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Assessment of Physical and functional properties of finger millet grain varieties

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Abstract
The current study aimed to determine the physical properties of finger millet (FM) cultivars (GPU-48, Indaf-7, ML-365, MR-1and MR-6). The moisture content; dimensional properties such as length, width, thickness, geometric mean diameter, and arithmetic mean diameter; physical properties such as one thousand (1000) sample weight, bulk density, true density, porosity, sphericity, aspect ratio, surface area, and sample volume; functional properties such as water absorption capacity (WAC), dispersibility, and viscosity were determined. Scanning electron microscopy (SEM) analysis of FM cultivar varieties were also evaluated. Results revealed that ML-365 cultivar was higher than other samples in moisture content, width, thickness, geometric mean diameter, arithmetic mean diameter, surface area and sample volume. Data showed that MR-6 was higher in viscosity cold paste and viscosity cooked paste than in other FM cultivars. SEM findings revealed that starch granules of raw FM flours had oval/spherical and smooth surface. In conclusion study findings are 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.

Keywords: Finger millet, physical properties**,** dimension properties, functional properties

Introduction
Millets are small seeded grasses that grow on dry zones as rain fed crops, under marginal conditions of soil fertility and moisture. Millets are one of the oldest foods known to humans and probably the first cereal grain to be used for domestic purposes. The millets can be classified broadly into two types for convenience namely, major and minor millets based on their seed size. Major millets include sorghum (*Sorghum vulgare*), finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*), while minor millets include little (*Panicum miliare*), proso (*Panicum miliaceum*), kodo (*Paspalum scrobiculatum*), Italianor foxtail (*Setaria italica*) and barnyard millet (*Echinochloa frumantacea*). Small millets are small grained cereals and are the staple food of the millions inhabiting the arid and semiarid tropics of the world. Millets are distributed in most of the Asian. Finger millet belongs to the family Poaceae and is more commonly known as ragi or madua in India, rapoko in South Africa and dagusa in Ethiopia [1, 2]. Globally, 12% of the total millet area is under finger millet cultivation, covering more than 25 countries of Africa and Asia [3]. It forms a predominant essential food for people living on marginal lands and with limited economic resources. An agronomically sustainable crop, it can grow on marginal lands, high altitudes and can easily withstand drought and saline conditions, requires little irrigation and other inputs and yet maintain optimum yields. From the nutritional perspective, finger millet is considerably rich in minerals and its micronutrient density is higher than that of the world’s major cereal grains; rice and wheat [4, 5]. A few varieties of finger millet are sporadically grown and consumed in some parts of India. Therefore, to make people aware about the quality parameters of these millets as compared to other cereal grains, the present study was designed with the following objective, *viz.*, to determine the moisture, physical and functional properties of the varieties of finger millet grains.

Materials and Methods
Sorting of finger millet grains
Mixed grain cultivars were purchased from Southern dry zone of Karnataka India. Foreign materials were removed from the grains by immersion in clean water. Finger millet varieties GPU-48, Indaf-7, ML-365, MR-1 and MR-6 were used.

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 and functional properties of FM flours such as WAC, BD, dispersibility and viscosity (cold and cooked paste) were performed in 5 replicates for each grain cultivar.

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 FM were milled into FM flour using 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 [6].

Moisture content on wet basis

The moisture content (%) was determined with hot air oven drier using the method 44–15. using below equation [7]. 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:

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

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

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 digital vernier caliper at an accuracy of 0.01 mm [8].

Geometric mean diameter

The geometric mean diameter (mm) was determined based on the measured dimensions of finger millet samples using below equation [8]. Geometric mean diameter (Dg) is equivalent to
$Dg = (L \times W \times T)^{1/3}$

Where,
L = length. W = width. T = thickness.

Arithmetic mean diameter

The arithmetic mean diameter (mm) of the sample was obtained using the methods of Mpotokwane, *et al.* 2008 [8] Arithmetic mean diameter was calculated from the dimensional values using below equation: Arithmetic mean diameter.

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

Where,
L = length.
W = width.
T = thickness.

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) [9].

Bulk density

Bulk density (kg/m^3) is described as the ratio of the mass of the sample to its total volume [10]. It was determined by filling a 500 mL cylinder with grains using method of Mariotti, Alamprese, Pagani, and Lucisano [11]. Bulk density (kg/ m^3) was calculated as a ratio between the sample weight and the volume of the cylinder using below equation:

$$\text{Bulk density} = \frac{\text{Sample weight}}{\text{Volume}}$$

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 below equation [12].

$$\text{True density} = \frac{30 \text{ g}}{V2\text{-}V1}$$

Where,
Pt = true density, V1 = initial volume and V2 = final volume.

Porosity

Porosity (%) is defined as the fraction of the space in bulk grain that is not occupied by the grain [9]. It was calculated using below equation from the true density and bulk density using method of Vanrnamkhasti *et al.*, 2008 [10].

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

Where
ε = porosity
Pt = true density
Pb = bulk density

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.* [13].

$$\Phi = \frac{(LWT)1/3}{L} \times 100$$

Where,
Φ = Sphericity.

Aspect ratio

The aspect ratio (%) was calculated using below equation, method of Vanrnamkhasti *et al*. 2008 [10] as follows:

$$\text{Aspect ratio} = \frac{\text{Width}}{\text{Length}} \times 100$$

Surface area

The surface area, mm^2 of three FM cultivars were calculated using below equation, method of Karababa & Coşkuner, 2013 [12]

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

Where,
$B = (WT)^{1/2}$

Sample volume

The volume (mm^3) of the grains was calculated Eq. (10), method of Karababa & Coşkuner 2013 [12].

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

W = width; L = length.

Water absorption capacity (WAC)

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 water bath at 30 °C for 30 min. The centrifuge tubes were centrifuged at 3000 rpm for 15 min. The supernatants were discarded and the residues were weighed. Two different weights of the centrifuge tubes gave water absorbance using below equation, method of Sawant *et al.* 2013 [14].

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

Where,

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

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 using below equation [15].
% Dispersibility = 100 - volume of settled particles

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 [16].

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) [37].

Results and Discussion

Moisture content of finger millet grains

Table 1 shows the results of the mean moisture content (%) of the FM grain varieties that ranged from 7.97±0.25 to 9.19±0.11%. ML-365 showed a higher moisture content than other FM varieties and least moisture content was observed in GPU-48. The results showed that the moisture content (%) were within the specified percentage of < 12% as shown in the work of Saleh *et al*. 2013 [6]. Moisture content is one of the important factors that govern the physical properties of grain [18]. It is also a good indicator as to whether the grains can be stored for a long or short period. According to Abdullah *et al*. 2012 [19] 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.

Table 1: Moisture Content of Finger Millet Grain Varieties

FM Varieties	Moisture (%)
GPU - 48	7.97±0.25
Indaf - 7	8.23±0.19
ML – 365	9.19±0.11
MR – 1	8.87±0.46
MR – 6	8.25±0.24

Values are expressed as Mean±S.D; n=5

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 1.55±0.01to 1.35±0.01 mm for length; 1.40±0.01 to 1.21±0.01 mm for width and 1.31±0.01 to 1.17±0.01 mm for thickness (Table 2). Length values were for Indaf-7 and width values and thickness for ML-365 were higher when compared with other samples. The geometric mean diameter ranged from 1.41±0.01 mm to 1.30±0.00 mm and arithmetic mean diameter from 1.41±0.01 mm to 1.30±0.01 mm. Similar observation was reported in other studies where the length, breadth and thickness of foxtail millet (*Setaria itatica*): variety-HMT 1001 were 2.17 mm, 1.59 mm and 1.45 mm respectively. The length, breadth, thickness and length/breadth ratio of whole grainkodo millet were found 2.61 mm, 1.96 mm, 1.33 mm and 1.33 mm respectively [20]. The geometric mean diameter and arithmetic mean diameter was also highest in ML-365 in the present study. Therefore, ML-365 grain showed a difference on all dimensions except for length studied as compared to other FM varieties.

Table 2: Dimensional Properties of Finger Millet Grain Varieties

Dimensions (mm)	GPU - 48	Indaf – 7	ML – 365	MR – 1	MR – 6
Length	1.50±0.01	1.55±0.01	1.52±0.01	1.35±0.01	1.53±0.01
Width	1.36±0.01	1.21±0.01	1.40±0.01	1.31±0.01	1.37±0.01
Thickness	1.29±0.01	1.17±0.01	1.31±0.01	1.23±0.01	1.30±0.01
Geometric mean Diameter	1.38±0.01	1.30±0.00	1.41±0.01	1.30±0.01	1.40±0.00
Arithmetic mean Diameter	1.38±0.01	1.31±0.00	1.41±0.01	1.30±0.01	1.40±0.00

Values are expressed as Mean±S.D; n=5

Physical and functional properties of finger millet grain cultivars/flours

The results of physical properties of FM grain varieties were represented in Table 3. The highest mean result for 1000 sample weight was obtained from Indaf-7, 691.00±12.02 g and the lowest mean result for 1000 sample weight was 456.20±2.14 g from ML-365. Vidhyavathi analyzed the physical characteristics of brown and white varieties of finger millet and found that in brown varieties thousand grain weight ranged from 2.2 to 3.1g, thousand seed volume ranged from 2.0 to 2.5 ml [21]. In a similar study, Thilagavathi *et al*. reported that maximum thousand grain weight was observed in pearl millet (11.39 g) followed by kodo millet (2.45 g) and little millet (2.23 g) [22]. The differences in the parameters of the present study might be due to differences in environmental conditions during plant development, the position in the panicle (the better developed grains are on the top of the panicle) and also the varietal differences. Results of analysis also showed that bulk density ranged from 963.00±2.83 to 1136.16±0.79 kg/m^3 respectively, with Indaf-7 showing the highest bulk density and GPU-48 showing the lowest bulk density. The difference of bulk densities may be due to the fact that it is influenced by many factors. Gaines *et al*. reported that rain causes grain kernels to swell but subsequent drying does not return some layers of the pericarp to their original pre-rain size, leaving some of the pericarp layers to exhibit a loose or puffed appearance [23]. These changes cause decrease of grain density and test weight, but do not influence the flour yield.

Indaf-7 FM cultivar had the highest true density of cultivar kg/m^3, followed by MR-1 which is the lowest cultivar 1475.40±0.49 kg/m^3. Various factors like moisture content, pest infestation, maturity etc. affects the density of grains. The mean porosity results varied from 22.99±0.04 to 35.06±0.25%. The highest percentage was found on GPU-48 with the lowest on MR-1 FM cultivar. A study by Zewdu and Solomon 2007 [24] 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 [25], porosity ranged from 45.1 to 48.8% for pearl millet cultivars (babapuri, bajra and GHB 30) at a moisture content of 7.4%. Balasubramanian and Viswanathan 2010 [26] obtained 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 sphericity ranged from 84.03±0.48 to 95.99±0.58% where MR-1 was found to have a highest percentage and lowest percentage on Indaf-7 cultivar.

The mean results of aspect ratio ranged from 78.33±0.79 to 96.75±1.08% where MR-1 was found to have a highest percentage and lowest percentage on Indaf-7 cultivar. Adebowale *et al*. 2012 [27] revealed that millet grains were found to have 59.62% aspect ratio at a moisture content of 10% and Markowski *et al*. 2013 [28] also reported the same results of 47.4% at a moisture content of 9.95% [27, 28]. 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 surface area means results of this study varied from 4.73±0.03 to 5.85±0.04 mm2 in which the highest result was obtained from ML-365 cultivar and the lowest result from Indaf-7 cultivar. Results were obtained by Jain and Bal 1997 [25] who reported 12.27 to 16.38 mm^2 for pearl millet cultivars at moisture content of 7.4% while Adebowale *et al*. 2012 [27] 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 1.32±0.01 to 0.94±0.01 mm^3, respectively. The highest result was obtained from ML-365 cultivar and lowest results from Indaf-7. Jain and Bal (1997) [25] ranged from 3.79 to 5.79 mm^3 at a moisture content of 7.4%. Adebowale *et al*. 2012 [27] found the volume of 5.56 mm^3 for millet grains at a moisture content of 10%. MR-1 cultivar showed higher bulk density, sphericity and aspect ratio, whereas ML-365 showed highest in surface area and in sample volume. Indaf-7 showed higher in 1000 sample weight and in true density, whereas GPU-48 showed highest in porosity. The results for bulk density of grain cultivars reported by Jain and Bal 1997 [25] who studied 3 pearl millet cultivars ranged from 830.0 to 866.1 kg/m^3. Goswami *et al*. 2015 [18] reported a bulk density ranging from 684.99 to 777.50 kg/m^3 on FM grains [18]. Balasubramanian and Viswanathan 2010 [26] obtained the results ranging from 477.1 to 868.1 kg/m^3 at a moisture content of 11.1 to 25%. Bulk density is an essential factor that determines the grade and test weight of the grains during drying, storage and processing [27]. 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 grains such as WAC, dispersibility, viscosity cold paste and viscosity cooked paste. The findings observed by Dharmaraj *et al*. 2015 [29] who reported that 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 [30] reported that Bulk density 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 [31] reported that low bulk density of FM flour would be an advantage in the preparation of instant foods. Higher bulk density indicates that the flour can be used in food preparation while low bulk desnity flour is suitable to use in the preparation of weaning food formulation. Since GPU-48 FM flour had the least bulk desnity, it can be used in the preparation of the complementary foods.

Table 3: Physical properties of finger millet grain varieties

Dimensions (mm)	GPU - 48	Indaf – 7	ML – 365	MR – 1	MR – 6
1000 Sample Weight (g)	465.40±1.62	691.00±12.02	456.20±2.14	554.00±3.29	461.40±2.24
Bulk Density (Kg/m^3)	963.00±2.83	1134.60±2.80	973.00±2.83	1136.16±0.79	981.00±2.83
True Density (Kg/m^3)	1482.80±1.60	1592.60±2.33	1479.80±1.60	1475.40±0.49	1477.80±1.60
Porosity (%)	35.06±0.25	28.76±0.26	34.25±0.25	22.99±0.04	33.62±0.25
Sphericity (%)	92.34±0.43	84.03±0.48	92.69±0.48	95.99±0.58	91.30±0.53
Aspect Ratio (%)	91.18±0.84	78.33±0.79	92.11±0.35	96.75±1.08	89.69±0.90
Surface Area (mm^2)	5.61±0.04	4.73±0.03	5.85±0.04	5.08±0.04	5.71±0.02
Sample Volume (mm^3)	1.24±0.01	0.94±0.01	1.32±0.01	1.08±0.01	1.27±0.01

Values are expressed as Mean±S.D; n=5

The results of functional properties of FM grain varieties was represented in Table 4. Water absorption capacity (WAC) of FM flours ranged from 0.90±0.01 to 1.14±0.03 mL/g where Indaf-7 had the highest value and MR-1 with the lowest value. Indaf-7 showed a higher difference in WAC as compared to other FM samples. The results of WAC findings of Olapade *et al*. 2014 [15] who studied cassava – bambara flours with WAC values ranged 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 gelatinization [32]. Adebowale *et al*. 2012 [27] 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 Indaf-7 FM (90.36±0.28) while lower values were obtained from brown sample (84.73±0.64). Milky cream FM were significantly different in dispersibility as compared to ML-365 FM cultivar. The findings by Olapade *et al*. 2014 [15] who reported dispersibility ranged from 68 to 70.67% in cassava-bambara flours. According to Olapade *et al*. 2014 [15] the values of dispersibility may help produce fine constituent dough during mixing. The cold viscosity paste of the FM samples ranged from 4.84±0.04 to 5.63±0.03 cP while cooked viscosity ranged from 75.12±0.48 to 289.01±0.48 cP, respectively. MR-6 for cold and cooked paste were as compared to other FM cultivars. These results are similar to those of Dharmaraj *et al*. 2015 [29] who studied the cold and cooked viscosity pastes of native, hydrothermal and decorticated FM. Dharmaraj *et al*. 2015 [29] indicated that cold viscosity paste not measured on native FM but measured on hydrothermally treated and decorticated FM were 11 and 22 cP. Cooked viscosity pastes of native, hydrothermally treated and decorticated FM were 1717, 350 and 463 cP. On FM seed coat, Krishnan *et al*. 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 [16]. 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 [33].

Table 4: Functional Properties of Finger Millet Grain Varieties

Dimensions (mm)	GPU - 48	Indaf – 7	ML – 365	MR – 1	MR – 6
WAC (mL/g)	1.02±0.02	1.14±0.03	1.01±0.01	0.90±0.01	1.00±0.02
Dispersibility (%)	80.27±0.20	90.36±0.28	82.19±0.16	86.30±0.17	83.25±0.15
Viscosity cold paste	5.54±0.07	5.03±0.03	5.42±0.02	4.84±0.04	5.63±0.03
Viscosity cooked paste	281.25±0.84	75.12±0.48	271.12±0.48	269.66±0.48	289.01±0.48

Values are expressed as Mean±S.D; n=5

Scanning electron micrographs of FM varieties

Figure 1 to 5 shows the SEM structures of Indaf-7, GPU-48, ML-365, MR-6 and MR-1. FM starch granules which were at accelerating voltage of 5.000 kV. Indaf-7, GPU-48, ML-365, MR-6 and MR-1 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. Saleh *et al*. 2013 [6] 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. Sakhare *et al*. 2014 [34] studied the micro-structure of wheat flour and reported that milling may cause starch granules to be viewed as damaged. Gorinstein *et al*. 2004 [35] 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 [36].

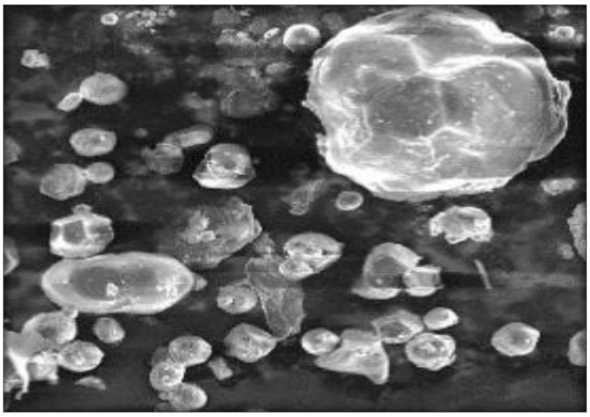

Fig 1: Showing scanning electron microscopic picture of Indaf-7

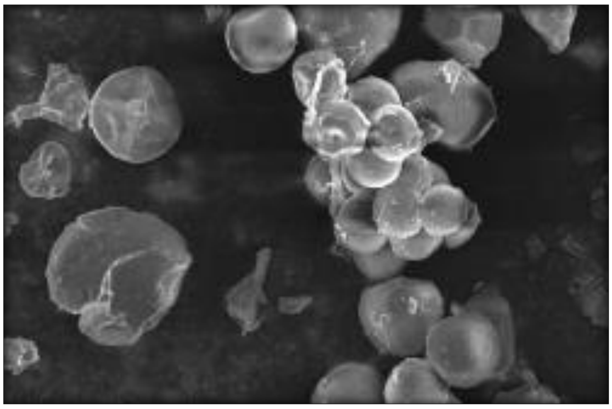

Fig 2: Showing scanning electron microscopic picture of GPU-48

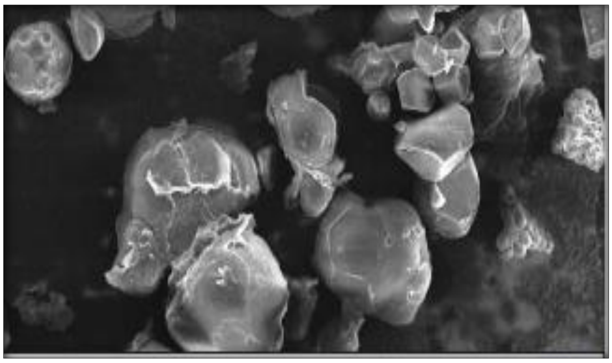

Fig 3: Showing scanning electron microscopic picture of ML-365

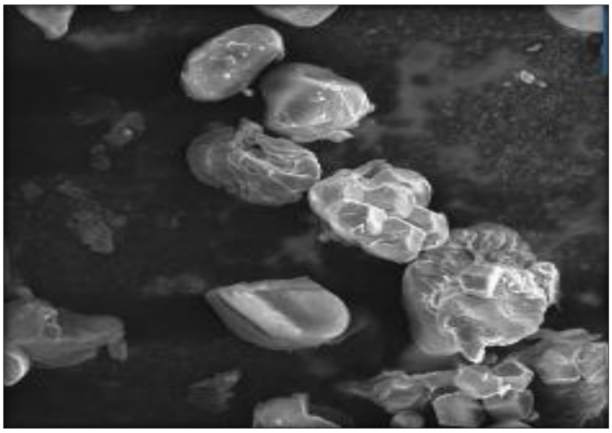

Fig 4: Showing scanning electron microscopic picture of MR-6

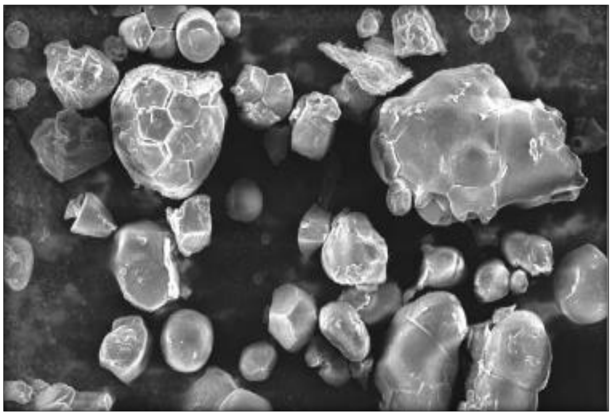

Fig 5: Showing scanning electron microscopic picture of MR-1

Conclusion
ML-365 was higher in moisture content, width, thickness, geometric mean diameter, arithmetic mean diameter, surface area and sample volume among other FM flour cultivar. Therefore, ML-365 FM cultivar 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. 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.

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