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Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub-Saharan Africa

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ABSTRACT

The study determined the physical properties of finger millet (FM) (*Eluesine coracana*) grains and the functional properties of FM flour. Physical properties such as colour attributes, sample weight, bulk density, true density, porosity, surface area, sample volume, aspect ratio, sphericity, dimensional properties and moisture content of grain cultivars were determined. Water absorption capacity (WAC), bulk density (BD), dispersibility, viscosity and micro-structure of FM flours were also evaluated. Data collected were analyzed using SPSS statistical software version 23.0. Results showed that milky cream cultivar was significantly higher ($p < 0.05$) than other samples in sample weight, bulk density, true density, aspect ratio and sphericity. However, pearl millet, used as a control, was significantly different from FM flour on all dimensional properties. Moisture content of milky cream showed higher significant difference for both grains and flours as compared to brown and black grain/flours. Milky cream cultivar was significantly different in L*, b*, C*, H* values, WAC, BD and dispersibility for both FM grains and flours. Data showed that brown flour was significantly higher in viscosity than in milky and black flours. Microstructure results revealed that starch granules of raw FM flours had oval/spherical and smooth surface. The study is important for agricultural and food engineers, designers, scientists and processors in the design of equipment for FM grain processing. Results are likely to be useful in assessing the quality of grains used to fortify FM flour.

1. Introduction

Finger millet also known as *ragi* (Takhellambam, Chimmand, & Prkasam, 2016) or *tamba* (Jideani, Takeda, & Hizukuri, 1996), is consumed without dehulling (Gull, Kmalesh, & Kumar, 2015). The grains are staple cereal food in some parts of Africa and India (Saleh, Zhang, Chen, & Shen, 2013; Siwela, Taylor, de Milliano, & Doudu, 2010). Although a gluten-free grain with low-glycemic index with nutritional and nutraceutical advantages, FM is neglected and underutilized (Amadou, Mahamadou, & Le, 2013; Jideani & Jideani, 2011). Finger millet belongs to the family *Poaceae* and originated in Ethiopia (Shiihii, Musa, Bhati, & Martins, 2011) before reaching India (Siwela et al., 2010). In terms of production in semi-arid regions, FM ranks fourth after sorghum, PM and foxtail millet (Shiihii et al., 2011; Upadhyaya et al., 2011).

The grains contain a high amount of calcium which is an essential macro-nutrients necessary for growing children, pregnant women and the elderly. This is due to calcium's importance for normal growth of body tissue such as strengthening bone and teeth. FM has also been reported to be rich in essential amino acids, such as methionine, tryptophan and lysine (Jideani, 2012). FM contains low amounts fat which contributes to reducing risks of diabetes mellitus and gastro-intestinal tract disorders (Muthamilarasan, Dhaka, Yadav, & Prasad, 2016). According to Jideani (2012), FM grains are also a good source of carbohydrates, phosphorus, magnesium and iron. The grains are also rich in vitamin B complex such as thiamine, riboflavin, folic acid and niacin (Gull et al., 2015; Saleh et al., 2013). Utilisation of the plant involves its use as a folk medicine for treatment of liver disease, measles, pleurisy, pneumonia and small pox (Bachar et al., 2013). Starch extracted from FM grains are used in the pharmaceutical industries in the preparation of granules for tablets and capsule dosages (Shiihii et al., 2011). Application of grains also involves its use in the preparation of baked products, composite flour, weaning foods, beverage and non-beverage products (Poutanen, 2012; Verma & Patel, 2013).

FM grains are found in different shapes, sizes and colours with the predominant colour being brown (Vadivoo, Joseph, & Ganesan, 1998). The physical properties of cereal grains include moisture content, 1000 sample weight, bulk density, true density, porosity, aspect ratio, sample

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volume, sample surface area and perpendicular dimensions (length, width and thickness) (Vanrnamkhasti et al., 2008). Current review of literature shows that physical properties of grains have been conducted on major cereal grains such as, wheat, rough rice and maize (Sangamithra et al., 2016; Vanrnamkhasti et al., 2008) when compared to millets, such as FM, foxtail millet, little millet, kodo millet, common millet and banyard millet (Balasubramanian & Viswanathan, 2010). Studies have also been conducted on legumes such as cowpea seeds, soy bean and bambara groundnuts (Bhattacharya & Malleshi, 2012; Jideani et al., 1996). However, data on physical properties of FM grain cultivars is still insufficient, especially in Sub-Saharan Africa with few studies reported in Asian countries such as India. The knowledge of the physical and functional properties will be useful in new product development (Faleye, Atere, Oladipo, & Agaja, 2013). Functional properties of cereal grains are the fundamental physico-chemical properties that reflect the complex interaction between the structure, molecular components, and composition and physico-chemical properties of food components. The functional property of food is defined as physical, chemical and/or organoleptic properties of food. Examples of functional properties of food include viscosity, foaming capacity, water absorption capacity, dispersibility, bulk density, oil absorption capacity and swelling capacity (Kumari & Raghuvanshi, 2015). The objective of this study was to determine the physical properties of FM grains and the functional properties of FM flour.

2. Materials and methods

2.1. Sorting of finger millet grains

Mixed grain cultivars were purchased from Thohoyandou market, Limpopo province, South Africa. Foreign materials were removed from the grains by immersion in clean water. After drying, the mixed grains were sorted into 3 different cultivars (80% - milky cream, 97% - brown and 85% - black) based on sample colour (Fig. 1). PM (*Pennisetum glaucum*) was used as control. The grain samples were randomly selected and 20 replicates were performed for dimensional properties (length, width and thickness). The determination of other physical properties such as moisture content, 1000 sample weight, bulk density, true density, porosity, aspect ratio, sample volume and sample surface area were performed in 5 replicates for each grain cultivar. Colour attributes were performed in 3 replicates for FM grain cultivars and flours. Functional properties of FM flours such as WAC, BD, dispersibility and viscosity (cold and cooked paste) were performed in triplicates.

2.2. Preparation of finger millet flour

The sorted samples were then soaked in cold water for 24 h at 30 °C. The soaked sample was dried at 60 °C for 24 h using hot air oven to a moisture content of 10–12%. The milky creamy, brown and black cultivars were milled into FM flour using Retsh ZM 200 miller at 18000 rpm for 3 min and sieved at 100 µm. The samples were then packed and sealed in a polythene bag for further analysis (Saleh et al., 2013). All the reagents used in this study were purchased from Merck Midrand, South Africa.

2.3. Moisture content on wet basis

The moisture content (%) was determined with hot air oven drier using the method 44–15.02 (AACC, 2000) using Eq. (1). A dry coded, clean crucible was placed in the oven for about 30 min, cooled and weighed. Four grams of FM grain cultivars and FM flours were weighed into the crucible, and recorded. The samples were dried at 101 to 105 °C for 24 h, removed and cooled until a constant weight was obtained. The results of moisture content (%) was calculated thus:

$$\%\text{moisture} = \frac{W2 - W3}{W2 - W1}\, x\, 100 \tag{1}$$

where: W_1 = weight of empty crucible
W_2 = weight of crucible + flour before drying
W_3 = weight of crucible + flour after drying

2.4. Dimensional properties

A total of twenty seeds were randomly selected from each cultivar milky cream, brown, black, and the control. Three different dimensional properties (mm) were determined by measuring the length (L), width (W) and thickness (T) of the grains using a venier digital caliper at an accuracy of 0.01 mm (Mpotokwane, Gaditlhatlhelwe, Sebaka, & Jideani, 2008).

2.4.1. Geometric mean diameter

The geometric mean diameter (mm) was determined based on the measured dimensions of finger millet samples using Eq. (2) (Mpotokwane et al., 2008).

Geometric mean diameter (Dg) is equivalent to

$$(\mathrm{L} \times \mathrm{W} \times \mathrm{T})^{1/3} \tag{2}$$

where: L = length.
W = width.
T = thickness.

2.4.2. Arithmetic mean diameter

The arithmetic mean diameter (mm) of the sample was obtained using the methods of Mpotokwane et al. (2008). Arithmetic mean diameter was calculated from the dimensional values using Eq. (3):

Arithmetic mean diameter

$$(\mathrm{Da}) = \frac{L + W + T}{3} \tag{3}$$

where: L = length.
W = width.
T = thickness.

Fig. 1. Finger millet grain cultivars: A = 80% milky creamy, B = 85% black, C = 97% brown and D = pearl millet. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.5. One thousand (1000) sample weight

Thousand sample weight was determined by weighing, recording the weight and counting manually the number of the sample. The grain samples were weighed using digital electronic balance with 0.01 g accuracy (Adam CPW plus-150p, USA) (Sangamithra et al., 2016).

2.6. Bulk density

Bulk density (kg/m^3) is described as the ratio of the mass of the sample to its total volume (Vanrnamkhasti et al., 2008). It was determined by filling a 500 mL cylinder with grains using method of Mariotti, Alamprese, Pagani, and Lucisano (2006). Bulk density (kg/m^3) was calculated as a ratio between the sample weight and the volume of the cylinder using Eq. (4):

$$\text{Bulk density} = \frac{\textit{Sample weight}}{\textit{volume}} \tag{4}$$

2.7. True density

The true density (kg/m^3) was determined by the liquid displacement method using a top loading balance. A total of 100 g of grains were immersed in graduated beaker containing distilled water. The amount of water displacement was recorded using Eq. (5) (Karababa & Coşkuner, 2013).

$$\text{Pt} = \frac{30\,g}{V2 - V1} \tag{5}$$

where: Pt = true density, V_1 = initial volume and V_2 = final volume.

2.8. Porosity

Porosity (%) is defined as the fraction of the space in bulk grain that is not occupied by the grain (Sangamithra et al., 2016). It was calculated using Eq. (6) from the true density and bulk density using method of Vanrnamkhasti et al. (2008).

$$\varepsilon = \frac{Pt - Pb}{Pt} \times 100 \tag{6}$$

where ε = porosity, p_t = true density and p_b = bulk density.

2.9. Sphericity

Sphericity (%) is explained as the ratio of the surface area of a sphere having the same volume as the grain to the surface area of the grain and was calculated using the method of Hamdani et al. (2014) Eq. (7).

$$\Phi = \frac{(LWT)1/3}{L}\, x\; 100 \tag{7}$$

where Φ = Sphericity.

2.10. Aspect ratio

The aspect ratio (%) was calculated Eq. (8), method of Vanrnamkhasti et al. (2008) as follows:

$$\text{Aspect ratio} = \frac{\textit{Width}}{\textit{Length}}\, x\; 100 \tag{8}$$

2.11. Surface area

The surface area, mm^2 of three FM cultivars and PM were calculated using Eq. (9), method of (Karababa & Coşkuner, 2013):

$$\text{Surface area} = \frac{\pi BL^2}{(2L - B)} \tag{9}$$

where B = (WT) $^{1/2}$.

2.12. Sample volume

The volume (mm^3) of the grains was calculated Eq. (10), method of (Karababa & Coşkuner, 2013).

$$\text{Surface volume} = \frac{\pi B^2 L^2}{6(2L - B)} \tag{10}$$

where B = (WT) $^{1/2}$
W = width; L = length.

2.13. Water absorption capacity

One (1) gram FM flour was transferred into weighing 50 mL centrifuge tubes in triplicate to which 10 mL of distilled water was added, stirred homogeneously with a glass rod and incubated in waterbath at 30 °C for 30 min. The centrifuge tubes were centrifuged at 3000 rpm for 15 min using a Model T-8BL Laby ™ centrifuge (Laboratory Instruments, Ambala Cantt India). The supernatants were discarded and the residues were weighed. Two different weights of the centrifuge tubes gave water absorbance using Eq. (11), method of Sawant, Thakor, Swami, and Divate (2013).

$$\text{Water absorption capacity} = \frac{V1 - V2}{V2} \times 100 \tag{11}$$

where: V1 = initial volume of the liquid.
V2 = final volume of the liquid.

2.14. Bulk density

Bulk density was determined by measuring 10 mL capacity graduated cylinder, weighed and recorded. The cylinder was filled with the flour sample and tapped gently from the bottom for 30 times until there was no further dimension of the sample level and calculated using Eq. (12), method of Mandge, Sharma, and Dar (2014).

$$\text{Bulk density (g/mL)} = \frac{\textit{Weight of FM flour}}{\textit{Volume of FM flour after tapping}} \tag{12}$$

2.15. Determination of dispersibility

A total of 10 g of the flour sample was weighed into 100 mL measuring cylinder and distilled water was added. The set up was stirred vigorously and allowed to stand for 3 h. The volume of settled particle was recorded and subtracted from 100 (Olapade, Babalola, & Aworth, 2014) using Eq. (13).

$$\%\text{Dispersibility} = 100 - \text{volume of settled particles} \tag{13}$$

2.16. Viscosity

Approximately 10 g of the flour was mixed with 90 mL of distilled water at 30 °C and allowed to hydrate for 30 min with occasional stirring. The viscosity of the slurry was measured in Brookfield viscometer (Model RV, Brookfield Engineering, Inc., USA) using spindle number Q3 rotating at 100 rpm and the cold paste viscosity was measured in centipoise (cP). Subsequently, the slurry was heated to boiling in a water bath at 95 ± 1 °C for a period of 20 min, cooled to 30 °C and cooked (Krishnan, Dharmaraj, Sai Manohar, & Malleshi, 2011).

2.17. Colour measurements of FM grain cultivar and flour

The colour measurements (L*, a*, b*, C* and H^{o}) of the grain and flour samples were determined using Lovibond LC 100 spectrocolorimeter and SV 100 test kit (Thilagavathi et al., 2015). The colour attributes were measured and expressed as positive and negative colour space values using L* (whiteness/brightness), a* (redness/greenness) and b* (yellowness/blueness). The chroma (C*) was expressed as either grey or the pure hue with hue (H^{o}) recorded using different colours such as yellow, green and blue values.

2.18. Scanning Electron Microscopy (SEM)

Microscopic structure of FM flour was mounted on a sample holder using double-sided scotch tape and was coated with thin layer of gold in a sputter coating equipment. All examinations were observed at an accelerated voltage of 5.000 kV using a scanning electron microscope coupled with electron probe microanalysis Energy Dispersive X-ray detector (Mervlin/Evo Germany) (Anyasi, Jideani, & Mchau, 2017).

2.19. Data analysis

The generated data were subjected to analysis of variance (ANOVA) using SPSS version 23 (SPSS, IBM, Chicago USA) and means were separated using the Duncan multiple range test. Significance will be accepted at 95% confidence interval ($p < 0.05$) (Kibar & Kibar, 2017).

3. Results and discussion

3.1. Moisture content of finger millet grains and flour

Fig. 2 shows the results of the mean moisture content (MC) of the FM grain cultivar that ranged from 7.88 ± 1.92 to 9.38 ± 3.08% while the moisture content of FM flours varied from 9.17 ± 1.44 to 11.67 ± 1.44%, respectively. Therefore, milky cream showed a significant difference ($p < 0.05$) for both grains and flours as compared to brown and black grain/flours. However, the MC of milky cream and black flours increased while brown flour decreased after milling grains into flours. These results compared with the control, PM showed a significantly higher than FM grain cultivars (FMGC) at the highest value of 15.38%. The results showed that the MC were within the specified percentage of < 12% as shown in the work of Saleh et al. (2013). The highest percentage was recorded for milky cream, and the lowest percentage for brown cultivar for both FM grain cultivar and flours (Fig. 2). Moisture content is one of the important factors that govern the physical properties of grain (Goswami, Manikantan, Gupta, & Vishwakarma, 2015). It is also a good indicator as to whether the grains can be stored for a long or short period. According to Abdullah, Ch'ng, and Yunus (2012) the higher the moisture content, the shorter the storage life of the grain as high moisture content can cause a rapid growth of mould on grains.

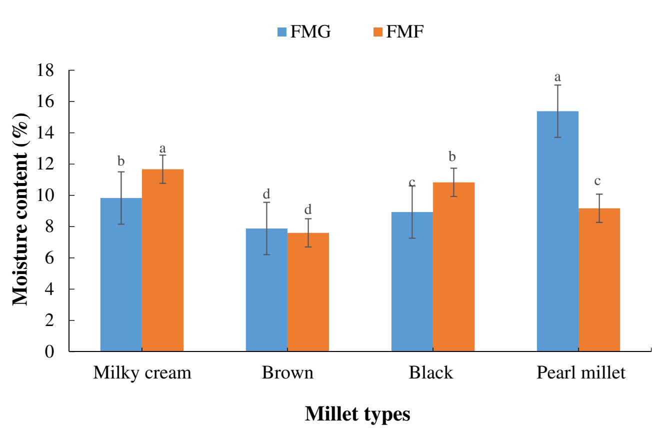

Fig. 2. Moisture content (%) of finger millet grain cultivars and flours. Note: FMG – finger millet grain and FMF – finger millet flour. Error bars indicate the standard deviations and letters a - d indicates significant difference.

Table 1
Dimensional properties of finger millet grain cultivars using Vernier Digital Caliper.

Dimensions (mm)	Milky creamy	Brown	Black	Pearl millet (control)
Length	$1.63^{b} \pm 0.01$	$1.67^{b} \pm 0.01$	$1.41^{c} \pm 0.00$	$3.85^{a} \pm 0.01$
Width	$1.28^{c} \pm 0.01$	$1.47^{b} \pm 0.01$	$1.38^{b} \pm 0.01$	$2.40^{a} \pm 0.01$
Thickness	$1.22^{d} \pm 0.01$	$1.35^{b} \pm 0.01$	$1.27^{b} \pm 0.01$	$2.31^{a} \pm 0.00$
Geometric mean diameter	$1.36^{c} \pm 0.18$	$1.49^{b} \pm 0.13$	$1.35^{c} \pm 0.06$	$2.81^{a} \pm 0.71$
Arithmetic mean diameter	$1.38^{c} \pm 0.22$	$1.50^{b} \pm 0.06$	$1.35^{c} \pm 0.07$	$2.85^{a} \pm 0.86$

The mean ± standard deviation, $n = 20$. Values followed by the same letters in the same row are not significantly different ($p < 0.05$).

3.2. Dimensional properties of finger millet cultivars

The mean results of the length, width and thickness of the three cultivars were measured using venier digital caliper and ranged between 1.67 ± 0.01 to 1.41 ± 0.00 mm for length; 1.47 ± 0.01 to 1.28 ± 0.01 mm for width and 1.35 ± 0.06 mm to 1.22 ± 0.01 mm for thickness (Table 1). Similar results were obtained by Hamdani et al. (2014) for length, width and thickness and ranged from 8.57 ± 1.20 to 11.31 ± 1.10 mm; 2.70 ± 0.24 to 3.70 ± 0.18 mm; and 2.24 ± 0.09 to 2.85 ± 0.16 mm for hulled barley and SKO-20 oats at the moisture content of 8.0%. Similar results were obtained for PM cultivars (babapuri, bajra, & GHB 30) with length, width and thickness ranging from 2.98 mm to 3.12 mm, 1.86 mm to 2.24 mm and 1.70 to 2.01 mm (Jain & Bal, 1997).

Length values were significantly higher ($p < 0.05$) for black cultivar while creamy and brown were not significantly different. Width values for milky cream were significantly higher ($p < 0.05$) while brown and black were not significantly different. Thickness values for milky cream were significantly higher when compared with other samples. The geometric mean diameter ranged from 2.81 ± 0.71 mm to 1.35 ± 0.06 mm and arithmetic mean diameter from 2.85 ± 0.86 mm to 1.35 ± 0.07 mm. The results for geometric and arithmetic mean diameters were similar to the results obtained on millet grains as reported by Adebowale, Fetuga, Apata, and Sannai (2012), where the average length, width and thickness were 3.85 mm, 2.06 mm and 2.05 mm. Similar, results were also obtained for geometric and arithmetic mean diameters, 2.44 mm and 4. 94 mm at a moisture content of 10%.

Jain and Bal (1997) who studied the geometric and arithmetic mean diameters of PM cultivars, the results were as follows: 1.82 mm to 2.12 mm and 1.72 mm to 2.08 mm at the moisture content of 7.4%. Other similar arithmetic mean diameter results from hulled and hulless barley were 4.96 ± 0.50 and 5.34 ± 0.31 mm, while for sabzaar oats and SKO-20 oats they were 6.00 ± 0.26 and 5.41 ± 0.44 mm, respectively. Similar results for geometric mean diameter were also found as 4.33 ± 0.27; 4.53 ± 0.24 mm; 4.22 ± 0.21 mm and 4.01 ± 0.20 mm for hulled barley, hulless barley, sabzaar oats and SKO-20 respectively at the moisture content of 8.0% (Hamdani et al., 2014). The geometric and arithmetic mean diameters were significantly higher in brown, milky cream and black cultivar respectively (Table 1). Therefore, PM grain showed a significant difference on all dimensions studied as compared to FMGC.

Table 2
Some physical properties of finger millet grain cultivars.

Physical properties	Milky creamy	Brown	Black	Pearl millet
1000 kernel weight (wt.g)	775.8[a] ± 5.27	496.8[c] ± 5.00	573.4[b] ± 7.17	176.8[d] ± 1.94
Bulk density (kg/m^3)	1158[a] ± 16.51	993.6[c] ± 11.44	1146.80[b] ± 16.04	354.6[d] ± 3.85
True density (kg/m^3)	1613.4[a] ± 48.02	1515.6[c] ± 34.88	1515.8[c] ± 35.33	1531.2[b] ± 42.72
Porosity (%)	28.25[a] ± 2.47	32.41[b] ± 5.40	24.31[b] ± 2.10	76.83[a] ± 0.47
Aspect ratio (%)	92.21[a] ± 0.83	88.3[b] ± 0.55	73.55[c] ± 0.23	87.81[b] ± 0.92
Sphericity (%)	92.43[a] ± 0.15	83.21[b] ± 0.08	73.75[c] ± 0.10	64.17[d] ± 0.16
Surface area (mm^2)	5.81[a] ± 0.82	6.97[b] ± 0.94	5.73[c] ± 0.90	24.81[a] ± 1.41
Volume (mm^3)	0.86[a] ± 0.02	1.07[b] ± 0.06	0.82[c] ± 0.16	3.59[a] ± 1.12

The mean ± standard deviation, $n = 5$. Values followed by the same letters in the same row are not significantly different ($p < 0.05$).

3.3. Physical and functional properties of finger millet grain cultivars/flours

The highest mean result for 1000 sample weight was obtained from milky cream cultivar, 775 ± 5.27 g and the lowest mean result for 1000 sample weight was 496.8 ± 5.00 g from brown cultivar. Milky cream was significantly different ($p < 0.05$) on 1000 sample weight as compared to other samples (Table 2). The results agree with the findings of Balasubramanian and Viswanathan (2010) which were 185.8 kg at a moisture content of 11.1 to 25%. In the work of Siwela, Taylor, de Milliano, and Doudu (2007) similar mean results of 2.86 ± 0.11 g were reported. Results of analysis also showed that bulk density ranged from 993.6 ± 11.44 to 1551.6 ± 16.51 kg/m^3 respectively, with milky cream showing the highest bulk density and brown cultivar showing the lowest bulk density. These results were in line with those by Zewdu and Solomon (2007) who reported 696 to 840 kg/m^3 for teff millet at a moisture content ranging from 5.6 to 29.60%. Milky cream FM cultivar had the significantly highest ($p < 0.05$) true density of 1613.4 ± 48.02 kg/m^3, followed by black cultivar 1515.8 ± 35.33 kg/m^3 and brown 1515.6 ± 34.88 kg/m^3 respectively. These results were in line with the findings by Vanrnamkhasti et al. (2008) for rough rice, where the mean true density ranged from 1193.38 to 1269.10 kg/m^3, respectively. Similar results for true density, 884.4 to 1988.7 kg/m^3 were obtained by Balasubramanian and Viswanathan (2010) at a moisture content of 11.1 to 25%. Jain and Bal (1997) obtained similar results on the true density of 3 PM studied which ranged from 1578 to 1623 kg/m^3. Zewdu and Solomon (2007) also reported similar results of 1207 to 1361 kg/m^3 for teff millet grain at a moisture content of 5.6 to 29.6%.

The mean porosity results varied from 24.31 ± 2.10 to 32.41 ± 5.40%. The highest percentage was found on brown cultivar with the lowest on black FM cultivar. These results are similar to those reported by Sangamithra et al. (2016) where porosity ranged from 51.30 to 55.83% at a moisture content of 8.7 to 21.7% for maize. A similar observation was reported by Al-Mahasnesh and Rababah (2007) ranging from 45.61 to 46.66% for green wheat. A study by Zewdu and Solomon (2007) ranged from 38.31 to 42.32% for teff millet at a moisture content of 5.6 to 29.0% and in a study by Jain and Bal (1997), porosity ranged from 45.1 to 48.8% for PM cultivars (babapuri, bajra and GHB 30) at a moisture content of 7.4%. Balasubramanian and Viswanathan (2010) obtained similar results of 32.5 to 63.7% at a moisture content of 11.1 to 25% for minor millets in which FM grain was part of the study. The mean results of aspect ratio ranged from 73.55 ± 0.23 to 92.21 ± 0.83% where milky cream was found to have a highest percentage and lowest percentage on black cultivar. Adebowale et al. (2012) revealed that millet grains were found to have 59.62% aspect ratio at a moisture content of 10% and Markowski, Zuk-Gołaszewska, and Kwiatkowski (2013) also reported the same results of 47.4% at a moisture content of 9.95%. The mean results of sphericity ranged from 73.75 ± 0.10 to 92.43 ± 0.15%, respectively. The highest result was obtained on milky cream cultivar and the lowest result on black cultivar. The results are in line with the findings of Baryeh (2002) of 78.30 to 80.30% at a moisture content of 5.00 to 22.5%. Similarly, the works of Jain and Bal (1997) showed that sphericity ranged from 93.74 to 94.25% for PM cultivars (*babapuri*, *bajra* and GHB 30). The surface area mean results of this study varied from 5.73 ± 0.90 to 6.97 ± 0.94 mm^2 in which the highest result was obtained from brown cultivar and the lowest result from black cultivar. Similar results were obtained by Jain and Bal (1997) who reported 12.27 to 16.38 mm^2 for PM cultivars at moisture content of 7.4% while Adebowale et al. (2012) showed that the surface area of millet grain was 18.8 mm^2 at a moisture content of 10%. The mean sample volume of the samples studied varied from 1.07 ± 0.06 to 0.82 ± 1.12 mm^3, respectively. The highest result was obtained from brown cultivar and lowest results from black cultivar. Jain and Bal (1997) had similar results which ranged from 3.79 to 5.79 mm^3 at a moisture content of 7.4%. Adebowale et al. (2012) found the volume of 5.56 mm^3 for millet grains at a moisture content of 10%. Milky cream cultivar was significantly higher ($p < 0.05$) than other cultivars for 1000 sample weight, bulk density, true density, aspect ratio and sphericity (Table 2).

The results for bulk density of grain cultivars were similar to those reported by Jain and Bal (1997) who studied 3 PM cultivars ranging from 830.0 to 866.1 kg/m^3. Goswami et al. (2015) also reported a bulk density ranging from 684.99 to 777.50 kg/m^3 on FM grains. Balasubramanian and Viswanathan (2010) obtained the same results ranging from 477.1 to 868.1 kg/m^3 at a moisture content of 11.1 to 25%. Milky cream was significantly higher ($p < 0.05$) as compared to other samples (Table 2). Bulk density is an essential factor that determines the grade and test weight of the grains during drying, storage

Table 3
Some functional properties of raw finger millet flour.

Functional properties	Finger millet grain flours			Pearl millet
	Milky cream	Brown	Black	
WAC (mL/g)	1.23[a] ± 0.06	1.03[c] ± 0.66	0.93[d] ± 0.06	1.13[b] ± 0.15
Bulk density (kg/m^3)	0.93[a] ± 0.02	0.91[b] ± 0.01	0.89[c] ± 0.01	0.89[c] ± 0.00
Dispersibility (%)	92.03[a] ± 0.38	84.73[d] ± 0.64	87.37[b] ± 0.15	87.27[c] ± 0.40
Viscosity, cold paste (cP)	5.00[c] ± 0.00	6.00[b] ± 0.00	5.00[c] ± 0.00	6.67[a] ± 0.58
Viscosity, cooked paste (cP)	57.67[d] ± 1.15	306.7[a] ± 3.51	288.3[b] ± 2.52	110.3[c] ± 2.52

The mean ± standard deviation, $n = 3$. Values followed by the same letters in the same row are not significantly different ($p > 0.05$). WAC – water absorption capacity.

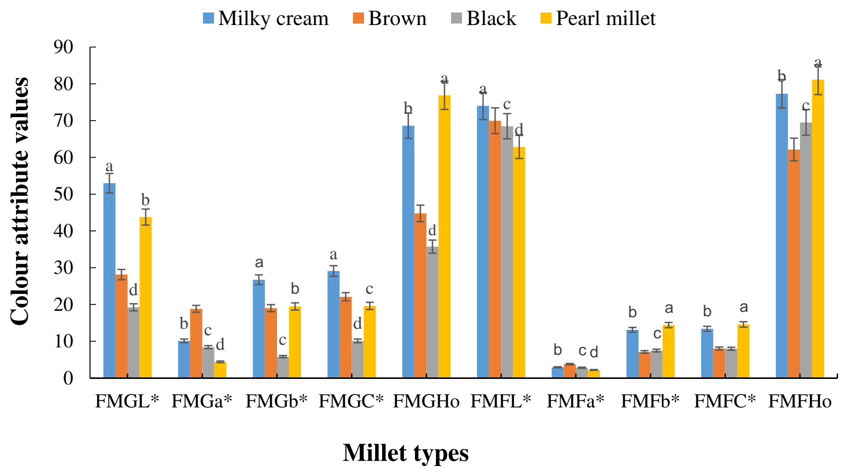

Fig. 3. Colour attributes of finger millet grains and flours. FMG = finger millet grain and FMF = finger millet flour. Error bars indicates the standard deviations what and letters a-d indicates significant difference.

and processing (Adebowale et al., 2012). Bulk density results will help in storage and processing because the size and shape of the grains were similar thus indicating high quality and better production of grains into flours. Table 3 shows the results of functional properties on FM flours such as bulk density, water absorption capacity, dispersibility, viscosity and micro-structure. The results of bulk density (BD) were highest on FM milky cream (0.93 ± 0.02 g/mL) and lowest on black flour (0.89 ± 0.01 g/mL). Milky cream flour indicated a significant difference ($p < 0.05$) higher as compared to brown and black.

Similar findings were observed by Dharmaraj, Meera, Yella Reddy, and Malleshi (2015) who reported the native, hydrothermally treated and decorticated FM whole meal and the values were as follows: 0.83, 0.77 and 0.80 g/mL. Mandge et al. (2014) reported that BD ranged from 1.30 to 1.47 g/mL for raw and cooked multigrain porridge. This is a reflection of the load the flour samples can carry if allowed to rest directly on one another. Akpata and Akubor (1999) reported that low BD of FM flour would be an advantage in the preparation of instant foods. Higher BD indicates that the flour can be used in food preparation while low BD flour is suitable to use in the preparation of weaning food formulation. Since black FM flour had the least BD, it can be used in the preparation of the complementary foods (Akpata & Akubor, 1999).

Water absorption capacity (WAC) of FM flours ranged from 0.93 ± 0.06 to 1.23 ± 0.06 mL/g where milky cream flour had the highest value and black flour with the lowest value. Milky cream showed a higher significant difference ($p < 0.05$) in WAC as compared to other FM samples. The results of WAC were similar to findings of Olapade et al. (2014) who studied cassava – bambara flours with WAC values ranging between 114 and 251%. The WAC of flour or isolate is a useful indicator for determining if the flour can be incorporated into aqueous food formulations, especially those involving dough handling. Lower WAC is suitable for making thinner gruels and also indicates the amount of water available for gelatinisation (Giami, 1993). Adebowale, Adegoke, Sanni, Adegunwa, and Fetuga (2012) mentioned that high WAC values indicate loose structure of starch polymers while low values indicate the compactness of the structure.

The dispersibility (%) of FM flour was higher on milky cream FM (92.03 ± 0.38) while lower values were obtained from brown sample (84.73 ± 0.64). Milky cream FM were significantly different in dispersibility as compared to brown and black flours. The findings of this study were similar to those by Olapade et al. (2014) who reported dispersibility ranging from 68 to 70.67% in cassava-bambara flours. According to Olapade et al. (2014), the values of dispersibility may help produce fine constituent dough during mixing.

The cold viscosity paste of the flour samples ranged from 5.00 ± 0.00 to 6.00 ± 0.00 cP while cooked viscosity ranged from 57.67 ± 1.15 to 306.7 ± 3.51 cP, respectively. Brown flour for cold and cooked paste were significantly higher ($p < 0.05$) as compared to milky cream and black FM flours. These results are similar to those of Dharmaraj et al. (2015) who studied the cold and cooked viscosity pastes of native, hydrothermal and decorticated FM. Dharmaraj et al. (2015) indicated that cold viscosity paste not measured on native FM but measured on hydrothermally treated and decorticated FM were 11 and 22 cP. The PM flour varied significantly in cold viscosity compared to other FM flours with the highest value of 6.67 cP. Cooked viscosity pastes of native, hydrothermally treated and decorticated FM were 1717, 350 and 463 cP. On FM seed coat, Krishnan et al. (2011) obtained results ranging from 12.0 to 21.0 cP for cold viscosity paste while the cooked viscosity ranged from 48.0 to 248.0 cP. This showed that it contained unprocessed carbohydrates. These low molecular weight carbohydrates contribute to reduced viscosity, possess less water-binding ability and may be more easily digested and absorbed as required by infants. Therefore, reduced viscosity is a good indicator for the appropriateness of a weaning food blend for infants (Usman, Bolade, & James, 2016).

3.4. Colour measurements

Fig. 3 shows the results of the colour measurements of grain samples as recorded in terms of the L*, a*, b*, C* and H° values. L* values ranged from 19.23 ± 0.42 for black to 52.97 ± 1.76 for milky cream grain cultivars. L* values of FM flours ranged from 68.47 ± 0.85 to 74.00 ± 0.62 (Fig. 3). Milky cream FM flour was significantly higher on L* values as compared to both brown and black grain/flour samples. This result is similar to that by Siwela et al. (2007) which ranged from 45.9 ± 0.9 to 68.4 ± 0.6 for FM grain type.

Positive values obtained for coordinates a* and b* were significantly different ($p < 0.05$) among samples and the a* values were 18.28 ± 0.81 for grain and 3.77 ± 0.06 for flour. Mean values for b* were 19.38 ± 0.15 for grain and 13.1. ± 0.20 for flour. The positive values for a* and b* coordinates indicate that all samples had varying concentration of red and yellow pigmentation in their grains. The control showed a significantly higher b* and c* values with the highest recorded values of 14.4 and 14.57, respectively.

The H° values ranged from 35.73° ± 1.06 to 68.63° ± 0.06, with the highest hue angle obtained from milky cream cultivar and the lowest hue angle from black cultivar for the grain cultivars. Therefore, H° values for FM flours varied from 62.13° ± 0.98 to 77.3° ± 0.36 where the highest hue angle was obtained from milky cream cultivar and the lowest hue angle from black cultivar. The H° values are measured as an angle of 0° - 360° with 0° representing red, 90° for yellow, 180° for green and 270° for blue. Hue angle is considered the qualitative attribute of colour and is based on colours which have been traditionally defined as reddish, greenish and others. The hue angle is most

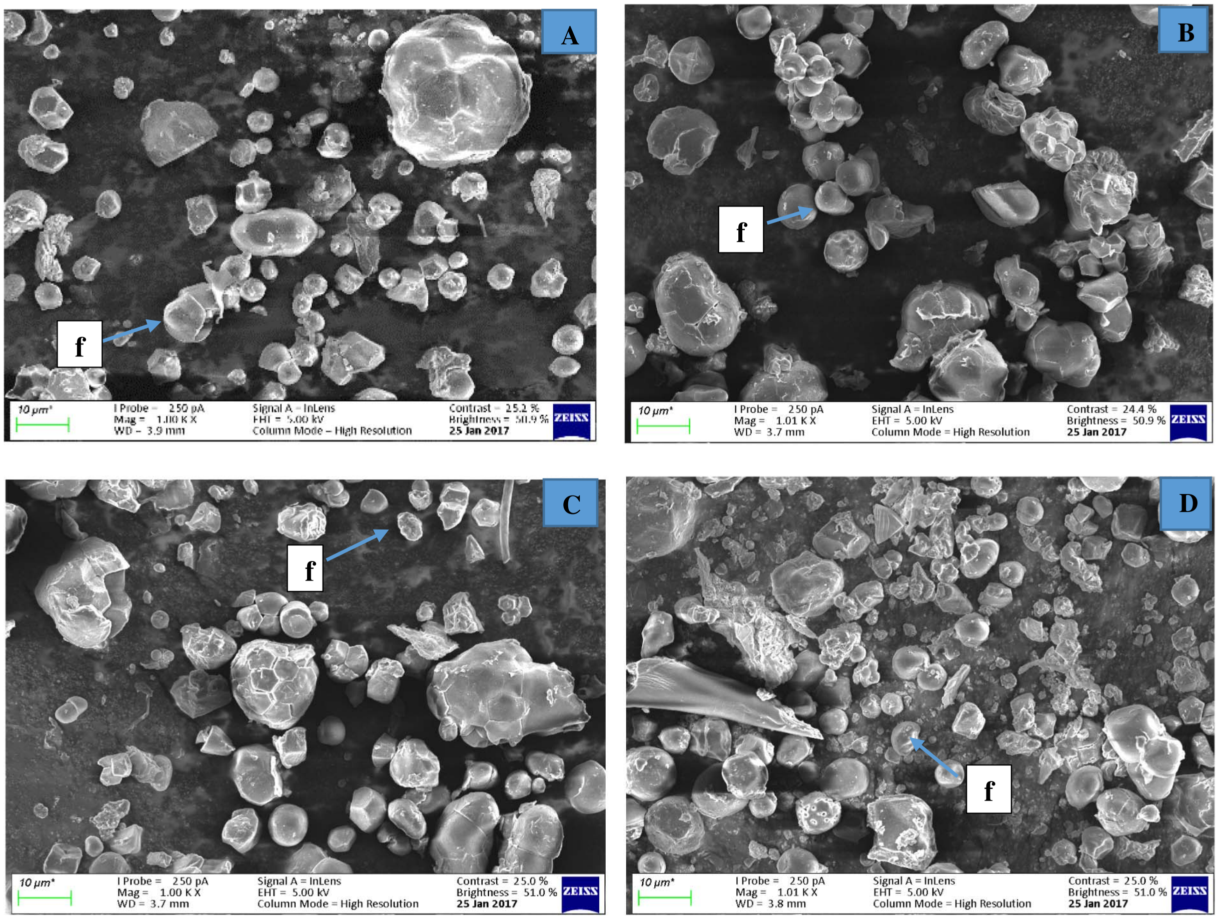

Fig. 4. Scanning electron microscopic structures of RFM flours: A = milky cream; B = brown; C = black and D = pearl millet. Scale bar 10 μm. Note: f –starch granules.

critical to humans with normal colour vision for perception and acceptability. Therefore, PM showed a significant difference on hue angle on both grain and flour with the highest value of 76.87 and 81.13.

The C* values for grain cultivars ranged from 10.1 ± 3.99 to 29.1 ± 2.03 while for FM flours, it varied from 13.4 ± 0.20 to 7.977.97 ± 0.23. Chroma increases with increasing pigment concentration and decreases as the sample becomes darker. Food samples can have similar hue angle and chroma, but will only be distinguished using their L* values (Wrolstad & Smith, 2010). The higher the chroma values, the higher the colour intensity of the grain samples perceived by humans. Colour is thus an essential quality parameter in the food processing industry and it attracts the consumer's choice and preferences (Pathare, Opara, & A-Said, 2013). Milky cream cultivar showed significance difference ($p < 0.05$) on L*, b*, C* and H^{o} values compared to both brown and black grain cultivars/flours (Fig. 3).

Similar results were also obtained by Krishnan et al. (2011) who reported FM seed coated with the L* ranging from 34.0 to 51.2, a* from 5.0 to 5.8 and b* ranging from 7.6 to 11.1. Mandge et al. (2014) reported the L-value of 53.6 for raw multigrain porridge and 41.6 for cooked multigrain porridge. Mean a* and b* values ranged from 5.0 to 5.8 and 15.8 to 18.4. The hue angle values correspond to whether the object is red, orange, yellow, blue or violet. The positive values in the hue angle of the samples show that the product does not deviate from the colour therefore adding a positive factor to the current study. This is because lightness and yellowness in the colour of flour are important factors in terms of consumer acceptance (Bhol & John Don Bosco, 2014). Bhol and John Don Bosco (2014) reported H$^{\circ}$ value of 67.24 and the chroma value was 14.48 for 20 g wheat/100 g malted FM. The findings of this study were similar to those by Siroha, Sandahu, and Kaur (2016) who studied 5 PM varieties whose values ranged from 52.5 to 75.1.

3.5. Scanning electron micrographs of FM flour

Fig. 4 shows the microscopic structure of FM starch granules which was at accelerating voltage of 5.000 kV. Milky cream, brown and black flours showed that the loosened starch granules had various shapes which were mainly isolated, oval/spherical or polygon and the smooth surface may be caused by soaking, drying and milling grain into FM whole meal flour. The control also showed the same features compared to FM flour.

Saleh et al. (2013) reported that the soaking technique improves the bioavailability of nutrients such as minerals. Milling process shows a negative impact on nutritional contents because protein, fat, ash and fibre contents were reduced but increased the digestibility/bioaccessibility of grains (Saleh et al., 2013). Sakhare, Inamdar, Soumya, Indrani, and Venkateswara Rao (2014) studied the micro-structure of wheat flour and reported that milling may cause starch granules to be viewed as damaged. Gorinstein et al. (2004) reported that milling of cereal grains also causes the microstructure changes in proteins and influences the fine microstructure to occur. Drying is a process that preserves grains and various essential characteristics of grains undergo changes during drying due to the loss of water from the inner structure and the surrounding surface. It was observed that physical characteristics of food may be altered during drying which are caused by changes in food microstructure (Sun, Gong, Li, & Xiong, 2014). Anyasi et al. (2017) reported the microstructures of unripe bananas whose shape became irregular in comparison to each cultivar. Therefore, PM grain/flour was used as control because most studies were conducted on physical and functional properties on various PM cultivars instead of FM grain/flour.

The results of PM helped in the verification of accuracy of the FM results.

4. Conclusion

Milky cream was significantly higher in moisture content, L*, b*, C*, WAC, bulk density, dispersibility, 1000 sample weight, true density, aspect ratio and sphericity among other FM grain and FM flour. Therefore, milky cream FM flour may be used by food processors for the development of the new food products that can also be consumed in urban areas especially by people who suffer from chronic diseases. Pearl millet cultivars were significantly different as compared to FM cultivars on all dimensional properties. The information from this study can be used by agricultural engineers, food engineers, food processors and food scientists. The information is potentially useful in the designing of equipment which is suitable for planting, harvesting, storage, processing and packaging of grains and flour. Moreover, the size and shape such as geometric mean diameter and sphericity properties of the FM grains need to be known by manufacturers as they contribute in designing better equipment suitable for grain and other food processing operations. Therefore, data obtained on the physical and functional properties of grains may measure the quality of grains used to produce fortified FM flour with zinc and vitamin B_2.

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References

AACC (2000). In D. E. Bruns (Ed.). *Official methods of analysis*(10th ed). St Paul, MN: American Association of Cereal Chemists.

Abdullah, M. H. R. O., Ch'ng, P. E., & Yunus, N. A. (2012). Some physical properties of musk lime (*Citrus Microcarpa*). *International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering, 6*(12), 1122–1125.

Adebowale, A. A., Adegoke, M. T., Sanni, S. A., Adegunwa, M. O., & Fetuga, G. O. (2012). Functional properties and biscuit making potentials of sorghum-wheat flour composite. *Journal of Food Technology, 7*(6), 372–379.

Adebowale, A. A., Fetuga, G. O., Apata, C. B., & Sannai, L. O. (2012). Effect of variety and initial moisture content on physical properties of improved millet grains. *Nigerian Food Journal, 30*(1), 5–10.

Akpata, M. L., & Akubor, P. I. (1999). Chemical composition and selected functional properties of sweet orange (*Citrus sinensis*) seed flour. *Plant Foods for Human Nutrition, 54*, 353–362.

Al-Mahasneh, M. A., & Rababah, T. M. (2007). Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering, 79*, 1467–1473.

Amadou, I., Mahamadou, E. G., & Le, G.-W. (2013). Millets, Nutritional composition, some health benefits and processing - A Review. *Food Science and Technology, 25*(7), 501–508.

Anyasi, T. A., Jideani, A. I. O., & Mchau, G. R. A. (2017). Effect of organic acid pretreatment on microstructure, functional and thermal properties of unripe banana flour. *Journal of Food Measurement and Characterization, 11*, 99–110.

Bachar, K., Imangour, E., Khaled, A. B., Abid, M., Haddad, M., Yahya, L. B., ... Ferchichi, A. (2013). Fibre content and mineral composition of the finger millet of the Oasis of Gabes of Tunisia. *Journal of Agricultural Science, 5*(2), 219–226.

Balasubramanian, S., & Viswanathan, R. (2010). Influence of moisture content on physical properties of minor millets. *Journal of Food Science, 47*(3), 279–284.

Baryeh, E. A. (2002). Physical properties millets. *Journal of Food Engineering, 51*, 39–46.

Bhattacharya, S., & Malleshi, N. G. (2012). Physical, chemical and nutritional characteristics of premature-processed and matured green legumes. *Journal of Food Science and Technology, 49*(4), 459–466.

Bhol, S., & John Don Bosco, S. (2014). Influence of malted finger and red kidney bean flour on quality characteristics of developed bread. *LWT - Food Science and Technology, 55*, 294–300.

Dharmaraj, U., Meera, M. S., Yella Reddy, S. Y., & Malleshi, N. G. (2015). Influence of hydrothermal processing on functional properties and grain morphology of finger millet. *Journal of Food Science and Technology, 52*(3), 1361–1371.

Faleye, T., Atere, A. O., Oladipo, O. N., & Agaja, M. O. (2013). Determination of some physical and mechanical properties of some cowpea varieties. *African Journal of Agricultural Research, 8*(49), 6485–6487.

Giami, S. Y. (1993). Effect of processing on the proximate composition and functional properties of cowpea (*Vigna unquiculata*) flour. *Food Chemistry, 47*, 153–158.

Gorinstein, S., Pawlzik, E., Delgado-Licon, E., Yamamoto, K., Kobayashi, S., Taniguchi, H., ... Trakhtengerg, S. (2004). Use of scanning electron microscopy to indicate the similarities and differences in pseudocereal and cereal proteins. *International Journal of Food Science and Technology, 39*, 183–189.

Goswami, D., Manikantan, M. R., Gupta, R. K., & Vishwakarma, R. K. (2015). Moisture dependent selected postharvest engineering properties of *ragi* (*Eleusine coracana*) grown in Northern Hills of India. *Journal of Postharvest Technology, 3*(3), 082–088.

Gull, A., Kmalesh, P., & Kumar, P. (2015). Optimisation and functionality of millet supplemented pasta. *Food Science and Technology, 35*(4), 626–632.

Hamdani, A., Rather, S. A., Shah, A., Gani, A., Wani, S. M., Masoodi, F. A., & Gani, A. (2014). Physical properties of barley and oats cultivars grown in high altitude Himalayan regions of India. *Journal of Food Measurement and Characterization, 8*, 296–304.

Jain, R. K., & Bal, S. (1997). Properties of pearl millet. *Journal of Agricultural Engineering Research, 66*, 85–91.

Jideani, I. A. (2012). *Digitaria exilis* (*acha/fonio*), *Digitaria iburua* (*iburu/fonio*) and *Eleusine coracana* (*tamba/*finger millet) - Non-conventional cereal grains with potentials. *Scientific Review and Essays, 7*(45), 3834–3843.

Jideani, I. A., & Jideani, V. A. (2011). Developments on the cereal grains *Digitaria exilis* (*acha*) and *Digitaria iburua* (*iburu*). *Journal of Food Science and Technology, 48*(3), 251–259.

Jideani, I. A., Takeda, Y., & Hizukuri, S. (1996). Structures and physiochemical properties of *acha* (*Digitaria exilis*), *iburu* (*D. iburua*) and *tamba* (*Eleusine coracana*). *Cereal Chemistry, 73*(6), 77–685.

Karababa, E., & Coşkuner, Y. (2013). Physical properties of carob bean (*Ceratonia siliqua* L.): An industrial gum yielding crop. *Industrial Crops and Products, 42*, 440–446.

Kibar, B., & Kibar, H. (2017). Determination of the nutritional and seed properties of some wild edible plants consumed as vegetable in the Middle black sea region of Turkey. *South African Journal of Botany, 108*, 117–125.

Krishnan, R., Dharmaraj, U., Sai Manohar, R., & Malleshi, N. G. (2011). Quality characteristics of biscuits prepared from finger millet seed coat based composite flour. *Food Chemistry, 129*, 499–506.

Kumari, N., & Raghuvanshi, R. S. (2015). Physico-chemical and functional properties of buckwheat (*Fagopyrum esculentum* Moench). *Journal of Eco-friendly Agriculture, 10*(1), 77–81.

Mandge, H. M., Sharma, S., & Dar, B. N. (2014). Instant multigrain porridge: effect of cooking treatment on physicochemical and functional properties. *Journal of Food Science and Technology, 51*(1), 97–103.

Mariotti, M., Alamprese, C., Pagani, M. A., & Lucisano, M. (2006). Effect of puffing on ultrastructure and physical characteristics of cereal grains and flours. *Journal of Cereal Science, 43*, 47–56.

Markowski, M., Zuk-Gołaszewska, K., & Kwiatkowski, D. (2013). Influence of variety on selected physical and mechanical properties of wheat. *Industrial Crops and Products, 47*, 113–117.

Mpotokwane, S. M., Gaditlhatlhelwe, E., Sebaka, A., & Jideani, V. A. (2008). Physical properties of Bambara groundnuts from Botswana. *Journal of Food Engineering, 89*, 93–98.

Muthamilarasan, M., Dhaka, A., Yadav, R., & Prasad, M. (2016). Exploration of millet models for developing nutrient rich *graminaceous* crops. *Plant Science, 242*, 89–97.

Olapade, A. A., Babalola, Y. O., & Aworth, O. C. (2014). Quality attributes of *fufu* (fermented cassava) flour supplemented with bambara flour. *International Food Research Journal, 21*(5), 2025–2032.

Pathare, P. B., Opara, U. L., & A-Said, F. A. (2013). Color measurement and analysis in fresh and processed foods: A Review. *Food and Bioprocess Technology, 6*, 36–60.

Poutanen, K. (2012). Past and future of cereal grains as food for health. *Trends in Food Science and Technology, 25*, 58–62.

Sakhare, S. D., Inamdar, A. A., Soumya, C., Indrani, D., & Venkateswara Rao, G. (2014). Effect of flour particle size on microstructural, rheological and physico-sensory characteristics of bread and south Indian parotta. *Journal of Food Science and Technology, 51*(12), 4108–4113.

Saleh, S. M., Zhang, Q., Chen, J., & Shen, Q. (2013). Millet grains, Nutritional quality, processing and potential health benefits. *Comprehensive Reviews in Food Science and Technology, 12*, 281–295.

Sangamithra, A., Swamy, G. J., Sorna, P. R., Nandini, K., Kannan, K., Sasikala, S., & Suganya, P. (2016). Moisture dependent physical properties of maize kernels. *International Food Research Journal, 23*(1), 109–115.

Sawant, A. A., Thakor, N. J., Swami, S. B., & Divate, A. D. (2013). Physical and sensory characteristics of ready-to-eat food prepared from finger millet based composite mixer by extrusion. *Agricultural Engineering International Journal, 15*(1), 100–105.

Shiihii, S. U., Musa, H., Bhati, P. G., & Martins, E. (2011). Evaluation of physicochemical properties of *Eleusine coracana* starch. *Nigerian Journal of Pharmaceutical Sciences, 10*(1), 91–102.

Siroha, A. K., Sandahu, K. S., & Kaur, M. (2016). Physicochemical, functional and antioxidant properties of flour from pearl millet varieties grown in India. *Journal of Food Measurement and Characterization, 10*, 311–318.

Siwela, M., Taylor, J. N. R., de Milliano, W. A. J., & Doudu, K. G. (2010). Influence of phenolics in finger millet on grains and malt fungal load, and malt quality. *Food Chemistry, 121*, 443–449.

Siwela, M., Taylor, J. R. N., de Milliano, W. A. J., & Doudu, K. G. (2007). Occurrence and location of tannins in finger millet grain and antioxidant activity of different grain type. *Cereal Chemistry, 84*(2), 169–174.

Sun, Q., Gong, M., Li, Y., & Xiong, L. (2014). Effect of dry heat treatment on the physicochemical properties and structure of proso millet flour and starch. *Carbohydrate Polymers, 110*, 128–134.

Takhellambam, R. D., Chimmand, B. V., & Prkasam, J. N. (2016). Ready-to-cook millet flakes based on minor millets for modern consumer. *Journal of Food Science and*

Technology, 53(2), 1312–1318.
Thilagavathi, T., Kanchana, S., Banumathi, P., Hemalatha, G., Vanniarajani, C., Sundar, M., & Ilamaran, M. (2015). Physico-chemical and functional characteristics of selected millets and pulses. *Indian Journal of Science and Technology, 8*(S7), 147–155.
Upadhyaya, H. D., Ramesh, S., Sharma, S., Singh, S. K., Varshney, S. K., Sarma, N. D. R. K., ... Singh, S. (2011). Genetic diversity for grains nutrients contents in a core collection of finger millet, *Eleusine coracana* L. germpalsm. *Field Crops Research, 121*, 42–52.
Usman, M. A., Bolade, M. K., & James, S. (2016). Functional properties of weaning food blends from selected sorghum [Sorghum bicolor (L.) Moench] varieties and soybean (*Glycine max*). *African Journal of Food Science, 10*(8), 112–121.
Vadivoo, A. S., Joseph, R., & Ganesan, N. M. (1998). Genetic variability and diversity for protein and calcium contents in finger millet [*Eleusine coracana* (L.) Gaertn] in relation to grains color. *Plant Foods for Human Nutrition, 52*, 353–364.
Vanrnamkhasti, M. G., Mobli, H., Jafari, A., Keyhani, A. R., Soltanabadi, M. H., Rafiee, S., & Kheiralopour, K. (2008). Some physical properties of rough rice (*Oryza sativa* L.) grain. *Journal of Cereal Science, 47*, 496–501.
Verma, V., & Patel, S. (2013). Value added products from nutri-cereals, Finger millet (*Eleusine coracana*). *Emirates Journal of Food Agriculture, 25*(3), 169–176.
Wrolstad, R. E., & Smith, D. E. (2010). Colour analysis. In S. S. Nielsen (Ed.). *Food analysis* (pp. 573–586). New York: Springer Science + Business Media. https://doi.org/10.1007/978-1-4419-1478-1.
Zewdu, A. D., & Solomon, W. K. (2007). Moisture-dependent physical properties of teff seed. *Biosystems Engineering, 96*(1), 57–63.