Eco. Env. & Cons. 30 (October Suppl. Issue) : 2024; pp. (S254-S266)
Copyright@ EM International
ISSN 0971–765X

DOI No. http://doi.org/10.53550/EEC.2024.v30i06s.039

Engineering properties of selected finger millet cultivars (*Eleusine corocana* L.) in three different forms of fresh, cooked and malted condition for development of value added products

P. Hemasankari*, B. Dayakar Rao[1], Avinash Singode, A. Srinivas[2], K. N. Ganapathi[3] and C. Tara Sathyavathi[4]

***ICAR-IIMR, Telangana, India**
[1]Agril. Economics, ICAR-IIMR, Telangana, Hyderabad 500 030, India
[2]ICAR-IIMR, Telangana, Hyderabad 500 030, India
[3]Pl. Breeding), ICAR-IIMR, Telangana, Hyderabad 500 030, India
[4]ICAR-IIMR, Telangana, Hyderabad 500 030, India

(Received 16 March, 2024; Accepted 24 May, 2024)

ABSTRACT

Finger millets are grown for their nutritional significance and are subjected to processing for making value added products. Physical properties are used for design and development of machineries for cleaning, grading, dehulling, conveying and polishing. The finger millet cultivars are obtained after harvest from ICAR-IIMR field and tested for its moisture content at wet basis (%) using Indosaw moisture meter. The physical properties of selected 7 cultivars of finger millet (*Eleusine corocana* L.), CFMV-2, KMR-204, Suvarnamukhi, Vegavathi, PR-204, Dhalamandia and Bhalumandia were tested for its physical properties like moisture content,% wet basis, length, width, thickness, sphericity, aspect ratio, volume, frontal area, different diameters, geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent mean diameter, shape factor, 1000 grain weight, bulk density, true density porosity, angle of repose and coefficient of friction parameters. The moisture content in wet basis of the cultivars ranges from 13.8% to 16.3%±0.32. The importance of length, width and thickness decides the aperture size of the machine in separation process of materials. The length, width and thickness ranges from 1.5-1.92mm±0.02, 1.42-1.75 mm±0.05 and 1.26-1.56m±0.06. Finger millet gains significance among all millets because of its calcium content that is more than in rice and wheat. The fresh finger millet after harvest was obtained from the field of ICAR-IIMR and was subjected to soaking and then cooking. Water uptake ratio ranged between 1.40-1.60±0.03. The grains with higher bulk density exhibit slow water uptake and thus result in longer cooking periods. Hydration capacity ranged between 21.64-82.32±41.53. Hydration index ranged between 0.87-3.29±1.66. Swelling capacity ranged between 13.51-44.44±3.89. Swelling index ranged between 0.42-1.48 ±0.73. More the swelling power of the grain less is the nutrient density. 1000 kernel density ranged between 708.74-1150 ± 70.98. Percentage increase in weight of the cooked millet is 2.06-3.84± 0.23. Percentage increase in volume is 0.14-0.44±0.04. Generally the grain in the malted form is expected to be more nutritious than that of the ordinary grain. The grain moisture content before malting ranges in between 13.8-16.3%wb. Values were the result of two replications and tested for 5% level of significance. ($p \leq 0.05$). The values were tested for its significance using SPSS 16.0 version. Three dimensional graphs were drawn using Design Expert Software version 12.0.

(*Scientist (ss)(AS&PE), [1]Principal Scientist, Senior Scientist(Pl. Breeding), [2]Scientist (ss)(Extn.), [3]Principal Scientist, [4]Director)

Key words: *Engineering properties, Finger millets, Value added products*

Introduction

Finger millets are grown for their nutritional significance and are subjected to processing for making value added product. Physical properties are used for design and development of machineries for cleaning, grading, dehulling, conveying and polishing. This study helps in finger millet processing for achieving more nutritional and healthy diet to the future needs of the nation. Finger millet gains significance among all millets because of its calcium content that is more than in rice and wheat. This study is much needed for selection of better finger millet variety with better cooking qualities to reassure the nutritional security of both farmers and consumers for the crop to be grown in a particular area. Finger millets are grown in different areas for its nutritional significance. Generally the grain in the malted form is expected to be more nutritious than that of the ordinary grain. Finger millets are grown in different areas for its nutritional significance. Though very small in size it contributes much needed calcium and other nutrients for the nourishing mother and for the younger generation for the growth of bones and teeth. Finger millet one of the major millet has rich amount of dietary fibre and calcium. It is a poor man's crop and it satisfies the hunger of the physically active people of low income. The comparison between these three forms indicates a more healthy choice for nutritious finger millet rich diet for the future generation among the selected varieties. It ranks sixth in production after Wheat, Rice, Maize, Sorghum and Bajra in India (Pawar *et al.,* 2020).

Methods and Materials

The finger millet cultivars are obtained after harvest from ICAR-IIMR field and tested for its moisture content at wet basis (%) using indosaw moisture meter. The physical properties of selected 7 cultivars of finger millet (*Eleusine Corocana*), CFMV-2, KMR-204, Suvarnamukhi, Vegavathi, PR-204, Dhalamandia and Bhalumandia like moisture content, both % wet basis and % dry basis, bulk density, true density porosity, length, width, thickness, sphericity, aspect ratio, volume, frontal area, different diameters, geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent mean diameter, shape factor, sphericity, surface area,1000 grain weight using standard procedure and the pearson correlation coefficient for all the parameters using SPSS 16.0 version. Moisture content was determined using hot air oven method and represented in %wb.

1) Length, width and thickness was determined using vernier callipers (AOAC, 2005).
2) Geometric mean diameter = $(LWT)^{1/3}$ (Mpotokwane *et al.*, 2008).
3) Arithmetic mean diameter = $(L+W+T)^{1/3}$ (Mpotokwane *et al.*, 2008).
4) Sphericity = $[(LWT)^{1/3})/L]100$ (Hamdani *et al.*, 2014)
5) Surface area = $(\pi BL^2)/(2L-B)$ (Karababa and Coskuner, 2013)
   Where, $B = (WT)^{0.5}$
6) Sample volume = $(\pi B^2L^2)/[6(2L-B)]$ (Mpotokwane *et al.,* 2008).
   Where, L= Length, W= Width, T= Thickness,
7) Bulk density = Sample weight/volume (Vanrnamkhasti *et al.*, 2008)
8) True density = Weight of grains/volume of displaced toluene (Karababa and Coskuner, 2013)
9) Porosity (ε) = $[(P_t-P_b)/P_t]*100$ (Vanrnamkhasti *et al.,* 2008)
   Where, P_t = True density, P_b- Bulk density
10) % Moisture content =(Loss in weight/Weight of sample)×100 (AACC,2000)
11) $V_t=\pi((4gd\rho_t(6Z/¶)/3\rho_a*0.44))$
    v_t is the terminal velocity, m is the mass of the falling object, g is the acceleration due to gravity, C_d is the drag coefficient, 5 density of the fluid through which the object is falling, and A is the area projected by the object, Z shape factor of the grain (Gorial and O'Callaghan, 1990)
12) Hydration capacity was calculated as the difference in weight of grains after soaking for 24h. It was expressed as weight per gram. (Murugod *et al.,* 2019)
13) Swelling capacity is calculated as the difference in volume of grains after soaking for 24h. It was expressed as weight per gram. (Murugod *et al.*, 2019)
14) Swelling index=(Swelling capacity per 1000 grain)/(grain volume per 1000 grain) (Kantha *et al.,* 1986)

15) Hydration index = (Hydration capacity per 1000 grains)/(dry weight of 1000 grains) (Kantha *et al.*, 1986)

Cooking was done taking 10g of the sample and cooking in the water bath at controlled conditions of temperature and time. The malting of grains was done with cleaned, sorted and immersed grains in distilled water for 6h. The grains were later spread on stainless trays lined with muslin wet cloth. The malted grains were dried in the oven dryer at 50°c for 1h. Dried grains were kept in airtight polythene bags for further usage (Olamiti *et al.*, 2020). Values were the result of two replications and tested for 5% level of significance. ($p \leq 0.05$) The values were tested for its significance using SPSS 16.0 version. Three dimensional graphs were drawn using Design Expert Software version 12.0.

Results and Discussion

The moisture content in wet basis of the raw cultivars ranges from 13.80% to 16.30% ±0.32. Minimum is in Dhalamandia, 13.80%±0.32, KMR-204, 13.97%±0.32, Vegavathi, 14.70% ±0.32, PR-202, 14.90%±0.32, Suvarnamukhi, 15.23 % ± 0.32, Bhalumandia, 15.30 %±0.32 and CFMV-2,16.3%±0.32. Main dimensions of grain are considered in selecting, designing the suitable size of the screen perforations and determination the proper method for grading and separation. The importance of length, width and thickness are in deciding the aperture size of the machine particularly in separation process of materials. The length, width and thickness ranges from 1.50-1.92mm, 1.42-1.75mm and 1.26-1.56 mm. Sphericity ranges between 0.82-0.96, aspect ratio is minimum in Vegavathi, 85.14 followed by Bhalumandia, 85.42, CFMV-2,85.80, PR-202, 93.09, Suvarnamukhi, 94.67, KMR-204, 94.70 and Dhalamandia, 97.08. The volume ranges from 1.50-2.81 mm^3 and surface area ranges from 1.58-2.40 mm^2. The average geometric mean diameter is 1.35 mm, arithmetic mean diameter is 1.54 mm. The true density is minimum in Vega -vathi, 1120.77kg/m^3 followed by PR-202, 1165.56 kg/m^3, KMR-204, 1180.50kg/m^3, Suvarna -mukhi, 1250kg/m^3, Dhalamandia, 1252.50kg/m^3, Bhalumandia, 1310.24kg/m^3 and CFMV-2, 1355.5 kg/m^3. The bulk density ranges between 572.34-664.75kg/m^3 Porosity ranges between 40.69% to 57.76%. Static angle of repose ranges between 21.80 to 28.91, dynamic angle of repose ranges between 30.25° to 36.03°. The coefficient of friction of the wooden surface ranges from 0.59 to 0.75, average moisture content, %wb is 14.89, average mc, %db is 17.50%, average 1000 grain weight is 2.58°. Shape factor ranges between 0.85 to 1.60. Equivalent mean diameter ranges between 3.01 to 4.34. The hardness of a material can be defined as its resistance to plastic defor -mation caused by a force applied through an indenter. Grain hardness is important for the flour industry because it has significant impacts on milling, baking and qualities of grain. Hardness factor of the selected millet cultivars is in between 0.75 to 1.16.

Width ranges from 0.168cm±0.01 to 0.23cm±0.01. Width is measured using slide projec -tor. Average width is 0.198cm±0.01, PR-202, 0.16cm±0.01 followed by Vegavathi, 0.18 cm± 0.01, KMR-204,0.19 cm±0.01, Bhalumandia, 0.19cm±0.01, Dhalamandia, 0.20cm±0.01, Suvarna -mukhi, 0.20 and CFMV-2,0.23cm±0.01. The thickness of the ragi grain cultivars varies from 1.51 to 1.55±0.01mm. The minimum thickness is in Vegavathi, PR-202, 1.51 mm and maximum is in Bhalumandia, 1.55 mm. The minimum thickness is in Vegavathi, 1.51 mm followed by CFMV-2,1.52 mm, KMR-202, Suvarnamukhi and Dhalamandia, 1.53 mm and Bhalumandia, 1.55 mm±0.01. Three dimensional graphs are shown in Fig. 1, **represents** the relationship between length, width and thickness with porosity of raw selected cultivars of millet grain.

Sphericity and aspect ratio are determined to know the grain sliding and rolling nature in the hopper. Higher the aspect ratio indicates the higher rolling nature of the grain. Sphericity parameter shows the shape character of the particle relative to the sphere having same volume. The shape of product is an important parameter that affects conveying characteristics of solid materials by air or water. The shape is also considered in calculation of various cooling and heating loads of food materials. The sphericity of the finger millet, (*Eleucine Corocana*) minimum value is in 0.84±0.01, Bhalumandia followed by CFMV-2,PR-202 and Dhalamandia, 0.88±0.01 and Suvarnamukhi, 0.91±0.01 and Vegavathi, 0.91±0.01. The aspect ratio ranges from 1.10 to 1.19. The minimum is in Suvarnamukhi, Vegavathi, 1.10 followed by KMR-204, 1.12, PR-202, 1.13, Dhalamandia, 1.14, CFMV-2, 1.14 and Bhalumandia, 1.19. Volume determination in grain is much necessary for the determination of density and in deciding packaging material size. The volume of the grain is minimum in Vegavathi,

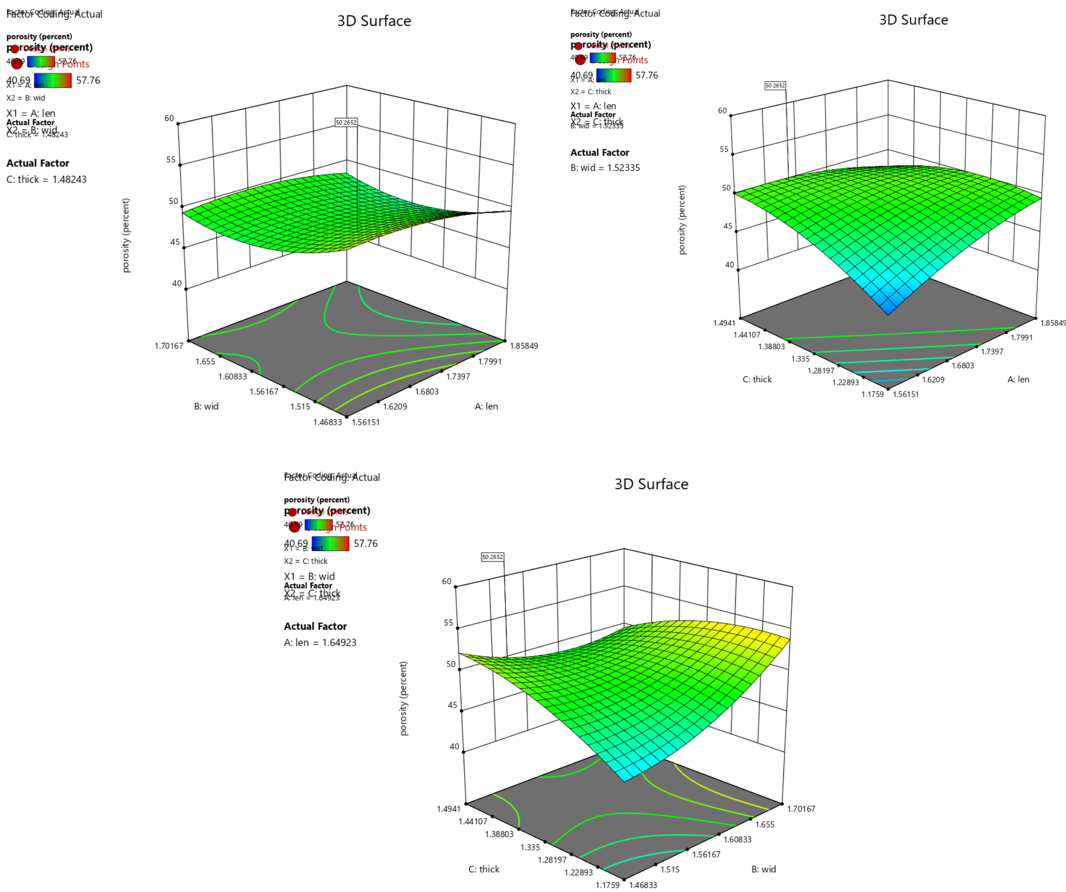


Fig. 1. Relationship between length, width and thickness with porosity of raw selected cultivars of finger millet grain.

19.98mm^3 followed by Suvarnamukhi, 20.84mm^3, PR-202,21.02,KMR-204,21.41mm^3,CFMV-2,21.81mm^3, Dhalamandia, 22.35mm^{3}and Bhalamandia, 25.25mm^3±0.64.

The bulk density is considered for determination of capacity, designing seed hopper dimensions in seed planters and cleaning and grading equipment. Bulk density is measured from weight and volume of the sample. The range of bulk density of the selected finger millets ranges from 572.54kg/m^3±11.26 to 664.75kg/m^3±11.26 . Minimum bulk density is in CFMV-2,572.54 kg/m^3 ±11.26 followed by KMR-204, 607.92 kg/m^3 ± 11.26, Dhalamandia, 609.86kg/m^3± 11.26, PR-202, 612.15kg/m^3±11.26, Bhalumandia, 620.66 kg/m^3 ± 11.26, Suvarnamukhi, 647.62 kg/m^3 ±11.26 and Vegavathi, 664.75 kg/m^3±11.26.True volume and true density are helpful in calculating the transportation of the grain in the liquid media. True density is measured using toluene displacement method. The range of true density is 1120.77kg/m^3 ±31.45 to 1355.5 kg/m^3±31.45. Minimum true density is Vegavathi, 1120.77kg/m^3±31.45 followed by PR-202, 1165.56 kg/m^3± 31.45,KMR-204,1180.5kg/m^3±31.45, Dhalamandia,1252.5kg/m^3±31.45, Bhalumandia, 1310.24 kg/m^3±31.45 and CFMV-2, 1355.5 kg/m^3 ± 31.45.

Porosity is measured using bulk density and true density and it is expressed in percentage. The porosity ranges from 47.30%±1.07 to 55.33%±1.07. Minimum porosity is PR-204, 47.3%±1.07, followed by Suvarnamukhi, 48.19%±1.07, KMR-204, 48.21%±1.07, Vegavathi, 49.3 7 %±1.07, Dhalamandia, 51.31%±1.07, Bhalumandia, 52.14%±1.07 and CFMV-2, 55.33%± 1.07.

The frontal area and the related diameters are essential for determination of terminal velocity Reynold's number and drag coefficient. The surface area of the grain is minimum in Vegavathi, 8.73±0.01mm^2 followed by Suvarnamukhi, 8.87mm^2±0.23, KMR-204, 9.18mm^2± 0.23, PR-202, 9.22 mm^2±0.23, CFMV-2, 9.40 mm^2±0.23, Dhalamandia, 9.55mm^2±0.23and Bhalumandia, 10.56 mm^2±0.23. The geometric and arithmetic mean diameters are used to calculate the equivalent diameter of the grain. The geometric mean diameter is minimum in 1.36mm± 0.01, Vegavathi followed by Suvarnamukhi, PR-202,1.37 mm± 0.01, CFMV-2, KMR-204, 1.38mm± 0.01, Dhalamandia,1.39 mm±0.01 and Bhalumandia, 1.41mm± 0.01. The arithmetic mean diameter is minimum in Vegavathi, 1.59±0.01 followed by Suvarnamukhi, PR-202, 1.37 mm± 0.01, CFMV-2, KMR-204, 1.38±0.01, Dhalamandia, 1.39mm± 0.01 and Bhalumandia, 1.41± 0.01. Estimating the mass of seed is necessary to assess the required mass of seed for planting a limited area and number of seed in each hole. The 1000 grain weight ranges between 2.10 to 2.95g±0.13. Minimum is in KMR-204, 2.10g, Suvarnamukhi, 2.30 ± 0.13, Dhalamandia, 2.35g ± 0.13, Vegavathi, 2.60±0.13, Bhalumandia, 2.85±0.13, CFMV-2, 2.9±0.13 and PR-202, 2.95±0.13.

Shape factor varies between 1.38-1.84 and it is minimum in 1.38±0.06,Vegavathi follow ed by Suvarnamukhi,1.41±0.06,KMR-204,1.46±0.06,PR-202,1.50±0.06,CFMV-2,1.54±0.06, Dh -alamandia, 1.58±0.06 and Bhalumandia,1.84±0.06. Shape factors are dimensionless quantities used in image analysis and microscopy that numerically describe the shape of a particle; independent of its size.Square mean diameter varies in between 8.08±0.18 to 9.56±0.18. Minimum is in Vegavathi, 8.08 followed by Suvarnamukhi, 8.22±0.18, KMR-204, PR-202, 8.46±0.18, CFMV-2, 8.62±0.18, Dhalamandia, 8.75±0.18 and Bhalumandia, 9.56±0.18. Equivalent mean diameter varies in between 3.68±0.07 followed by Suvarnamukhi, 3.74±0.07, KMR-204, PR-202, 13.83±0.07, Dhalamandia, 3.93±0.07, CFMV-2,3.98±0.07 and Bhalumandia, 4.24±0.07. Hardness is the resistance of a material to localized deformation.

Pearson correlation coefficient was worked out for all the physical parameters tested and some of the important results were as follows, true density and porosity are correlated and the highest correlation coefficient is 0.82 thicknesses and porosity coefficient is 0.34. Sphericity and porosity are negatively correlated and the correlation coefficient is (-0.49). Porosity and moisture content are positively correlated and the correlation coefficient is 0.56. Moisture content and 1000 grain weight are positively correlated, Correlation coefficient is 0.68. Coefficient of friction and width are positively correlated and the correlation coefficient is 0.39. The angle that the plane of contact between two bodies makes with the horizontal when the upper body is just on the point of sliding: the angle and tangent is the coefficient of friction between the two bodies. The relationship between flow properties and angle of repose has been established. When the angle of repose is less than 25 degrees, the flow is said to be excellent, on the other hand, if the angle of repose is more than 40 degrees, the flow is considered to be poor. The static angle of repose in Dhalamandia,21.80°±1.09 followed by Bhalumandia, 22.73±1.09, KMR-204, 23.19± 1.09, CFMV-2,25.02±1.09, Vegavathi, 27.21±1.09, PR-202, 28.48±1.09 and Suvarnamukhi, 28.91 ±1.09. The dynamic angle of repose is in Vegavathi, 30.25±0.91, Dhalamandia, 31.82± 0.91, Suvarnamukhi, 32.27±0.91, KMR-204, 33.68±0.91 and PR-202, 36.83±0.91 (Table 2). The material generally moves or slides in direct contact with trough, casing, and other components of the machine. The various parameters affect the power requirement to drive the machine. The frictional losses are one of the factors that must be overcome by providing additional power to the machine. Hence, the knowledge of coefficient of friction of the agricultural materials is necessary. The coefficient of friction is a ratio used to quantify the friction force between two objects in relation to the normal force that is keeping them together. The coefficient of friction is an important consideration during material selection and surface requirement determination. Coefficient of friction (ì) this describes the roughness between two surfaces. A high coefficient of friction produces more friction. The static friction between two surfaces is always higher than the kinetic friction rougher surfaces tend to have higher effective values whereas smoother surfaces have lower due to the friction they generate when pressed together. Most dry materials in combination have friction coefficient values between 0.3 and 0.6. Static friction is dependent on the magnitude of the force applied while kinetic friction is independent of the magnitude of the force that is applied. The static coefficient of friction is minimum in 0.58, Vegavathi follow -ed by Dhalamandia, 0.62±0.02, Suvarnamukhi, 0.63± 0.02, KMR-204, 0.67±0.023, Bhalumandia, 0.69 ± 0.02, CFMV-2,0.73±0.023 and PR-202, 0.75±0.023 (Table 1).

The moisture content in dry basis in raw millet grains varied between 16.01%±0.44 to 19.47%±0.44. Minimum is in Dhalamandia, 16.01%±0.44 followed by KMR-204, 16.24%±0.44, Vegavathi, 17.23%± 0.44, PR-202, 17.51% ±0.44, Suvarnamukhi, 17.97% ± 0.44, Bhalumandia, 18.06%±0.44 and CFMV-2, 19.47%±0.44. The lower the μ value represents the free flowing characteristic of the grain. The density of the grains decides the size of screening surface. The density ranges between 980kg/m^3 to 1432.2kg/m^3. The minimum density is in KMR-204,98 kg/m^3 followed by Dhalamandia, 1051.61kg/m^3, Suvarnamukhi, 1103.49kg/m^3, Bhalumandia, 1128.50kg/m^3,Vegavathi, 1301.18 kg/m^3,CFMV-2,1329.38 kg/m^3 and PR-202, 1403.19kg/m^3. The value of angle of internal friction is equal to the tangent of the coefficient of friction for the material. The angle of internal friction is an important property that helps to estimate the lateral pressure in storage silos. Angle of internal friction values are also used in designing of storage bins and hopper for gravity discharge. The coefficient of friction between grains is required as a design parameter for design of shallow and deep bins. The coefficient of friction is tested in 4 different materials of stainless steel, glass, plastic and wooden surfaces. The static coefficient of friction is more in stainless steel, 0.56±0.06 and least in plastic surface, 0.50±0.06. The dynamic coefficient of friction is more in stainless steel (0.55±0.05) and least in plastic, 0.42± 0.04. (Table 1). The dynamic angle of internal friction is more in ss, 28.88±2.23 and least in plastic, 22.79 ±1.88.Glass angle of inter-

Table 1. Coefficient of friction of different cultivars of raw finger millet

S. No.	Cultivars	SS		Glass		Plastic		Wooden	
		Dyna	Static	Dyna	Static	Dyna	Static	Dyna	Static
1	CFMV-2	0.57	0.58	0.46	0.49	0.41	0.58	0.48	0.49
2	KMR-204	0.52	0.55	0.51	0.54	0.41	0.57	0.50	0.55
3	Suvarnamukhi	0.61	0.62	0.48	0.53	0.41	0.45	0.43	0.58
4	Vegavathi	0.57	0.58	0.49	0.55	0.40	0.43	0.43	0.52
5	PR-202	0.54	0.57	0.53	0.54	0.51	0.52	0.43	0.47
6	Dhalamandia	0.58	0.61	0.46	0.55	0.40	0.48	0.51	0.57
7	Bhalumandia	0.46	0.44	0.56	0.57	0.39	0.46	0.49	0.48
	average	0.55	0.56	0.50	0.54	0.42	0.50	0.47	0.52
	minimum	0.46	0.44	0.46	0.49	0.39	0.43	0.43	0.47
	maximum	0.61	0.62	0.56	0.57	0.51	0.58	0.51	0.58
	sem	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02
	sd	0.05	0.06	0.04	0.03	0.04	0.06	0.04	0.05
	cv	8.95	10.40	7.73	4.94	9.44	11.80	8.19	8.91
	s/ns(5%)	s	s	s	s	s	s	s	s

Table 2. Angle of internal friction of different cultivars of raw finger millet

S. No.	Cultivars	Angle of internal friction							
		SS		Glass		Plastic		Wooden	
		Dyna	Static	Dyna	Static	Dyna	Static	Dyna	Static
1	CFMV-2	29.68	30.33	24.70	26.10	22.29	30.11	25.64	26.10
2	KMR-204	27.47	28.81	27.02	28.37	22.29	29.90	26.79	29.03
3	Suvarnamukhi	31.38	31.80	25.87	27.92	22.29	24.47	23.27	30.33
4	Vegavathi	29.90	30.33	26.10	28.81	21.80	23.27	23.27	27.47
5	PR-202	28.59	29.89	28.15	28.36	27.02	27.70	23.27	25.17
6	Dhalamandia	30.46	31.67	24.89	28.99	22.20	25.97	27.25	29.81
7	Bhalumandia	24.70	24.04	29.55	29.98	21.65	24.84	26.43	25.64
	average	28.88	29.55	26.61	28.36	22.79	26.61	25.13	27.65
	minimum	24.70	24.04	24.70	26.10	21.65	23.27	23.27	25.17
	maximum	31.38	31.80	29.55	29.98	27.02	30.11	27.25	30.33
	sem	0.84	1.00	0.67	0.45	0.71	1.02	0.68	0.79
	sd	2.23	2.64	1.76	1.19	1.88	2.69	1.81	2.10
	cv	7.74	8.93	6.62	4.20	8.26	10.12	7.19	7.58
	s/ns(5%)	**s**	**s**	**s**	**s**	**s**	**s**	**s**	**s**

nal friction is more than that of wooden surface. The static angle of internal friction is more in ss, 29.55±2.64 and least in glass 28.36±1.19. The angle of internal friction of wooden, 27.68±2.10 is more than plastic, 26.61±2.69 (Table 2).

The fresh finger millet after harvest were obtained from the field of ICAR-IIMR and were subjected to soaking for 24h and then cooking. The finger millet grains of different variety were cooked in a graduated test tube for 45 minutes. The principal reason of soaking is to gelatinize the starch into the grain. The temperature maintained in the shaking hot water bath was 80ºC. The end point of cooking was complete gelatinization of starch. The knowledge of physical properties of finger millets affect the conveying characteristics of solid materials by air or water and cooling and heating loads of food materials. The length is defined as the longest axis of the grain. The width is the second longest axis of the grain and the thickness is the shortest axis. The length, width and thickness of the cooked millets of different cultivars ranged from 1.72-1.93 mm±0.07, 1.65-1.87±0.05 and 1.57-1.80mm±0.04. Three dimensional graphs are shown in Fig. 2, the relationship between length, width and thickness with porosity of cooked selected cultivars of millet grain.

The importance of elongation ratio and flatness ratio is used in packing of the particles of one size depends upon their shape. Elongated grains were determined by the relation between the length, width and thickness of the grain. The flatness ratio is the ratio of the thickness to the width. The elongation ratio is the ratio of the width to the length. Elongation ratio is the ratio of length to thickness. Elongation ratio ranged from 1.13 to 1.69±0.03. L/B ratio varies from 1.00 to 1.05mm ±0.03. Flatness ratio varied from 1.03-1.14 mm±0.01. The ratio between the elongation ratio and flatness ratio is termed as shape factor and it varied from 1.03-1.64±0.07. The physical dimensions increased with increase in moisture content of the grain and this coincided with the findings of Felipe Pereira de Moura, 2018. Sphericity of seeds is one of the important parameters in designing of hopper to process the seeds. Sphericity of the cooked millets ranged from 0.94-0.98±0.01. Roundness index or angular index varied from 5.18 to

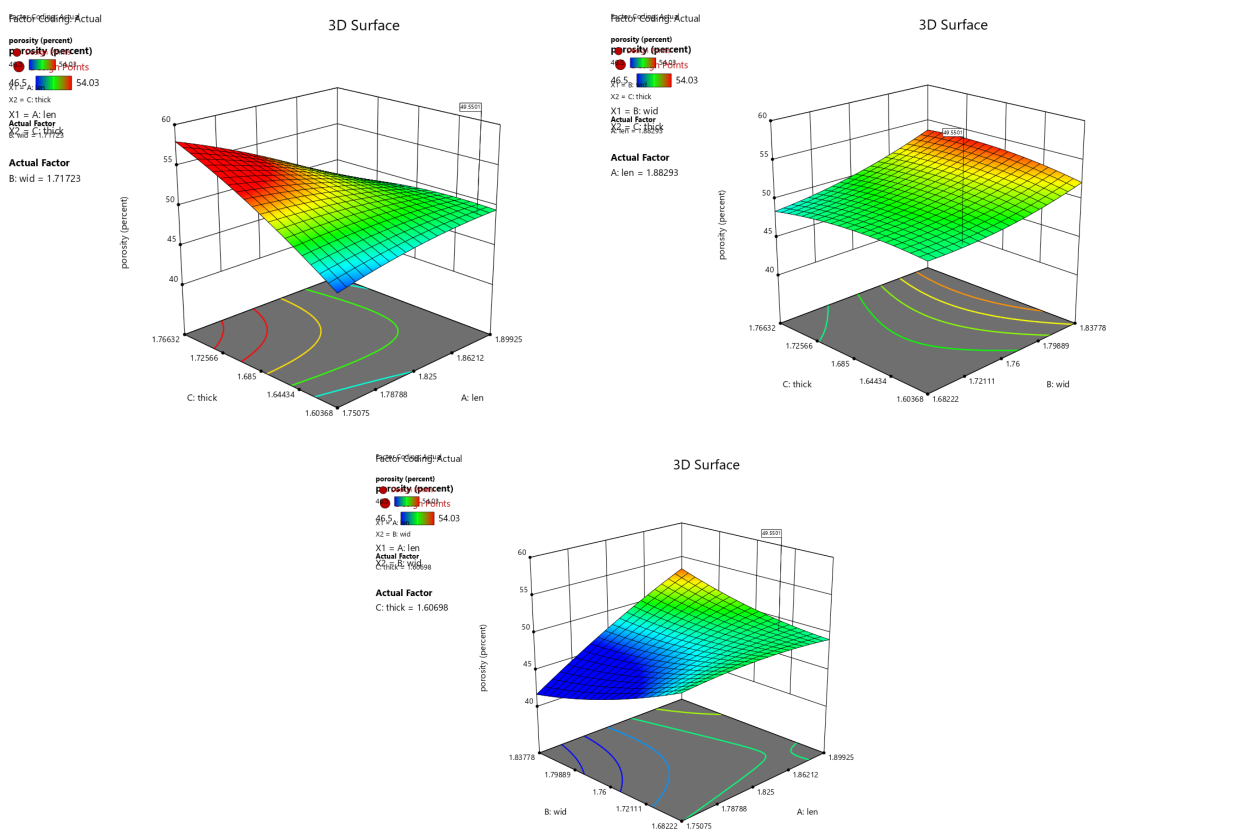


Fig.2. Relationship between length, width and thickness with porosity of cooked selected cultivars of finger millet grain

5.87±0.11. Aspect ratio is in between 1.00 to 1.05±0.01. Volume and surface area is in between 2.35-3.42±0.17 to 2.14-2.85±0.09. Geometric mean diameter varied between the selected cultivars from 1.66-1.85±0.03. Arithmetic mean diameter varied from 1.66-1.85±0.03. The bulk density is a measure of heaviness of a grain sample that is important in determining the storage capacity, packaging requirements, material handling and application in wet processing in the food industries. Bulk density varied from 569.05 kg/m^3 to 633.33kg/m^3±8.78. True density varied from 1063.64kg/m^3 to 1377.80kg/m^3±36.11. Porosity ranged between 46.50% to 54.03%±1.05. Hardness factor of the cooked millets ranged from 1.15-1.82±0.10. Square mean diameter ranged between 8.43-10.38±0.31. Equilibrium mean diameter ranged between 3.91-4.69±0.12. 1000 kernel weight ranged between 2.66-3.87±0.18. Percentage increase in length between the cooked and the uncooked finger millet ranged between 0.52-19.25±2.73. Percentage increase in width ranged between 3.49-23.53±2.85. Percentage increase in thickness ranged between 0.64-38.33± 4.43. The cooking quality parameters include water uptake ratio, elongation ratio, hydration index, swelling index and 1000 kernel weight, percentage increase in weight and volume were also determined. Water uptake ratio ranged between 1.40-1.60±0.03. Water uptake ratio is minimum in PR-202 variety, 1.40±0.03 followed by Dhalamandia, 1.41±0.03, Bhalumandia and in Suvarnamukhi, 1.41±0.03, CFMV-2,1.45± 0.03, Vegavathi, 1.50±0.03 and KMR-204, 1.60± 0.03. Lower WAC is suitable for making thinner gruels and also indicates the amount of water available for gelatinisation mentioned that high WAC values indicate loose structure of starch polymers while low values indicate the compactness of the structure. (Ramashia *et al.,* 2018). The grains with higher bulk density exhibit slow water uptake and thus result in longer cooking periods. Hydration capacity ranged between 21.64-82.32 ±41.53. Hydration index ranged between 0.87-3.29± 1.66. This hydration capacity coincided with the findings of Sravanthi *et al.,* 2021. Swelling capacity ranged between 13.51-44.44±3.89. Swelling index ranged between 0.42-1.48±0.73. More the swelling power of the grain less is the nutrient density.1000 kernel density ranged between 708.74-1150± 70.98. Percentage increase in weight of the cooked millet is 2.06-3.84 ± 0.23. Percentage increase in volume is 0.14-0.44±0.04. Expansion rate varied from cooked to uncooked millet is 0.27-0.38±0.01. Percentage increase in 1000kernel weight is 0.59-0.76± 0.02. Fig. 4 represents length, width, thickness, bulk density, true density, porosity of different forms of selected cultivars of finger millet grain.

Generally the grain in the malted form is expected to be more nutritious than that of the ordinary grain. Finger millet has superior malting characteristics compared to other millets and ranks next to barley malt (Banusha and Vasantharuba, 2013). Malting is a germinated cereal grain, in this the grains are made to germinate by soaking in water and is then halted from germinating further by drying with hot air. Malting grain develops the enzymes, α-amylase, β-amylase required for modifying the grain starches into sugars. The grain moisture content before malting ranges in between 13.80-16.3%wb. The sprouted (malted) millets moisture content ranges between 19.60-21.10%wb. Sprouted millets physiochemical properties are much needed for packaging design and storage of value added products to retain the freshness of the stored millet product. Moisture content increased with malting and the percentage increase is 21.94 % ±1.47 to 31.85%±1.47. Malting includes supplying the body with antioxidants and B vitamins and improves bone health. Malt is a good source of essential amino acid. The length, width and thickness ranged between 1.81mm± 0.04, 1.68 mm ±0.04 and 1.59mm±0.04. Three dimensional graphs are shown in Fig. 3, the relationship between length, width and thickness with porosity of malted selected cultivars of millet grain. The changes that took place at the molecular level during malting could have resulted in a reduction of interparticle attraction, thereby reducing the bulk density (Kundai Thelma Murungweni *et al.,* 2023). Elongation ratio ranged between 0.55-0.71± 0.02. L/B ranged between 1.02-1.17±0.02. Flatness ratio ranged between 1.03-1.09±0.01. Sphericity ranged between 0.88-0.97± 0.01. Angularity index or roundness ratio ranged between 4.71-5.53±0.12. Aspect ratio varied between 1.02-1.17±0.02. Malt extract is a rich source of soluble fibre that helps improve digestion by optimizing good bacteria. Volume of all selected millets varied between 1.77-2.85 mm^3 ±0.16. Surface area ranged between 1.77-2.43mm^2±0.09. Malt contributes the sugars necessary for fermentation. Geometric mean diameter varied between 1.55-1.80 mm±0.04. Arithmetic mean diameter varied between 1.55-1.81mm ±0.02. The square mean diameter varied between 7.88-10.3 mm±0.36. The equivalent mean diameter varied between 3.66-4.64 mm±0.14. Percentage increase in length varied between 1.54-13.71±2.04, percentage increase in width varied between 0.57-7.61±2.19, the percentage increase in thickness varied between 5.67-35.09±3.70.1000 kernel weights ranged between 0.32-0.61g ±0.04. Shape factor ranged between 0.59-1.37±0.06. The bulk density ranged between 159.70-257.91±13.68kg/m^3. Due to enzymatic breakdown of starch to sugars during germination, the viscosity and bulk density of porridge made from sprouted grains are significantly lower (Mbithi Mwikya *et al.*, 2000). The true density ranged between 980.39-2016± 138.35 kg/m^3. Porosity ranged between 82.13%±0.93-89.34 %±0.93. The density decreased drastically in malted form of millet grain than in raw and cooked form. This coincided with the findings of density being decreased in sorghum cultivars of Trust Beta *et al*., 1995.

The length of cooked millet grains is more than raw by 7 and more than sprouted by 1.63%, raw grain is 5-52% less than sprouted form. The width of cooked millet grains is more than raw by 13.41%, sprouted is 16.32% less than cooked, raw grains is 7.74% less than sprouted. The thickness of cooked grain is more by 18.67% than raw, cooked is 4.22% more than sprouted, raw grain is less by 5.09% than sprouted grain. The elongation ratio of cooked is 5.22% more than raw, cooked is 14.93% more by 14.93% than sprouted and raw grain is 13% more than sprouted. The volume of cooked grain is 34% more than raw grain, 15.33% cooked is more than sprouted, sprouted is 22.25% more in sprouted than raw grain. The GMD of cooked is 13.0% more than raw grain, 2.84% is more in cooked than in sprouted, sprouted is 10.53% more than raw grain. The amd of cooked is 12.64% more in cooked than raw, 2.84% more in cooked than sprouted and 9.94% more in sprouted than raw grain. The raw grain is 6.96% more than cooked, cooked is 1.87% more than sprouted, raw grain is more by 8.70% than sprouted

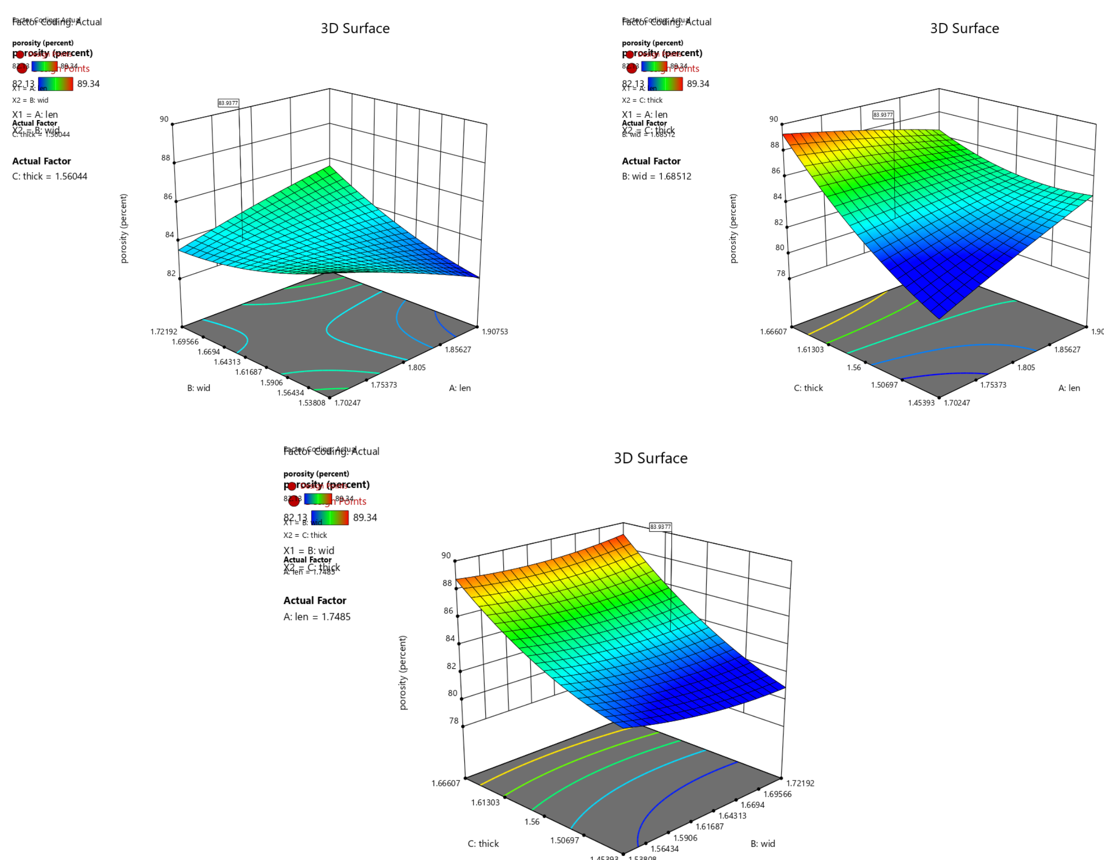
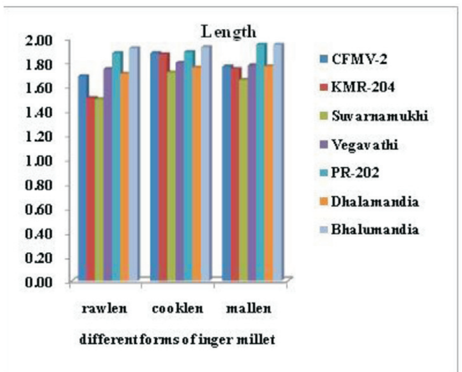
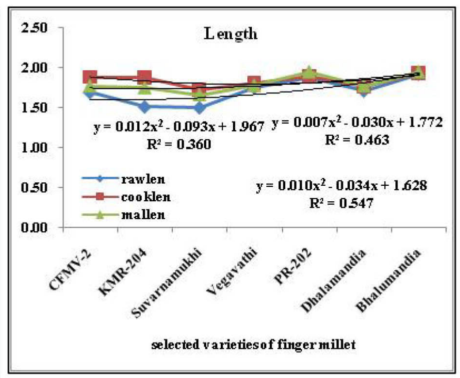


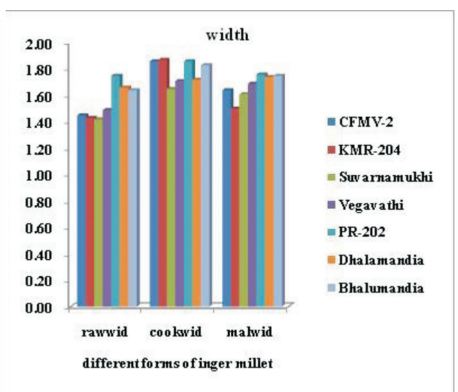
Fig. 3. Relationship between length, width and thickness with porosity of malted selected cultivars of finger millet

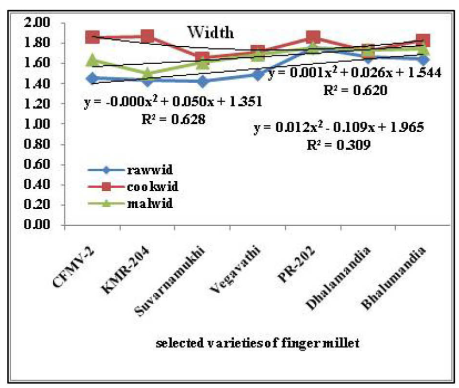
grain. The cooked grain is 18.49% more than raw grain, sprouted is 4.99% more than cooked, raw grain is 22.56% less than sprouted grain. Hausner ratio is 2.44% more in cooked than raw grain, 68.80% more in sprouted than cooked grain, 69.56% more in sprouted than raw grain. Cooked grain is 20.66% more than raw grain, cooked grain is 5.92% more than raw, sprouted is 13.67% more than raw grain. Surface area is 24.90% more to cooked than raw, sprouted is 10.76% less than cooked, sprouted is 15.63% more than raw grain. Sprouted grain is 16.51% more than raw millet, cooked grain is 5.50% more than raw millet, cooked is 11.65% more than raw millet grain. Angularity of raw grain is 30% less than cooked, 20.45% more than sprouted, sprouted is 12% more than raw grain. Terminal velocity is 6.96% more in raw than cooked, 8.55% more in raw than sprouted and 1.71% more in sprouted than raw grain. Volume expansion rate is 35.37% more in sprouted than cooked finger millets. Water absorption rate in cooked is 94.82% more than sprouted form.

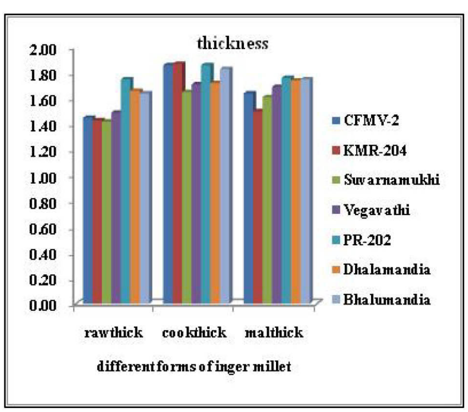
The theoretical terminal velocity and drag coefficient is the most important aerodynamic properties, that should be calculated for pneumatic conveying, separation, cleaning, harvesting and drying of mil-

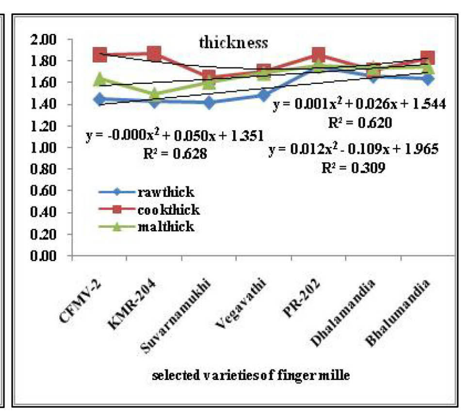












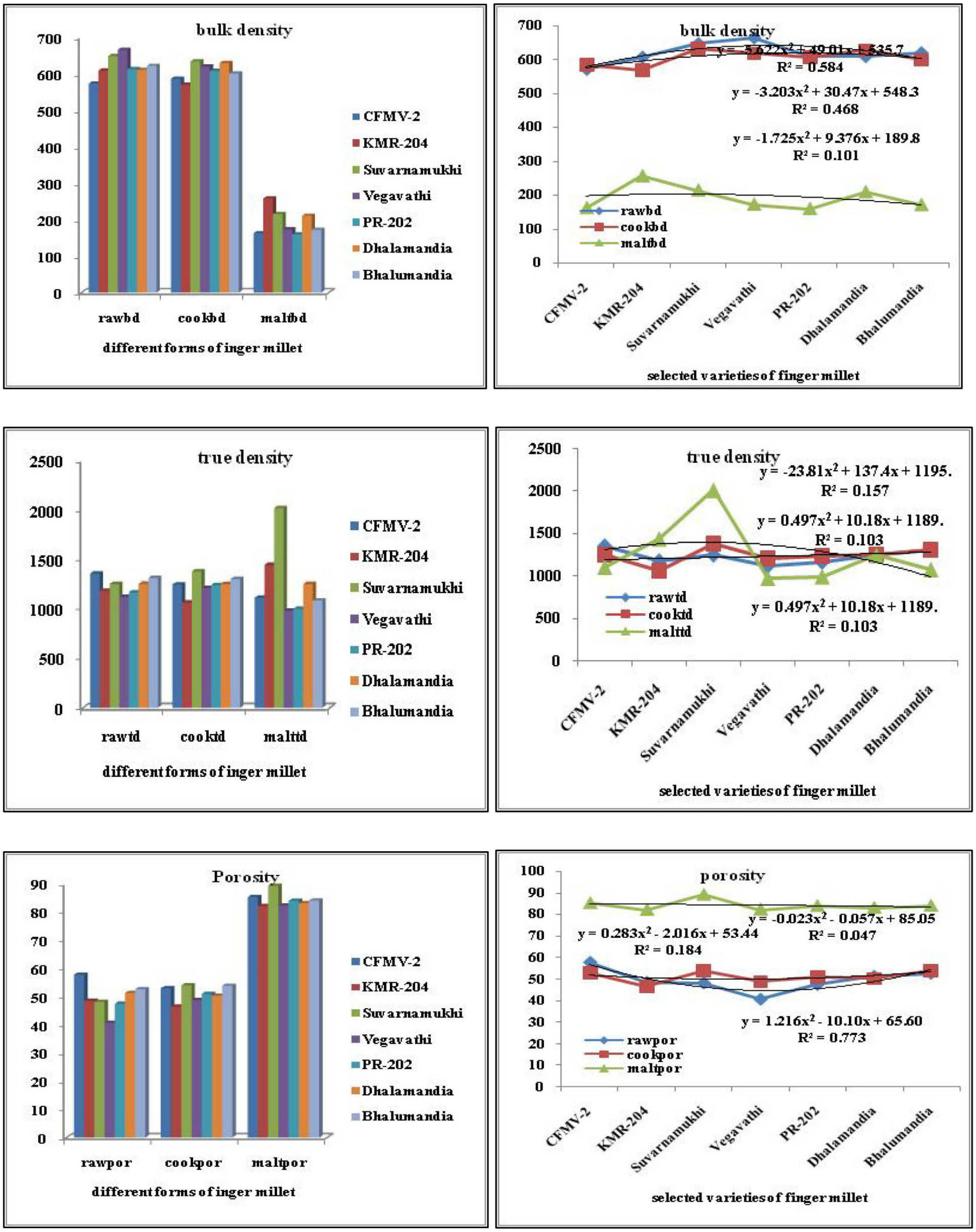


Fig. 4. Length, width, thickness, bulk density, true density, porosity of different forms of selected cultivars of finger millet grain.

let products. The theoretical terminal velocity for raw finger millet ranges from 1.11m/s (PR-202) to 1.80m/s (Vegavathi) ±0.01, in cooked form, 0.97(CFMV-2) to 1.15m/s(PR-202) ±0.02, in sprouted form, 1.12 (Dhalamandia) to 1.25m/s (CFMV-2)±0.02.

The drag coefficient is one of the parameters in estimating the aerodynamic characteristics of the finger millet grains. Drag coefficient is used in the design of fluidized bed drier. The drag coefficient includes the determination of terminal velocity of the grains, bulk density of grains and drag force. Drag is a mechanical force and it is generated by the interaction and contact of a solid body, grains with the fluid air. The calculation of drag coefficient is used in the design of vertical pneumatic conveyors for specific grain conveyance in processing plant. The drag coefficient of grains is a function of Reynolds number and lies within the limits of a sphere (0.44) and of a cylinder (1.0) depending on the shape of the grain. The drag coefficient of different cultivars of finger millet ranges from 0.58 to 0.84±0.04 for cooked millets it is 0.50-0.68±0.023 for sprouted millets it is 0.50-0.72±0.023. PR-202 is the least drag coefficient variety and Suvarnamukhi is the most drag coefficient variety in both raw and in cooked form. In malted form the most drag coefficient variety, KMR-204 and the least drag coefficient variety is CFMV-2. The drag coefficient in raw form is least in PR-202 followed by Bhalumandia, then Dhalamandia, then Vegavathi, then CFMV-2, KMR-204 and then Suvarnamukhi. The drag coefficient in cooked form is least in PR-204, then Bhalumandia, then, KMR-204, then CFMV-2, then Dhalamandia, then CFMV-2, then Vegavathi and then Suvarnamukhi. The drag coefficient in malted form is least in CFMV-2 followed by PR-204, then Bhalumandia, then Dhalamandia, then Vegavathi, then Suvarnamukhi and then KMR-204. The drag coefficient varies from 0.52 (PR-202)-0.73 (Suvarnamukhi) ±0.03 in raw form, in cooked it varies from, 0.43(PR-202)-0.64 (Suvarnamukhi) ±0.03 and in sprouted form it is 0.40 (CFMV-2)-0.70 (KMR-204)±0.03. The cooked grain drag coefficient is 17.64% less than raw, 1.69% less to cooked than sprouted, raw grain is 15.7% more than sprouted. The resistance coefficient varies from 1.10 (Vegavathi)-1.25 (PR-202)± 0.06 in raw form, in cooked form,1.17(PR-202) to 1.64(CFMV-2)±0.06 and in sprouted form, 0.98 (CFMV-2)-1.23 (Dhalamandia)±0.03.

Conclusion

Physical properties are used for design and development of machineries for cleaning, grading, dehulling, conveying and polishing. The average bulk density of raw finger millets is more in different finger millet than that of cooked and sprouted millets by 2% and 69% respectively. The true density of sprouted is 2.2% more than cooked and 2.8% more than raw millet, cooked is more from sprouted by 0.5%. In average porosity, the raw millet is 3% less than cooked, the cooked is 39.47 less than sprouted, sprouted is 41.31% more than raw millet. The average 1000 kernel weight in raw is 20% less than cooked, cooked is 86.88% more than that of sprouted, raw millet is 83.72% more than sprouted grain. The average aspect ratio of raw is 11.65% less than cooked, cooked is 5.5% less than sprouted and sprouted is 16.51% more than raw finger millet. These engineering parameters of the three forms of finger millet helps in the design of material handling devices of pneumatic involved in making value added products and in packaging of finger millets. Finger millet gains significance among all millets because of its calcium content that is more than in rice and wheat. The eminent selected varieties can be popularized based on the results of this study. The sprouted cereals in particular the underutilized millets contribute tremendously towards value added products boosting the growth of all age groups in physical and serves as a food for lengthy and healthy lifestyle preventing diabetes thus achieving nutritional security to our nation.

Acknowledgement

The author's wishes to thank the director, ICAR-IIMR for the facilities provided during the study.

References

AACC, 2000. In: D.E. Bruns (Ed.) *Official Methods of Analytics*(10th ed.) St.Paul, MN: American Association of cereal chemists.

AOAC, 2005. *Official Methods of Analysis.* Association of Official Analytical Chemists International. In: Horwitz, W. (Ed.), 18th Ed. AOAC Press, Arlington, VA, USA, 2005.

Banusha, S. and Vasantharuba, S. 2013. Effect of malting on nutritional contents of finger millet and mungbean. *American Eurasian J. Agric. & Environ. Sci.* 13(12):1642-1646. ISSN:1818-6769.

Felipe Pereira de Moura and Thiago Rochas dos Santos Mathias, 2018. A comparative study of dry and wet milling of barley malt and its influence on granulometry and wort composition. *Beverages.* 4:51.

Gorial, B.Y. and O'callaghan, J.R. 1990. Aerodynamic properties of grain/straw materials. *J. Agric. Eng. Res*. 46: 275-290.

Hamdani, A., Rather, S.A., Shah, A., Gani, A.,Wani, S.M., Masoodi, F.A. and 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: 286-304.

Karababa, E. and Coskunar, 2013. Physical properties of carob bean(*Ceratomia siliqua. L.*,) An Industrial gum yielding crop. *Industrial Crops and Products.* 42:440-446.

Kantha, S.S., Hattiarachchy, N.S. and Erdman, J.W. 1986. Nutrients, anti-nutrient contents and solubility profiles of nitrogen, phytic acid and selected minerals in winged bean flour. *Cereal Chem*. 63: 9-13.

Kundai Thelma Murungweni, Shonisani Eugenia Ramashia and Mpho Edward Mashau, 2023. Effect of malting on physico-chemical, antioxidant, and micro structural properties of finger millet (*Eleusine coracana*) flours. *Food Sci Nutr*.12: 547-563. DOI: 10.1002/ fsn3.3790.

Mbithi-Mwikya, S.J., Van Camp, Y., Yiu and Yghebareit, A. 2000. Nutrient and antinutrient changes in finger millet (*Eleusine coracana*) during sprouting. *Lebenom Wiss, U. Technology*. 33: 9-14.

Mpotokwane, S.W., Gaditlhatlhelwe, E., Sebaka, A. and Jideani, V.A. 2008. Physical properties of *Bambarra groundnuta* from Botswana. *Journal of Food Engineering.* 89: 93-98.

Murugod, P.P., Murulli, N.V., Sidarodha Padeppagol and Kattinani, 2019. Physico chemical properties and nutritional factors of kodo millets. *Int. J. Pure. App. Bio Sci*. 7(1): 117-123. ISSN:2320-7051.

Olamiti, G., Takalani, T.K., Beswa, D. and Jideani, A.I.O. 2020. Effect of malting and fermentation on colour, thermal properties, functional groups and crystallinity level of flours from pearl millet (*Pennisetum glaucum) and sorghum(sorghum bicolor)*. *Heliyon.* (6): e05467.

Pawar, P.P., Sawate, A.R., Kshirsagar, R.B. and Agarkar, B.S. 2020. Studies on physio chemical properties of finger millet (*Eleusine coracana*) and pearl millet(*Pennisetum glaucam*). *The Pharma Innovation Journal.* 9(2):05-08.

Ramashia, S.E., Gwaha, E.T., Medduous Taylor, S., Anyanin, T.A. and Jideani, A.J.O. 2018. Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub Saharan Africa. *Food Research International.* 104:110-118p, Elsevier Publications.

Sravanthi, D., Supraja, T., Kamalaja, T. and Kavitha Kisan, 2021. Physical, functional and cook -ing properties of PRSW 43 finger millet. *The Pharma Innovation Journal*. 202:10(7):172 -176.

Trust Beta, Lloyd, W. Rooney and Raloh D.Waniska, 1995. Malting characteristics of sorghum cultivars. *Cereal Chemists*. 2(6): 533-538p, American Association of Cereal Chemists Inc.

Vanrnamkhash, M.G., Mobli, H., Jafari, A., Keyhani, A.R., Soltanabadi, M.H., Rafier, S. and Kherralopour, K. 2008, Some physical properties of rough rice (*Oryza Sativa. L.*) grain. *Journal of Cereal Science.* 47: 496-501.