PHYSICAL AND FUNCTIONAL PROPERTIES OF TRADITIONAL MILLET CULTIVARS (*ELEUSINE CORACANA* L.)

K.DIVYA [1] , A.KARPAGA VALLI[2], G.LAVANYA[3], J.ISHWARYA[4]
1. Research scholar, PG & research Department, Department of Microbiology, Kamban college of Arts and Science for women, Tiruvannamalai. – 606603.
2,3,4. Assistant Professor Research scholar, PG & research Department, Department of Microbiology,Kamban college of Arts and Science for women, Tiruvannamalai. -606603.

ABSTRACT

The Millets are grown in warm weather belonging to the grass family (Poaceae). The most commonly cultivated millets are Finger millet (Eleusine coracana), Proso millet (Panicum miliaceum), Little millet (Panicum sumatrense), Sonoran millet (Panicum sonorum), Pear millet (Pennisetum glaucum), Brown top millet (Brachiaria ramosa), like this many have been present in Tamil Nadu, and Karnataka. Many variety of millets has been spreads into world wide such places are East Asia, South Asia, West Africa, and East Africa. The millets are rich in protein, fibre, vitamins and minerals. Widely millets have been consumed by humans for about 7,000 years and potentially yield a role of multi-crop agriculture and settled in farming societies. The four types of traditional finger millet cultivars has been analysed for moisture content on wet basis, the millets are Milky cream millet, Brown millet, Black millet, Pearl millet. The characterization of powdery particles can be viewed by using SEM. Physical and dimensional properties has been carried out, Arithmetic mean, Geometric mean, Equivalent diameter, Aspect ratio, Sphericity and Surface area and the results were analyzed by applying the Duncan Multiple Range test (DMRT) procedure using ANOVA. All these dimensions and analysis show the quality of grains used to produce fortified FM flour with Zinc and Vitamins. Keywords: Finger millet, Moisture content, Dimensions.

INTRODUCTION

Divergence in the rice grain quality represents its economic value and has also a fundamental role in popularity of traditional cuisine or intensifies significant candidate adoption from commercial varieties. Physical characteristics, cooking, sensory and engineering properties, textural and nutritional profiles comprise the major grain qualities. Each quality traits or characteristic traits would be valued by the preference of the consumers, which differs according to their traditional cooking habits and culture (Fitzgerald, McCouch, & Hall, 2009). Grain quality indicators such as kernel elongation and length/breadth ratio have essential characteristics in the food industry and consumer preference. Genotypic or varietal differences among the millet varieties aids in increasing the costumers‟‟ satisfaction and admiration of the specific rice variety, and the knowledge familiarity of physical properties of grain materials is also convenient for designing suitable technologies for grain processing operations such as sorting, drying, heating, cooling, milling, and optimization associated with each specific variety (Mir, Bosco, & Sunooj, 2013).

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). Although a gluten- free grain with low- glycemic index with nutritional and nutraceutical advantages, FM is neglected and underutilized (Amadou, Mahamadou, & Le, 2013). Finger millet belongs to the family Poaceae and originated in Ethiopia (Shiihii, Musa, Bhati, & Martins, 2011) before reaching India. In terms of production in semiarid regions, FM ranks fourth after sorghum, PM and foxtail millet (Shiihii 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, 2011).

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 (2011), 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 (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). Starches 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 (Verma & Patel, 2013).

FM grains are found in different shapes, sizes and colours with the predominant colour being brown. The physical properties of cereal grains include moisture content, 1000 sample weight, bulk density, true density, porosity, aspect ratio, sample 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 cerealgrains such as, wheat, rough rice and maize, when compared to millets, such as FM, foxtail millet, little millet, kodo millet, common millet and banyard millet. Studies have also been conducted on legumes such as cowpea seeds, soy bean and bambara groundnuts (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 organolepticproperties 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).

MATERIALS AND METHODS

Plant material - Sorting of finger millet grains

The mixed grain cultivars kernels were collected from the traditional finger millets (FM) cultivating farmers in November, 2019 in and around Namakkal and Salem District, Tamil Nadu, India. The samples were collected from different farmers, to sustain average sample quality of each variety (in average amount of 700 g). 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.

Fig.1 Finger millet grain cultivars: A = 80% milky creamy, B=85% black, C= 97% brown and D=pearl millet.

Cultivar samples were cleaned from small particles (as stones and dried weeds) and kept in closed plastic bags in room temperature till the laboratory tests. Only good quality finger millet grains were used for the analysis, and each measurement was taken in required number of repetitions to ensure significant result. The physical analysis was carried out in the Laboratory of Plant biotechnology, PG and Research, Department of Biotechnology (DST-FIST funded), Mahendra Arts and Science College (Autonomous), Namakkal, India between November, 2019 and March, 2020.

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, 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.

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).

Moisture content on wet basis

The moisture content (%) was determined with hot air oven drier using the method 44–

15.02 (AACC, 2000) using following equation. 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 (%) were calculated thus:

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

where: W1 = weight of empty crucible, W2 = weight of crucible + flour before drying,W3 = weight of crucible + flour after drying

Physical and Dimensional Properties

Length, width and thickness

The length L (mm), width W (mm), and thickness T (mm) of the rice kernels were determined by use of Vernier caliper with accuracy of 0.01 mm. FM kernels were randomly selected, and each of their dimension was measured and recorded 20 times on each cultivar.

Arithmetic mean diameter

The arithmetic mean diameter (mm) of the sample was obtained using the methods ofMpotokwane et al. (2008). Arithmetic mean diameter was calculated from the dimensional values using the following equation,

Geometric mean diameter

The geometric mean diameter (mm) was determined based on the measured dimensionsof FM

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

samples using equation given by Mpotokwane et al., (2008).

Geometric mean diameter (Dg) is equivalent to $(L \times W \times T)^{1/3}$

Aspect ratio

The aspect ratio *Ra* (−) was calculated using formula (Varnamkhasti et al., 2008):

$$R_2 = \frac{W}{L}$$

Sphericity

The sphericity of rice *φ* (−), was defined by the formula mentioned by Mohsenin (1986):

$$\varphi = \frac{(L \times W \times T)^{1/3}}{L}$$

Breadth and Surface area

For calculation of surface area S (mm^2) were used previously recorded variables length, width, and thickness. The formula for surface area was described by Mohsenin (1986) and Jain and Bal (1997) as the following:

where $B = (W \times T)^{1/2}$ (mm) is a function of width and thickness. Ratio between length and breadth also calculated.

Volume

$$S = \frac{\pi \times B \times L^2}{2 \times L - B}$$

Volume of grain V (mm^3) was calculated by the formula mentioned by Jain and Bal (1997) as following:

Scanning Electron Microscopy (SEM)

$$V = \frac{1}{4} \times \left[(\pi/6) \times L \times (W \times T)^2\right]$$

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).

Statistical analysis

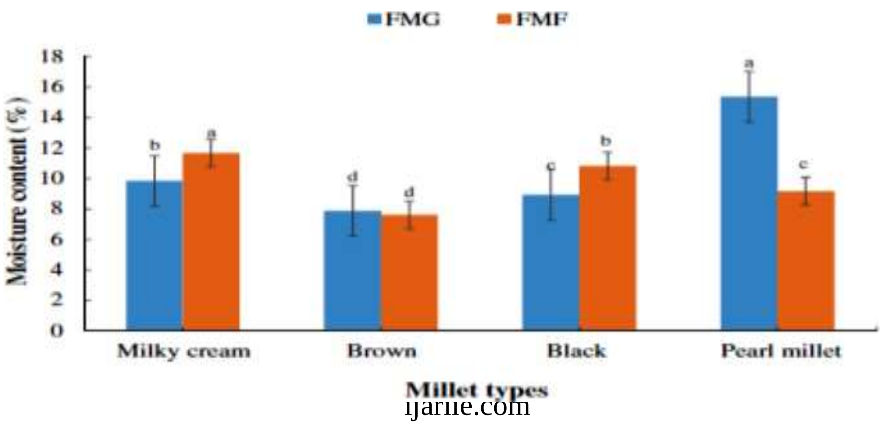
All the experiments were carried out in triplicate and tabulated as mean, standard error (SE). The replications in each individual analysis were done 10 times for each cultivar. The Pearson"s correlation coefficient was used to assess the interrelationship among various quality parameters. The results were analyzed by applying the Duncan Multiple Range test (DMRT) procedure using Analysis of Variance ANOVA. Difference between means was declared statistically significant at $p > 0.05$. Principal component analysis (PCA) was performed to classify the rice cultivars with different physicochemical and cooking characteristics by using SPSS 21.0 version.

RESULTS AND DISCUSSION

Moisture content of finger millet grains and flour

The results of the mean moisture content (MC) of the FM grain cultivar were 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 was within the specified percentage of< 12% as shown in the work of Saleh et al. (2013).

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.

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.

Dimensional properties of finger millet cultivars

The mean results of the length, width and thickness of the three cultivars were measured using vernier 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).

Table 1 Dimensional properties of finger millet 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 significantlydifferent ($p < 0.05$).

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 from2.85 ± 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.Physical and functional properties of finger millet grain cultivars/floursThe 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 mm2 in which the highest result was obtained from brown cultivar and the lowest result from black cultivar.

Table 2 Some physical properties of finger millet grain cultivars.

Physical properties	Milky creamy	Brown	Black	Pearl millet
Aspect ratio (%)	$92.21^{a} \pm 0.83$	$88.3^{b} \pm 0.55$	$73.55^{c} \pm 0.23$	$87.81^{b} \pm 0.92$
Sphericity (%)	$92.43^{a} \pm 0.15$	$83.21^{b} \pm 0.08$	$73.75^{c} \pm 0.10$	$64.17^{d} \pm 0.16$
Surface area (mm^2)	$5.81^{a} \pm 0.82$	$6.97^{b} \pm 0.94$	$5.73^{c} \pm 0.90$	$24.81^{a} \pm 1.41$
Volume (mm^3)	$0.86^{a} \pm 0.02$	$1.07^{b} \pm 0.06$	$0.82^{c} \pm 0.16$	$3.59^{a} \pm 1.12$

The mean ± standard deviation, n =5. Values followed by the same letters in the same row arenot significantly different ($p < 0.05$). PM - control

Similar results were obtained by Jain and Bal (1997) who reported 12.27 to 16.38 mm2 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 mm2 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 mm3, 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 mm3 at a moisture content of 7.4%. Adebowale et al. (2012) found the volume of 5.56 mm3 for millet grains at a moisture content of 10%. Milky cream cultivar was significantly higher ($p < 0.05$) than other cultivars for aspect ratio and sphericity (Table 2).

Scanning electron micrographs of FM flour

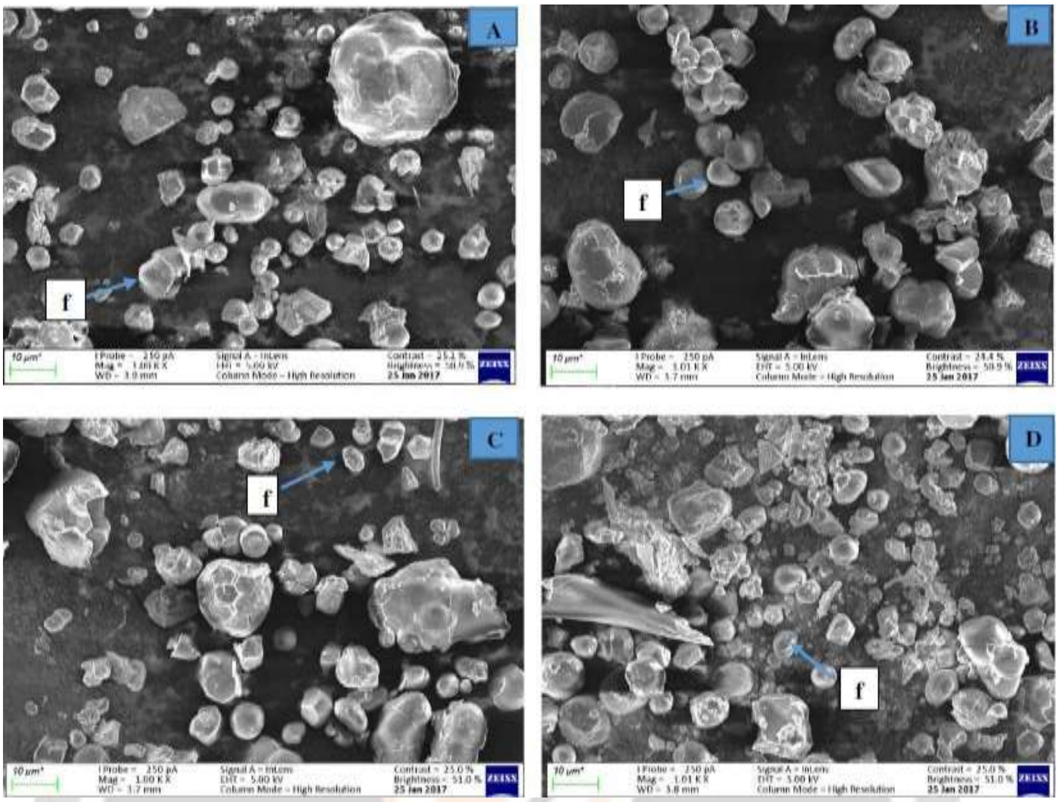


Fig. 3 Scanning electron microscopic structures of RFM flours : A = milky cream; B =brown;C= black and D= pearl millet. Scale bar 10 μm. Note: f –starch granules.

Fig. 3 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.

SUMMARY AND CONCLUSION

Milky cream was significantly higher in moisture content, 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 B2.

REFERENCES

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.

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 pretreatmenton 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.

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

Beddington, J. (2010). Food security: contributions from science to a new and greener revolution. *Philos. Trans. R. Soc. B. Biol. Sci.* 365, 61–71. doi: 10.1098/rstb.2009.0201

Chethan, S., and Malleshi, N. G. (2007). Finger millet polyphenols: optimization of extraction and the effect of pH on their stability. *Food Chem.* 105, 862–870. doi: 10.1016/j.foodchem.2007.02.012

Cline, W. R. (2007). *Global Warming and Agriculture: Impact Estimates by Country.* Washington, DC: Center for Global Development and Peterson Institute for international Economics.

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

FAO (2005). *The State of Food Insecurity in the World: Eradicating World Hunger – Key to Achieving the Millennium Development Goals.* Rome: FAO.

Fitzgerald, M. A., McCouch, S. R., & Hall, R. D. (2009). Not just a grain of rice: The quest for quality. [Review]. *Trends in Plant Science*, *14*(3), 133–139. https://doi.org/10.1016/j.tplants.2008.12.004

Ghadge PN, Prasad K (2012) Some Physical Properties of Rice Kernels: Variety PR-106. J Food Process Technol 3:175. doi:10.4172/2157- 7110.1000175

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., Jan, R., Nayik, G. A., Prasad, K., and Kumar, P. (2014). Significance of finger millet innutrition, health and value added products: a review. *J. Environ. Sci. Comput. Sci. Eng. Technol.* 3, 1601–1608.

Gupta, A. K., Gaur, V. S., Gupta, S., and Kumar, A. (2013). Nitrate signals determine the sensing of nitrogen through differential expression of genes involved in nitrogen uptake and assimilation in finger millet. *Funct. Integr. Genomics* 13, 179–190. doi: 10.1007/s10142-013-0311-x

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., & 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.

Kumar, A., Pathak, R. K., Gupta, S. M., Gaur, V. S., and Pandey, D. (2015). Systems biology for smart crops and agricultural innovation: filling the gaps between genotype and phenotype for complex traits linked with robust agricultural productivity and sustainability. *OMICS* 19, 581–601. doi: 10.1089/omi.2015.0106

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.

Lata, C. (2015). Advances in omics for enhancing abiotic stress tolerance in millets. *Proc. Indian Natl. Sci. Acad.* 81, 397–417.

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.

Meehl, G. A., Stocker, T. F., Collins, W. D., Friedlingstein, P., Gaye, A. T., Gregory, J. M., et al. (2007). "Global climate projections," in *Proceedings of the Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment*

Report of the Inter-governmental Panel on Climate Change, eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, et al. (Cambridge: Cambridge University Press), 749–844.

Mir, S. A., Bosco, S. J. D., & Sunooj, K. V. (2013). Evaluation of physical properties of rice cultivars grown in the temperate region of India.*International Food Research Journal*, *20*(4), 1521–1527.

Mohsenin NN (1986) Physical properties of plant and animal materials. Vol1 Physical characteristics and mechanical properties, Gordon and Breach Science Publishers, New York.

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.

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.

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.

Shukla, A., Lalit, A., Sharma, V., Vats, S., and Alam, A. (2015). pearl and finger millets: the hope of food security. Pearl and finger millets: the hope of food security. *Appl. Res. J.* 1, 59–66.

Singh, E., and Sarita (2016). Potential functional implications of finger millet (*Eleusine coracana*) in nutritional benefits, processing, health and diseases: a review. *Int. J. Home Sci.* 2, 151–155.

Stireman, J. O., Dyer, L. A., Janzen, D. H., Singer, M. S., Li, J. T., Marquis, R. J., et al. (2005). Climatic unpredictability and parasitism of caterpillars: implications of global warming. *Proc. Natl. Acad. Sci. U.S.A.* 102, 17384–17387. doi:10.1073/pnas.0508839102

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.

Vanrnamkhasti, M. G., Mobli, H., Jafari, A., Keyhani, A. R., Soltanabad i, 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.
Wang L, Xie B, Shi J, Xue S, Deng Q, Wei Y Tian B. 2010. Physicochemical properties and structure of starches from Chinese rice cultivars. Food Hydrocolloids 24:208–16.