as control and the samples were subjected to analyses.

Methods

Determination of nutritional composition

Proximate composition

The proximate composition (fat, moisture, protein, ash and crude fibre) of the malted and control flour samples were determined using the AOAC (2010) method (931.04, 945.38, 2000.11, 985.29 and 923.03, respectively). Carbohydrate content was determined by difference, while the energy value was calculated using the Atwater factor.

$$\text{Energy Value (Kcal)} = (\text{Protein} \times 4) + (\text{Fat} \times 9) + (\text{Carbohydrate} \times 4)$$

Amino acid profile

To determine the amino acid profile of the samples, 1 g of each sample was added to 20 ml of 6 N hydrochloric acid, the mixture was transferred into a hydrolysis tube, screwed with a cap and hydrolyzed for 22 h under atmospheric nitrogen. After hydrolysis, the hydrochloric acid was removed using a rotatory evaporator (R-1001-VN, Great Wall, China) and the residue was washed thrice with deionized water. Resultant sample was then dissipated in 1 ml acetate buffer, diluted to a known volume, placed in vials and injected into a high performance amino acid analyser (S7130, Biokal, Germany). The amino acid composition of the samples was expressed as percentage of the total protein. The percentage total essential amino acids

(% TEAA), total acidic amino acids (TAAA), total aromatic amino acids (TAEAA) and total sulphur amino acids (TSAA) were enumerated and the predicted protein efficiency ratio (PER) was calculated as:

$$\text{PER} = -0.468 + 0.454[\text{Leu}] - 0.105[\text{Tyr}]$$

Determination of physico-chemical properties

Oil absorption capacity (OAC)

The OAC of the malted and unmalted pearl millet flours were determined using the method of Nwosu (2010). About 2 g of sample was added to 20 ml of canola oil and homogenized at a high speed for 30 s with a blender (BLX50, Kenwood, Denmark). The homogenate was left to stand for 30 min, centrifuged for 30 min at 1000 rpm and the supernatant was removed. The OAC was expressed in ml/g and calculated as:

$$\text{OAC} = \text{Initial mass of sample} - \text{final mass of sample after the removal of supernatant}$$

Water Solubility Index (WSI) and swelling power (SP)

The WSI and SP were assessed following the procedure of Lan et al. (2008). Starch suspension (2% w/v) was placed in a water bath (WN B10, Memmert, Germany) for 30 min at 70 °C. The suspension was centrifuged for 15 min, the resultant precipitate was measured and the supernatant was dried in the oven at 105 °C until a consistent weight was achieved. The SC and WSI were calculated with the equations below:

$$\text{SC} = \text{sediment weight} \times \frac{100}{\text{starch weight(drybasis)}}$$

$$\text{WSI} = \frac{\text{total weight of supernatant after drying}}{\text{starch}} \times 100$$

Pasting properties

Pasting properties of unmalted and malted pearl millet flour were ascertained using a Rapid Visco Analyzer (3D+; Network Scientific, Australia). The breakdown, peak viscosity, final viscosity, trough, setback, pasting temperatures, and peak time values were read from the pasting profile with the aid of thermocline for Windows software coupled to a computer.

Phenolic content

The method of Wolfe et al. (2003) was used to evaluate the phenolic content of the malted and unmalted flours. About 5 ml of Folin–Ciocalteu reagent (10%) and 4 ml sodium carbonate was added to an aliquot of the samples in tubes. After which the tubes were vortexed for 15 s, and allowed to stand at 40 °C for 30 min. The absorbance of the solution was determined at a wavelength of 765 nm using an ultraviolet spectrophotometer (HP, Germany). The phenolic content was taken as the Gallic acid (GA) equivalents from a GA standard curve and expressed in mg/100 g.

Statistical analysis

All analysis was performed in triplicate and data were subjected to analysis of variance using SPSS Version 23 for windows (IBM Corporation, New York, USA). Variability within the means were separated by Duncan's multiple range test and significances were accepted at 5% confidence level ($p < 0.05$).

Results and discussions

Nutritional composition

Table 1 presents the proximate composition of malted and unmalted pearl millet flour (% dry weight basis). It was observed that the protein content of the malted pearl millet flour samples ranged from 7.67 to 9.19% and differed significantly when compared with the unmalted flour ($p < 0.05$). This can be linked to the accumulation of protein reserves during sprouting due to proteolytic enzyme activities (Senhofa et al. 2016). The enzyme reduces macromolecular compounds into more absorbable amino acids and proteins (Taraseviciene et al. 2009). This process in turn plays a significant role in the synthesis of cellular materials for the growth of shoots and roots during sprouting. There was a slight decrease in the ash contents of the pearl millet flour samples due to the increased malting period (1.31–1.68%). This could be because of the assimilation of mineral elements into the cell constituents and utilization of the available minerals during the process of germination. The crude fibre of the samples increased with increased malting periods. Some researchers have reported increase in crude fibre during malting, (Laxmi et al. 2015 (foxtail millet); Arif et al. 2011 (finger millet and mung bean). Arif et al. (2011) reported that build-up of crude fibre during finger millet malting might be due to the synthesis of structural components such as hemicellulose and cellulose. However, Devi et al. (2015) established that these components are usually built-up during the

Table 1 Effect of malting periods on the proximate composition of pearl millet flour (% dry weight basis)

Samples	Fibre	Ash	Protein	Fat	Moisture	Carbohydrate	Energy value
Control	0.77 + 0.02 ^a	1.68 + 0.06 ^d	7.52 + 0.07 ^a	6.34 ± 0.01 ^b	9.55 ± 0.04 ^a	74.14 ± 1.34 ^a	383.70 ± 2.14 ^b
A = 12 h malted pearl millet flour	0.82 + 0.04 ^b	1.68 + 0.03 ^d	7.67 + 0.04 ^a	5.98 ± 0.93 ^c	9.95 ± 0.02 ^b	73.90 ± 3.23 ^a	380.10 ± 3.19 ^a
B = 24 h malted pearl millet flour	0.87 + 0.10 ^b	1.62 + 0.04 ^d	7.87 + 0.06 ^{bc}	5.55 ± 0.42 ^b	10.79 ± 0.04 ^b	73.30 ± 2.34 ^a	374.63 ± 1.98 ^a
C = 36 h malted pearl millet flour	0.93 + 0.02 ^{bc}	1.53 + 0.02 ^c	8.71 + 0.04 ^b	5.55 ± 0.32 ^b	10.87 ± 0.04 ^b	72.41 ± 3.54 ^a	374.43 ± 2.24 ^a
D = 48 h malted pearl millet flour	0.95 + 0.03 ^c	1.48 + 0.08 ^b	8.83 + 0.13 ^{bc}	5.32 ± 0.96 ^b	10.95 ± 0.04 ^b	72.47 ± 1.32 ^a	373.08 ± 2.22 ^a
E = 60 h malted pearl millet flour	0.97 + 0.04 ^c	1.40 + 0.02 ^{ab}	8.88 + 0.06 ^{bc}	5.11 ± 0.43 ^b	11.03 ± 0.01 ^b	72.61 ± 1.34 ^a	371.95 ± 1.51 ^a
F = 72 h malted pearl millet flour	0.98 + 0.09 ^c	1.39 + 0.02 ^{ab}	8.92 + 0.18 ^{cd}	5.23 ± 0.04 ^b	11.36 ± 0.02 ^b	72.12 ± 2.56 ^a	371.23 ± 3.16 ^a
G = 84 malted pearl millet flour	1.21 + 0.08 ^d	1.34 + 0.04 ^a	9.08 + 0.10 ^d	5.02 ± 0.67 ^a	11.37 ± 0.03 ^b	71.98 ± 2.87 ^a	369.42 ± 1.99 ^a
H = 96 h malted pearl millet flour	1.38 + 0.06 ^e	1.31 + 0.02 ^a	9.19 + 0.11 ^d	5.00 ± 0.02 ^{aa}	11.20 ± 0.03 ^b	71.92 ± 2.98 ^a	369.44 ± 3.03 ^a

^aValues with different superscript(s) in the column are significantly different ($p < 0.05$)

^bResults are expressed as Mean and Standard deviation

germination stage of malting. Nevertheless, the fate of crude fibre during the different stages of malting needs to be further investigated.

Furthermore, a decrease was observed in the carbohydrate content of the malted flour from the Ex-Borno pearl millet variety. Due to hydrolysis by enzymes, starch granules become more soluble in water (Kent 1994) and this might have facilitated the observed decrease in the carbohydrate content. α -amylase is the principal enzyme responsible for the initial breakdown of starch granules while β -amylase also takes part in the conversion of starch into free simple sugars (Senhofa et al. 2016). Elkhier and Hamid (2008) proposed the uptake of simple sugars created through the action of amylolytic enzymes as an energy source for the growing embryo during malting. Ogbonna et al. (2012) also observed a significant decrease in the carbohydrate content of malted sorghum. The significant increase observed in the moisture content depicts water uptake by the viable pearl millet Ex-Borno variety grains during steeping. Furthermore, the fat levels of pearl millet flour samples decreased upon malting and the 96 h malted pearl millet flour sample had the lowest fat content. It is consequential that the reduction in fat also contributed to the significant ($p < 0.05$) lower energy values observed in the flour. The observed decrease in fat might be because of increased activities of enzymes and fat utilization during the germination. Decreased fat levels in the malted flours will ensure increased shelf life by reducing the chances of rancidity. Similar trends as increased protein, reduced

carbohydrate and fat was observed in a study by Pelembe et al. (2002) on the effect of malting on some properties of pearl millet from Mozambique (SDMV 89004) and Zimbabwe (SDMV 91018).

The effects of malting periods on the amino acid profile of malted and unmalted pearl millet flour in g/100 g protein are presented in Table 2. Amino acids are categorized as essential and non-essential. In this study, malting significantly ($p < 0.05$) affected the individual amino acids of pearl millet flour. Leucine was the dominant essential amino acid in the pearl millet flour samples (0.75/100 g) and this conforms to the findings of Basahy (1996) who stated leucine to be the principal amino acid in pearl millet. The lysine content of the samples ranged from 0.26 to 0.34 g/100 g protein, 96 h malted pearl millet flour had the highest lysine content. As the malting period increased, the lysine and aspartic acid increased. Storage protein in the pearl millet grain might have undergone proteolysis and contributed to the increase of these amino acids (Kuo et al. 2004). The increase in protein content initially observed might have led to an increase in the production of peptides, amino acids and other derivatives. Methionine and cysteine, which are sulphur containing amino acids usually limiting in cereals and legumes were found to be present in minute quantities in all the samples. There was a decrease in isoleucine, glycine, tyrosine, methionine, glutamic acid and cysteine contents when compared with the unprocessed pearl millet flour sample. This might be due to leaching of the nutrients into the steeping water or the migration of

Table 2 Effect of malting periods on the amino acid profile of malted and unmalted pearl millet flour (g/100 g protein) (dry weight basis)

	HIS	THR	LYS	ILE	LEU	PHE	MET	ASP	SER
C*	0.20 + 0.00 ^a	0.34 + 0.00 ^a	0.26 + 0.02 ^a	0.32 + 0.00 ^{ab}	0.75 + 0.00 ^a	0.41 + 0.02 ^a	0.01 + 0.00 ^{ab}	0.57 + 0.04 ^a	0.41 + 0.00 ^a
B	0.21 + 0.00 ^a	0.34 + 0.00 ^a	0.28 + 0.00 ^{ab}	0.31 + 0.00 ^{ab}	0.73 + 0.49 ^a	0.42 + 0.02 ^a	0.02 + 0.02 ^{abc}	0.60 + 0.77 ^b	0.41 + 0.08 ^a
C	0.20 + 0.01 ^a	0.35 + 0.02 ^a	0.28 + 0.03 ^{ab}	0.31 + 0.00 ^{ab}	0.71 + 0.02 ^a	0.40 + 0.02 ^a	0.03 + 0.00 ^{bc}	0.63 + 0.00 ^{bc}	0.40 + 0.00 ^a
D	0.19 + 0.00 ^a	0.35 + 0.00 ^a	0.30 + 0.00 ^{abc}	0.31 + 0.00 ^{ab}	0.71 + 0.49 ^a	0.39 + 0.02 ^a	0.04 + 0.00 ^{cd}	0.65 + 0.00 ^{bc}	0.39 + 0.00 ^a
E	0.19 + 0.00 ^a	0.36 + 0.00 ^a	0.31 + 0.01 ^{bc}	0.30 + 0.00 ^{ab}	0.69 + 0.02 ^a	0.39 + 0.00 ^a	0.04 + 0.00 ^{cd}	0.66 + 0.02 ^{bc}	0.39 + 0.00 ^a
F	0.190 + 0.00 ^a	0.36 + 0.00 ^a	0.31 + 0.00 ^{bc}	0.29 + 0.00 ^b	0.68 + 0.00 ^a	0.39 + 0.01 ^a	0.01 + 0.00 ^{ab}	0.68 + 0.00 ^c	0.39 + 0.00 ^a
G	0.18 + 0.00 ^a	0.37 + 0.01 ^a	0.32 + 0.014 ^{bc}	0.29 + 0.01 ^{ab}	0.67 + 0.02 ^a	0.38 + 0.02 ^a	0.01 + 0.00 ^a	0.69 + 0.06 ^c	0.39 + 0.01 ^a
H	0.18 + 0.01 ^a	0.38 + 0.05 ^a	0.34 + 0.00 ^c	0.28 + 0.00 ^a	0.63 + 0.00 ^a	0.35 + 0.02 ^a	0.01 + 0.00 ^a	0.70 + 0.02 ^d	0.35 + 0.00 ^a

	GLU	GLY	CYS	ARG	TYR	ALA	PRO	TRI
C*	1.28 + 0.07 ^{ab}	0.26 + 0.00 ^{ab}	0.04 + 0.00 ^{ab}	0.34 + 0.007 ^a	0.26 + 0.00 ^b	0.53 + 0.02 ^a	0.49 + 0.00 ^b	0.17 + 0.00 ^{ab}
B	1.29 + 0.14 ^{ab}	0.25 + 0.07 ^{ab}	0.03 + 0.00 ^{ab}	0.33 + 0.00 ^a	0.25 + 0.00 ^{ab}	0.55 + 0.04 ^{ab}	0.59 + 0.00 ^c	0.16 + 0.00 ^{ab}
C	1.27 + 0.11 ^{ab}	0.24 + 0.02 ^{ab}	0.03 + 0.00 ^{ab}	0.32 + 0.01 ^a	0.24 + 0.00 ^{ab}	0.55 + 0.04 ^a	0.57 + 0.00 ^{bc}	0.17 + 0.00 ^{ab}
D	1.24 + 0.04 ^{ab}	0.24 + 0.00 ^{ab}	0.03 + 0.024 ^{ab}	0.31 + 0.00 ^a	0.24 + 0.00 ^{ab}	0.54 + 0.01 ^{ab}	0.56 + 0.01 ^{bc}	0.17 + 0.00 ^{ab}
E	1.21 + 0.01 ^{ab}	0.23 + 0.01 ^{ab}	0.03 + 0.00 ^{ab}	0.31 + 0.00 ^a	0.23 + 0.02 ^b	0.54 + 0.00 ^{ab}	0.54 + 0.03 ^{bc}	0.19 + 0.42 ^{abc}
F	1.19 + 0.02 ^{ab}	0.23 + 0.00 ^{ab}	0.01 + 0.02 ^a	0.29 + 0.00 ^a	0.23 + 0.00 ^{ab}	0.53 + 0.00 ^a	0.53 + 0.06 ^{bc}	0.19 + 0.00 ^{abc}
G	1.15 + 0.01 ^{ab}	0.22 + 0.00 ^{ab}	0.01 + 0.024 ^{ab}	0.28 + 0.11 ^a	0.22 + 0.00 ^a	0.52 + 0.00 ^a	0.49 + 0.07 ^b	0.21 + 0.02 ^{bc}
H	1.08 + 0.04 ^a	0.22 + 0.02 ^a	0.01 + 0.00 ^b	0.27 + 0.00 ^a	0.22 + 0.00 ^a	0.51 + 0.00 ^a	0.40 + 0.02 ^a	0.23 + 0.03 ^c

^aValues with different superscript(s) in the column are significantly different ($p < 0.05$)^bResults are expressed as means and standard deviation^cHIS Histidine, THR threonine, LYS lysine, ILE isoleucine, LEU leucine, PHE phenylalanine, MET methionine, TRI tryptophan, ASP aspartic acid, SER serine, GLU glutamic acid, GLY glycine, ARG arginine, ALA alanine, PRO proline, TYR tyrosine, CYS cysteine, C* control^dSample A = malted pearl millet at 12 h, B = malted pearl millet at 24 h, C = malted pearl millet at 36 h, D = malted pearl millet at 48 h, E = malted pearl millet at 60 h, F = malted pearl millet at 72 h, G = malted pearl millet at 84 h and H = malted pearl millet at 96 h

Table 3 Summary of the amino acid score of malted and unmalted pearl millet flour

Sample	TEAA	TNEAA	TAA	TEAA/ TAA (%)	TSAA	% CYS in TSAA	TAEAA	TAAA	TBAA	TEAA: TNEAA	LEU/ ILE ratio	LEU- ILE	PER
Control	2.32	4.19	6.52	35.65	0.05	77.78	0.68	1.85	0.82	0.55	2.34	0.43	0.15
A = 12 h malted pearl millet flour	2.58	4.09	6.67	38.69	0.10	35.40	0.69	1.96	0.87	0.63	2.44	0.46	0.14
B = 24 h malted pearl millet flour	2.07	4.32	6.39	32.34	0.06	63.70	0.25	1.89	0.82	0.48	2.33	0.42	0.16
C = 36 h malted pearl millet flour	2.47	4.02	6.49	38.05	0.07	47.82	0.65	1.91	0.81	0.61	2.27	0.40	0.17
D = 48 h malted pearl millet flour	2.50	4.22	6.72	37.22	0.08	40.67	0.64	1.90	0.82	0.59	2.27	0.40	0.17
E = 60 h malted pearl millet flour	2.48	4.17	6.65	37.35	0.07	39.58	0.63	1.87	0.82	0.60	2.26	0.39	0.18
F = 72 h malted pearl millet flour	2.44	4.10	6.54	37.32	0.03	57.62	0.62	1.87	0.80	0.60	2.32	0.39	0.18
G = 84 h malted pearl millet flour	2.43	4.00	6.43	37.84	0.02	76.32	0.61	1.85	0.78	0.61	2.33	0.39	0.19
H = 96 h malted pearl millet flour	2.41	3.57	5.98	40.35	0.02	78.78	0.58	1.79	0.80	0.68	2.23	0.35	0.20

^aTEAA Total essential amino acid, TNEAA total non-essential amino acid, TAA total amino acid, TSAA total sulphur amino acid (cysteine + Methionine), CYS cysteine, TAEAA total aromatic essential amino acid (Phenylalanine + Tryptophan), TAAA total acidic amino acid (Glutamic acid + Aspartic acid), TBAA total basic amino acid (Lysine + Histidine + Arginine), Leu leucine, ILE isoleucine, PER protein efficiency ratio

these amino acids from the endosperm during germination (Grossmann et al. 1998). Moreover, the kilning process involved in the malting of pearl millet might have also led to the reduction of some of the amino acids due to Maillard reaction which involves reactions between aldehydes, dicarbonyls and the amino groups. Amino acids such as arginine, analine and proline increased within 36 h of malting and later decreased towards the end of the malting period. Gernah et al. (2011) emphasized that metabolic and growth activities cease at maturation and continue under

suitable conditions of temperature and moisture and this might have facilitated the trend observed for arginine, proline and analine.

The 48 h malted pearl millet flour had the highest total amino acid (6.72/100 g) and total sulphur amino acid (0.08/100 g), while 12 h malted sample had the highest total essential amino acid (2.58/100 g), total aromatic amino acid, leucine and isoleucine ratio (2.44/100 g) as shown in Table 3. The experimentally determined PER often range from 0 (very poor protein) to 4 (very good

Table 4 Essential amino acid score of malted and unmalted pearl millet flour

Amino acid	Ile	Leu	Lys	Met + Cys	Thr	Tri	His	Phe + Tyr
*Standard g/100 g Protein (Adults)	3.0	5.9	4.5	2.2	2.3	1.1	1.5	3.8
Control	11.43	11.36	4.57	1.98	10.30	1.59	10.79	10.71
A = 12 h malted pearl millet flour	11.43	11.82	4.83	4.18	10.30	13.64	11.32	10.87
B = 24 h malted pearl millet flour	11.25	11.14	4.91	2.26	10.45	14.55	10.79	3.97
C = 36 h malted pearl millet flour	11.25	10.83	4.91	2.76	10.61	15.45	10.53	10.24
D = 48 h malted pearl millet flour	11.25	10.83	5.26	3.00	10.76	15.91	10.26	10.08
E = 60 h malted pearl millet flour	10.89	10.45	5.34	2.88	10.91	17.27	10.26	9.92
F = 72 h malted pearl millet flour	10.54	10.38	5.43	1.18	11.06	17.73	9.74	9.84
G = 84 malted pearl millet flour	10.36	10.23	5.52	0.76	11.21	19.09	9.47	9.68
H = 96 h malted pearl millet flour	10.18	9.62	5.95	0.66	11.52	21.36	9.21	9.13

^aHIS histidine, THR threonine, LYS lysine, ILE isoleucine, LEU leucine, PHE phenylalanine, MET methionine, TRI tryptophan, CYS Cysteine,

*FAO/WHO 2007 standard

Table 5 Effect of malting periods on pasting and functional properties of malted and unmalted pearl millet flours

Samples	PT (°C)	FV (RVU)	SB (RVU)	BD (RVU)	PV (RVU)	CP (RVU)	HPV (RVU)	OAC (ml/g)	SP (%)	WSI (%)
Control	89.50 ^d ± 1.29	1559.0 ^b ± 23.43	1028.40 ^b ± 27.29	140.00 ^f ± 9.32	703.02 ^b ± 14.54	38.11 ^g ± 1.39	563.05 ^f ± 13.45	0.33 ± 0.58 ^a	2.55 ± 0.09 ^{gh}	5.13 ± 0.45 ^a
A = 12 h malted pearl millet flour	69.00 ^a ± 1.34	35.10 ^g ± 3.42	24.55 ^g ± 2.63	61.07 ^g ± 2.43	67.00 ^g ± 4.32	42.32 ^h ± 1.28	17.73 ^c ± 1.23	0.57 ± 0.03 ^{ab}	2.50 ± 0.05 ^{gh}	7.82 ± 0.19 ^b
B = 24 h malted pearl millet flour	71.60 ^b ± 1.87	24.40 ^f ± 2.01	23.52 ^f ± 2.12	60.02 ^d ± 3.56	60.09 ^f ± 3.43	30.45 ^f ± 1.43	14.67 ^d ± 0.89	0.64 ± 0.01 ^{ab}	2.44 ± 0.07 ^f	11.35 ± 0.08 ^c
C = 36 h malted pearl millet flour	72.00 ^b ± 1.22	11.05 ^e ± 2.12	18.45 ^e ± 1.39	53.01 ^e ± 3.58	54.35 ^e ± 4.34	22.40 ^e ± 1.09	14.33 ^d ± 0.78	0.69 ± 0.01 ^{ab}	2.37 ± 0.05 ^c	12.62 ± 0.42 ^d
D = 48 h malted pearl millet flour	72.00 ^b ± 1.78	11.60 ^e ± 1.52	16.13 ^d ± 2.19	42.00 ^e ± 2.43	52.04 ^d ± 2.45	21.23 ^e ± 1.23	11.43 ^c ± 0.98	0.69 ± 0.03 ^{ab}	2.37 ± 0.05 ^c	12.72 ± 0.12 ^d
E = 60 h malted pearl millet flour	72.00 ^c ± 1.09	9.06 ^d ± 1.12	16.06 ^d ± 2.12	38.34 ^b ± 2.56	52.66 ^d ± 2.93	18.34 ^d ± 1.12	9.04 ^d ± 1.12	0.70 ± 0.04 ^{ab}	2.21 ± 0.03 ^d	14.18 ± 0.04 ^e
F = 72 h malted pearl millet flour	72.65 ^c ± 1.65	7.08 ^c ± 0.23	15.04 ^c ± 1.32	38.04 ^b ± 3.12	43.54 ^c ± 3.00	17.36 ^c ± 0.89	1.09 ^c ± 0.23	0.74 ± 0.15 ^b	2.18 ± 0.05 ^c	14.18 ± 0.04 ^e
G = 84 h malted pearl millet flour	74.00 ^c ± 1.34	3.23 ^b ± 0.26	14.04 ^b ± 1.54	37.12 ^b ± 2.46	39.05 ^b ± 3.21	14.78 ^b ± 0.93	0.93 ^b ± 0.06	0.80 ± 0.05 ^b	2.12 ± 0.19 ^b	15.97 ± 0.87 ^f
H = 96 h malted pearl millet flour	81.00 ^d ± 2.01	2.00 ^a ± 0.24	13.10 ^a ± 1.52	33.23 ^a ± 3.15	33.10 ^a ± 2.43	3.00 ^a ± 0.05	0.15 ^a ± 0.01	0.82 ± 0.03 ^b	2.06 ± 0.02 ^a	17.24 ± 1.16 ^g

^aValues with different superscript(s) in the column are significantly different ($p < 0.05$)^bResults are expressed as mean. PT pasting temperature, CP cold paste viscosity, HPV hot paste viscosity, BD breakdown, SB setback, FV final viscosity^cOAC oil absorption, WSI Water Solubility Index, SP swelling power

protein), and the standard reference proposed by FAO/WHO is 2.5 (2007). All the pearl millet flour samples had PER values lower than 1.5. Moreover, the amino acid scores also varied between the samples and the essential amino acid scores of malted pearl millet are displayed in Table 4. Based on the amino acid scores and PER standards (FAO/WHO (2007)), the pearl millet flour samples cannot fully supply the required protein and essential amino acids required daily by an adult. The results suggests the supplementation or fortification of malted pearl millet flours with other protein/amino acids rich flour if such property is desired in a food system.

Physico-chemical properties

Table 5 presents the functional properties of malted and un-malted pearl millet flour. WSI is an indication of dextrinization and starch degradation, the WSI of the samples ranged from 5.13 to 17.24% and it increased as the malting period increased. The increase in the WSI could be explained by the development of lower molecular weight compounds by proteases and amylases in crystalline regions of the pearl millet granules which also increased hygroscopicity. This gives an indication that malting increased the amount of soluble and digestible materials in pearl millet. SP of starch measures the ratio of its sediment gel to dry weight (Lai and Cheng 2004). The SP decreased with subsequent increase in malting period up to 96 h. This may have to do with the fact that reserves of nutrients like starch and protein are broken down to soluble sugars by internal enzymes to support the growth of sprouts during germination (Claver et al. 2010). OAC depicts the potential of the flour protein to bind physically with fat through capillary action. It is an important property because fat increases mouth feel and acts as flavor retainer (Bolaji et al. 2014). In this study, the OAC of the samples ranged from 0.33 to 0.82% and the malted pearl millet flour samples had higher OAC indicating higher hydrophobic interaction when compared with the control sample. Also, the increase observed in OAC might be a function of protein dissociation and denaturation which may occur during malting thereby exposing the polar amino acid of the pearl millet proteins and enhancing hydrophobicity (Bolaji et al. 2014). The increase in OAC compared to the control, also suggests the presence of more non-polar amino acids in the malted samples and this conforms to the findings of Adebiyi et al. (2016) on the effect of malting and fermentation on some properties of pearl millet biscuit and flour.

Pasting properties of flour are usually associated with amylopectin, amylose, biological characteristics of the endosperm (granules) and starch content among others (Cozzolino et al. (2014). In this study, the pasting profile of malted pearl millet Ex-Borno variety was also investigated

(Table 5). The final viscosity reduced as the malting period increased and the unmalted pearl millet flour had the highest final viscosity (1559.0 RVU). Final viscosity defines the quality of a starch-based sample as an indication of its ability to form viscous paste or gel after it is cooked and cooled and also the resistance of the paste to shear force during stirring (Shimelis et al. 2006). The peak viscosity attained by gelatinised starch during heating ranged from 33 to 703 RVU; with the unmalted pearl millet flour having the highest peak viscosity. This trend was also reported by Pelembe et al. (2002). This may be due to the formation of non-polar structures during protein-starch interaction or denaturation of protein as evident in other properties studied. The decrease observed in the viscosity of the flour is also consequential of the action of the amylase enzymes which acts on the granules during germination making them more receptive. The higher vulnerability of granules also contributes to an easier breakdown under mechanical agitation (Grossmann et al. 1998). The control sample had the highest breakdown value (140 RVU) and the breakdown followed similar trend of reduction observed in the viscosities of the flour samples as the malting period increased. Setback is the point of the pasting profile where re-connection occurs between starch molecules to a greater or lesser degree (Kin et al. 1995). The setback index ranged from 13 to 1028 RVU. High setback value in the unmalted pearl millet flour is associated with a cohesive paste while a low value in sample malted for 96 h is an indication of formation of a non-cohesive paste (Kin et al. 1995). Low setback values in the

processed samples makes them useful for production of foods, which require low viscosity and paste stability at low temperatures such as weaning foods. The pasting temperature ranged between 69.05 and 89.5 °C and it is the lowest temperature needed to cook the flour. However, the control sample had significantly higher pasting temperature as compared with the malted samples. The higher pasting temperature of the un-malted flour may be a pointer to the presence of starch which is resistant to rupturing and swelling in the sample as observed by Kaur et al. (2007).

Pearl millet grain contains various antioxidants including phenolic acids and flavonoids which contest against free radicals (Obadina et al. 2016). Millet phenolics have currently received a lot of attention because of its health promoting properties, and pearl millet has been delineated to contain high levels of phenolic compounds (Chandkara and Shahidi 2011). Data on the total phenols in malted and unmalted pearl millet flour samples are displayed in Fig. 1. Phenolic content in all the malted samples decreased significantly and was found to vary between 130.20 and 169.90 mg/100 g with the unmalted pearl millet flour having the highest value. This decrease could be as a result of leaching or their entrance into the endosperm with imbibed water during steeping and germination. As such, they form complexes with the proteins and other molecules and become less extractable (Chandkara and Shahidi 2011). Taylor and Duodu (2015) accrued the changes in phenolic content during malting to the activities of enzymes such as polyphenol oxidase which are substrates of phenolic compounds. Nithya and Ramachandramurthy

Fig. 1 Effect of malting periods on the phenolic compounds of malted and unmalted pearl millet flour (mg/100 g)

(2007) reported that steeping and 48 h germination reduced total phenolics by 12 and 76%, respectively in the millet varieties they studied.

Conclusion

Malting improved some of the nutrients and functional properties of pearl millet flour. In particular, there was an increase in the protein, crude fibre, lysine, aspartic acid content of the pearl millet flour as well as the WSI and OAC. The total phenolic, carbohydrate, ash and fat content decreased as the malting period increased and significant changes were not observed in the phenylalanine, serine and leucine content of the flours. This study shows that malted pearl millet flour could be used in food system where qualities such as moderate protein, high fibre, and low pasting properties are desired.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interest to declare.

References

- Adebiyi JA, Obadina AO, Mulaba-Bafubandi AF, Adebo OA, Kayitesi E (2016) Effect of fermentation and malting on the microstructure and selected physico-chemical properties of pearl millet (*Pennisetum glaucum*) flour and biscuit. *J Cereal Sci* 70:132–139
- AOAC (2010) Official methods of analysis of AOAC international. AOAC International, USA: method: 93104; 92303; 94538; 96209; 98529; 99008; 200111
- Arif M, Bangash JA, Khan F, Abid H (2011) Effect of soaking and malting on the selected nutrient profile of barley. *Pak J Biochem Mol Bio* 44(1):18–21
- Basahy AY (1996) Nutritional and chemical evaluation of pearl millet grains (*Pennisetum typhoides* (Burm. f.) Stapf & Hubbard, Poaceae) grown in the Gizan area of Saudi Arabia. *Int J Food Sci Nutr* 47(2):165–169
- Bolaji OT, Oyewo AO, Adepoju PA (2014) Soaking and drying effect on the functional properties of ogi produce from some selected maize varieties. *Am J Food Technol* 2:150–157
- Chandkara A, Shahidi F (2011) Determination of antioxidant activity in free and hydrolysed fractions of millet grains and characterization of their phenolic profiles by HPLC-ESI-MSn. *J Funct Foods* 3:144–158
- Chivenge P, Mabhaudhi T, Modi AT, Mafongoya P (2015) The potential role of neglected and underutilised crop species as future crops under water scarce conditions in Sub-Saharan Africa. *Int J Environ Res Public Health* 12(6):5685–5711
- Claver IP, Zhang H, Li Q, Zhu K, Zhou H (2010) Impact of the soak and the malt on the physico-chemical properties of the sorghum starches. *Int J Mol Sci* 11:3002–3015
- Coulibaly A, Kouakou B, Chen J (2012) Extruded adult breakfast based on millet and soybean: nutritional and functional qualities, source of low glycemic food. *J Nutr Food Sci* 2:1–9
- Cozzolino D, Roumeliotis S, Eglinton JK (2014) The influence of starch pasting properties and grain protein content on water uptake in barley. *J Inst Brew* 120:38–44
- Devi CB, Kushwaha A, Kumar A (2015) Sprouting characteristics and associated changes in nutritional composition of cowpea (*Vigna unguiculata*). *J Food Sci Technol* 52:6821–6827
- Elkhier MKS, Hamid AO (2008) Effect of malting on the chemical constituents, antinutritional factors and ash composition of two sorghum cultivars (*feterita* and *tabat*) grown in Sudan. *Res J Agric Biol Sci* 4:500–504
- FAO, WHO (2007) Protein and amino acid requirements of infants and children. In report of a joint FAO/WHO/UNU expert consultation. WHO Tech Rep 935:161–182
- Gernah DI, Ariahu CC, Ingbian EK (2011) Effects of malting and lactic fermentation on some chemical and functional properties of maize (*Zea mays*). *Am J Food Technol* 6:404–412
- Grossmann MV, Mandarino E, Marcos JG, Yabu YC (1998) Chemical composition and functional properties of malted corn flours. *Brazilian Arc Biol Technol*, 41(2)
- Kaur A, Singh N, Ezekiel R, Guraya HS (2007) Physico-chemical, thermal and pasting properties of starches separated from different potato cultivars grown at different locations. *Food Chem* 101:643–651
- Kent NL (1994) Technology of cereals: an introduction for students of food science and agriculture. Elsevier, London
- Kin YS, Wiesenborn DP, Orr PH, Grant LA (1995) Screening potato starch for novel properties using differential scanning calorimetry. *J Food Sci* 60:1060–1065
- Kuo YH, Rozan P, Lambein F, Frias J, Vidal-Valverde C (2004) Effects of different germination conditions on the contents of free protein and non-protein amino acids of commercial legumes. *Food Chem* 86(4):537–545
- Lai HM, Cheng HH (2004) Properties of pregelatinized rice flour made by hot air or gum puffing. *Int J Food Sci Technol* 39:201–212
- Lan W, Hihua Y, Yun Z, Bijun X, Zhida S (2008) Morphological, physico-chemical and textural properties of starch separated from Chinese water chestnut. *Starch* 60:181–191
- Laxmi G, Chaturvedi N, Richa S (2015) The impact of malting on nutritional composition of foxtail millet, wheat and chickpea. *J Nutr Food Sci* 5:407
- Maidala AA, Dahuwa TN, Bakoshi AM, Gumal SA (2016) Effect of different malting periods on antinutritional factors of three locally grown sorghum varieties in Bauchi state, Nigeria. *IIARD Int J Appl Chem* 2(1):1–8
- Mc Donough C, Rooney M, Lloyd W, Serna-Saldivar SG (2000) The millets. *Cereal Sci Technol* 99:177–210
- Nithya KS, Ramachandramurthy Krishnamoorthy VV (2007) Effect of processing methods on nutritional and anti-nutritional qualities of hybrid (COHCU-8) and traditional (CO7) pearl millet varieties of India. *J Biol Sci* 7:643–647
- Nwosu JN (2010) The effects of processing on the functional properties of ‘Oze’ (*Bosqueia angolensis*) seeds. *Pak J Nutr* 9(8):781–786
- Obadina AO, Ishola IO, Adekoya IO, Soares AG, Piler de Carvalho CW, Barboza HT (2016) Nutritional and physico-chemical properties of flour from native and roasted whole grain pearl millet (*Pennisetum glaucum* [L]R Br). *J Cereal Sci* 70:247–252

- Ogbonna AC, Abujah CI, Ide EO, Udofia US (2012) Effect of malting conditions on the nutritional and anti-nutritional factors of sorghum grist. *Food Technol* 36(2):64
- Ojediran JO, Adamu MA, Jim-George DL (2010) Some physical properties of pearl millet *Pennisetum glaucum* seeds as a function of moisture content. *Afr J Gen Agric* 6:39–46
- Pelembe LAM, Dewar J, Taylor JRN (2002) Effect of malting conditions on pearl millet malt quality. *J Inst Brew* 108:7–12
- Saleh ASM, Zhang Q, Chen J, Shen Q (2013) Millet grains: nutritional quality, processing, and potential health benefits. *Compr Rev Food Sci Food Saf* 12:281–295
- Senhofa TK, Galoburda R, Cinkmanis I, Sabovics M, Sturite I (2016) Effects of germination on chemical composition of hull-less spring cereals. *Res Rural Dev* 1:91–97
- Shimelis AE, Meaza M, Rakshit S (2006) Physico-chemical properties, pasting behavior and functional characteristics of flours and starches from improved bean *Phaseolus Vulgaris L* varieties grown in East Africa. *CIGR E-J* 8:1–18
- Taraseviciene Z, Danilcenko H, Jariene E, Paulauskiene A, Gajewski M (2009) Changes in some chemical components during germination of broccoli seeds. *Not Bot Horti Agrobot Cluj Napoca* 37:173–176
- Taylor JR, Duodu KG (2015) Effects of processing sorghum and millets on their phenolic phytochemicals and the implications of this to the health-enhancing properties of sorghum and millet food and beverage products. *J Sci Food Agric* 95(2):225–237
- Wolfe K, Wu XL, Liu RH (2003) Antioxidant activity of apple peels. *J Food Chem* 51:609–614