Physical properties of dehusked and debranned selected Indian millets

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The impact of milling on the physical attributes of Indian minor millets, namely foxtail, little, kodo, barnyard and proso millets are examined in the present study. Dehusking and debranning processes led to a reduced 1000 kernel weight and volume but increased bulk and true density. Hardness varied significantly between all millets in all forms. Different millets differ in properties such as length, breadth, thickness, equivalent diameter, geometric mean diameter, arithmetic mean diameter, aspect ratio, surface area and sphericity in native, dehusked and debranned forms. Understanding these variations can aid in the design of storage, transportation and new millet processing machinery.

Keywords: Degree of milling, dimensional properties, geometrical, gravimetrical, milling.

MILLETS are climate resilient, have a lesser carbon footprint, and are popular food in India and several African countries. Millets are cereals of *Poaceae* family. The family of small millets consists of foxtail (*Setaria italica* L.), little (*Panicum sumatrense*), kodo (*Paspalum scrobiculatum* L.), barnyard (*Echinochloa esculenta* L.), proso (*Panicum miliaceum* L.), finger (*Eleusine coracana* L.) and brown top millets (*Urochloa ramosa* L.). Each millet is unique with respect to its morphological and nutritional characteristics, such as carbohydrates, proteins, dietary fibre, micronutrients and phytochemicals with nutraceutical qualities[1]. Millets are a rich source of calcium, iron, phosphorus, potassium and several other micronutrients. Furthermore, they are sources of phyto-chemicals such as phenolic compounds compared to other principal cereals (rice, wheat and maize). Millets contain various flavonoids and phytochemicals with several health-beneficial properties[2]. Although whole grain millets (unrefined or unpolished) offer several nutritional benefits, predominantly millets are sold in refined forms[3], which are nutritionally inferior and can contribute to higher glycemic load (GL) of Indian diets like white rice. In the context of an exponential increase in non-communicable diseases like diabetes in India, whole-grain foods are recommended[4]. Thus, whole grain millet can be a healthier choice.

In contrast to sorghum, pearl and finger millet, millets like foxtail, little, kodo, barnyard and proso millet need to be dehusked to remove in-edible husk to prepare unpolished ready-to-cook millets. Subsequently, they are debranned or milled like rice. Previous studies[5] have shown the effect of milling on the nutritional characteristics of barnyard millet, but information on the effect of dehusking and debranning on the physical properties of other minor millets is scarce. Physical characteristics of agricultural materials are vital for developing the transportation and storage systems of postharvest processing equipment[6]. Strengthening production, reducing crop losses and minimizing grain damage necessitates the development of efficient handling and processing equipment, which demands the assessment of physical and engineering properties[7]. As a result, this data will be useful not only to engineers but also to food researchers and processors, who may also find new uses for these millets by exploiting those properties[8]. In this context, in the current study, we have evaluated the physical properties of selected native (N), dehusked (DH) and debranned millets (DB).

Materials and methods

Materials

The Indian Institute of Millet Research in Hyderabad, India, provided the foxtail millet (DHFT 109 3), little millet (DHLM36 3), kodo millet (JK 41), barnyard millet (DHBM 93 2) and proso millet (TNAU 145) varieties. The native millet samples (millets with inedible husk) were precleaned to remove extraneous matter and dehusked in a lab-scale millets dehuller (Dhan Foundation, India). All millets could be thoroughly dehusked in a single pass, except for the kodo millet, which required three passes. The DH millets were debranned in barley pearler (Satake Corporation, Japan) fitted with variable frequency drive and millet-specific sieves. The duration of milling was set based on the preliminary experiments, the milled materials

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were graded in a set of standard tests of sieves, and the degree of milling was calculated as per the method mentioned in our previous study[9]. The degree of milling (DOM) of the foxtail, little, kodo, barnyard and proso millets were 8.1%, 9.5%, 6.8%, 13.6% and 7.0% respectively.

The N, DH and DB millets were taken for evaluation of physical and engineering properties.

Physical properties

Determination of 1000 kernel weight and volume: One thousand grains were chosen at random and weighed using a Mettler Toledo electronic balance to obtain their weight. Thousand kernels were counted in triplicates, and their weight was determined, and the 1000 kernel volume was determined using the toluene displacement method based on the mass and volume.

Bulk density and true density: The bulk density (BD) and true density (TD) were determined using the method by Gani *et al.*[10]. A graduated measuring cylinder was used to determine the BD of millets in triplicates.

$$\mathrm{BD} = M/V_\mathrm{b},$$

where M and V_b represent the sample mass and volume respectively. TD was determined.

$$\mathrm{TD} = M/V_\mathrm{t},$$

where M and V_t represent the sample grains mass of 1000 kernels and toluene volume displaced by the 1000 kernels respectively.

Diameter of equivalent sphere: Diameter of equivalent sphere (DE) was calculated as per the formula

$$\mathrm{DE\ (mm)} = (W_\mathrm{t}/Y_\mathrm{t})\ (6/\pi)^{1/3},$$

where W_t and Y_t represents seed weight (g) and TD of seed (g/ml) respectively.

Hardness: The hardness of 20 millet kernels taken individually was assessed for the grain hardness using a digital grain hardness tester (Parisa Technology, India).

Grain dimensional properties: Length (L), breadth (B) and thickness (T) of the 20 grains were measured using a digital Vernier caliper (±0.01 mm accuracy). Based on the L, B and T values, the geometric mean diameter (GMD), arithmetic mean diameter (AMD), aspect ratio (AR), surface area (SA) and sphericity (S) were determined by using the following formulas[11]

$$\mathrm{GMD} = (LBT)^{1/3},$$

$$\mathrm{AMD} = (L + B + T)/3,$$

$$\mathrm{AR} = (B/L) \times 100,$$

$$\mathrm{SA} = \mathrm{GMD}^2 * \pi\,(\mathrm{mm}^2),$$

$$S = (LBT)^{1/3}/L \times 100.$$

Statistical analysis: Duncan's multiple range test was used to determine differences between means in an analysis of variance with a level of significance of 0.05 (SPSS 16.0).

Results and discussion

Physical properties of native, dehusked and debranned millets

It is well known that millets under study contain distinct husk, bran (seed coat), embryo/germ and endosperm. While the husk is inedible, bran is edible and can be retained for food purposes. Hence, removal of the husk is mandatory. Dehusking and debranning decreased the 1000 kernel weight and volume while increasing both BD and TD. From the 1000 kernel weight of N, DH and DB millets, it can be inferred that the 1000 kernel weight was not significantly different between foxtail and barnyard millets in their N and DH form, while all other millets are significantly different ($P < 0.05$). Upon debranning of millets, there was a decrease in 1000 kernel weight from 11.8% for proso millet (lowest) to 31.6% for foxtail millet (highest) with different DOM. Decrease in 1000 kernel weight is also dependent on DOM. The 1000 kernel weight depends mainly on the biochemical content of the endosperm. Because the seed coat is cellulosic it considerably lighter than the endosperm matter. Similar to our results, a decrease in 1000 kernel weight after dehusking operation for kodo, barnyard and little millets was reported[12,13]. The DH millets contain germ, bran and endosperm portions of the grain. During debranning, the bran is mostly separated out, and the germ to some extent in the grains[9]. Since the bran content in millets is around 5%, its separation by debranning causes minimal changes in 1000 kernel weight. However, the decrease in 1000 kernel weight on debranning largely depends on the DOM; the higher the DOM, the greater the decrease, as it removes some portions of the sub-aleurone layer and peripheral endosperm contents. Among the millets studied, N proso showed the highest 1000 kernel volume of 6.07 ml, while the little millet showed the lowest 1000 kernel volume of 2.57 ml, while the foxtail, kodo and barnyard millets showed 2.73, 4.17 and 3.43 ml in their N form respectively. DH millets showed a decrease in 1000 kernel volume from 20.5% (lowest for foxtail millet) to 44.8% (highest for kodo millet); in the case of DB millets, the 1000 kernel volume reduced from 8.69% (lowest for kodo millet) to 35.4% (for foxtail millet) in different millets. Similarly, a decrease in 1000 kernel volume on semi-polished (1.70 ml) and fully polished (1.57 ml) barnyard millets compared to unpolished (2.00 ml) counterparts[14]. Dehusking and debranning the millets resulted in increase in the BD and TD. The BD for the N, DH and DB millets differed, and the DB millets had the highest BD compared to DH and N millets. The BD for the N millet values ranged from 1.03 to 1.23 g/ml, lowest for barnyard millet and highest for foxtail millet respectively. Whereas, for DH millets it ranged from 1.10 to 1.25 g/ml, lowest for proso millet and highest for little millet; on the other hand the values for DB millets were 1.32 to 1.61 g/ml, lowest for barnyard and highest for proso millet respectively. The BD of the grains depends not only on the shape of the grains but also on the filling of biochemical constituents in the endosperm. The oval shape of some of the millets, namely foxtail, little and proso, causes voids in the compacting, whereas barnyard and kodo, being relatively spherical, will have lesser voids between the grains. In addition, the inter-space between the husk and the bran layer (in the case of N millets) also influences the BD. It is a well-known fact that these millets have a gap between the husk and kernel (wholegrain), which may vary between millets, enabling husk separation during dehusking operation. However, information on the extent of gaps between different millets is not available, and studies on these lines can help to understand the impact of dehusking and debranning operations on BD of DH and DB millets. Accordingly, there was an increase in the BD on dehusking and debranning (Table 1). The TD values also follow similar trends, and the values are increased in DH millets from 4.9% foxtail millet to 27.3% for little millet and the values are varied on DB from 0.5% for barnyard millet to 13.9% for kodo millet. However, these values may vary if the millets are prepared with different DOM. Similarly, BD and TD of decorticated sorghum, and dehusked proso millets ranged from 0.61 to 0.79 g/ml and 1.25 to 1.66 g/ml were reported respectively. BD and TD are significant factors in deciding grade during processing and designing storage and transportation containers[14–16].

Higher grain weight and TD will result in a larger DE. Among the millets studied, proso millet showed significantly higher DE values in N, DH and DB forms. While the little millet showed the lowest values in N, DH and DB forms (Table 1). Shape and size are also important factors in cleaning and separating foreign matter, as well as for analysing the quality of food materials. They are essential for heat and mass transfer calculations, etc.

Hardness of the grains generally depends on the compactness of the starch granules and protein matrix in the cells of the endosperms. Normally, grains with a larger proportion of hard endosperm are known as vitreous grains, and softer grains are known as floury grains. In the harder portion of the endosperm, the cells are rigidly attached to each other. Meanwhile, in the softer portion it is loosely attached. Information on the endosperm texture of small millets is scanty. In the N grains, the husk acts as a cushion while measuring the hardness of the grains by the hardness tester. Hence, the hardness of the N grains does not reflect the texture of the grains, whereas, after dehusking and debranning, the measurement reflects the true hardness of the kernel. However, DOM also plays a role in determining the hardness, as higher DOM slightly affects the hardness of the endosperm. In the present study, this is reflected in the hardness of the N, DH and DB grains for five millets studied. From the values, it may be noted that the hardness values were decreased by 1.6 (barnyard millet) to 47.5% (kodo millet) on DH. On the other hand, the hardness values were decreased by 3.4% (kodo millet) to 24.6% (proso millet) upon debranning. Barnyard millet alone showed a slight increase in hardness upon debranning. Grain hardness influences the cooking as well as processing characteristics of millets. The softer the grains, the more breakage occurs during milling and vice versa. The hardness of the grains is known to influence popping and flaking characteristics also; this kind of information on the small millets is not readily available; in the case of sorghum, it has been reported that harder grains yield better quality grits, whereas softer grains yield more flour. This information on the N grains may help decide the milling quality of millets to obtain whole grains with higher yields[12,14]. The present study clearly elucidates the hardness values as they followed a decreasing order on dehusking and debranning. This could be due to a change in the endosperm structure or architecture during debranning.

Grain dimensional properties

Some of the physical and grain dimensional features of millet kernels, such as *L*, *B*, *T*, GMD, AMD, AR, SA and *S*, were determined in N, DH and DB millets so that the information generated could be useful in designing millet processing machinery. Based on the data generated for N millets on *L*, *B* and *T* it could be seen clearly that little millet is the smallest, and the proso millet was the biggest among millets studied, with other millets lying in between (Table 2). Also, on dehusking, the *L*, *B* and *T* values were highest in proso millet and the little millet had the lowest. Changes in grain *L*, *B* and *T* parameters were expressed as a percentage decrease in dehusking and debranning for different millets (Table 2). Considerable variations were observed between *L*, *B* and *T* values among the different millets. On debranning, there was a decrease in the *L*, *B* and *T* parameters in all the millets, but the values are not comparable because there were differences in the DOM. Except in foxtail millet, there were no appreciable changes in the *L*, *B* and *T* values on debranning of DH foxtail millet. Although the *L*, *B* and *T* values decreased on debranning, a strict comparison could not be made as there were variations in the DOM. From the milling studies, it is very

Table 1. Physical properties of native (N), dehusked (DH) and debranned millets (DB)

Name of the millet	Nature of millet	1000 kernel weight (g) (mean ± SD)	1000 kernel volume (ml) (mean ± SD)	Bulk density (g/ml) (mean ± SD)	True density (g/ml) (mean ± SD)	Diameter of equivalent sphere (mm) (mean ± SD)	Hardness (kg) (mean ± SD)
Foxtail	N	3.34 ± 0.42^{de}	2.73 ± 0.50^{d}	0.73 ± 0.00^{b}	1.23 ± 0.10^{cde}	3.39 ± 0.62^{d}	2.88 ± 0.80^{k}
	DH	2.78 ± 0.02^{c}	2.17 ± 0.12^{b}	0.91 ± 0.00^{j}	1.29 ± 0.07^{ef}	2.69 ± 0.14^{c}	2.12 ± 0.69^{j}
	DB	1.9 ± 0.09^{a}	1.4 ± 0.12^{a}	0.92 ± 0.008^{j}	1.38 ± 0.08^{fg}	1.70 ± 14^{ab}	1.7 ± 0.42^{i}
	% change N to DH	–16.8	–20.5	24.7	4.9	–20.6	–26.4
	% change DH to DB	–31.6	–35.4	1.09	6.3	–36.8	–19.8
Little	N	2.82 ± 0.16^{c}	2.57 ± 0.25^{cd}	0.78 ± 0.0^{c}	1.10 ± 0.15^{ab}	3.19 ± 0.19^{d}	1.35 ± 0.78^{g}
	DH	2.28 ± 0.01^{b}	1.63 ± 0.25^{a}	0.91 ± 0.02^{i}	1.40 ± 0.17^{g}	2.03 ± 0.19^{b}	1.02 ± 0.16^{c}
	DB	2 ± 0.07^{a}	1.3 ± 0.10^{a}	0.99 ± 0.01^{j}	1.51 ± 0.16^{i}	1.61 ± 0.12^{a}	0.8 ± 0.68^{a}
	% change N to DH	–19.1	–36.6	16.7	27.3	–36.4	–24.4
	% change DH to DB	–12.28	–20.24	8.8	7.5	–20.7	–21.6
Kodo	N	4.76 ± 0.29^{g}	4.17 ± 0.29^{g}	0.68 ± 0.03^{a}	1.14 ± 0.01^{bc}	5.17 ± 0.36^{h}	2.82 ± 0.52^{k}
	DH	3.4 ± 0.21^{d}	2.30 ± 0.17^{bc}	0.92 ± 0.05^{j}	1.39 ± 0.02^{fg}	2.85 ± 0.21^{c}	1.48 ± 0.3^{h}
	DB	3.19 ± 0.31^{de}	2.1 ± 0.06^{b}	0.95 ± 0.01^{j}	1.61 ± 0.12^{j}	2.65 ± 0.07^{c}	1.43 ± 0.34^{h}
	% change N to DH	–33	–44.8	35.3	21.9	–44.9	–47.5
	% change DH to DB	–6.2	–8.69	3.2	13.9	–7.01	–3.4
Barnyard	N	3.53 ± 0.18^{e}	3.43 ± 0.42^{e}	0.69 ± 0.00^{a}	1.03 ± 0.09^{a}	4.26 ± 0.52^{f}	1.25 ± 0.29^{e}
	DH	2.87 ± 0.01^{c}	2.20 ± 0.17^{b}	0.89 ± 0.0^{gh}	1.31 ± 0.13^{efg}	2.73 ± 0.21^{c}	1.23 ± 0.21^{d}
	DB	2.1 ± 0.15^{ab}	1.6 ± 0.12^{a}	0.98 ± 0.006^{j}	1.32 ± 0.12^{efg}	2.03 ± 0.14^{b}	1.25 ± 0.74^{e}
	% change N to DH	–18.7	–35.9	29	27.2	–35.9	–1.6
	% change DH to DB	–26.82	–27.27	10.1	0.5	–25.64	1.6
Proso	N	6.97 ± 0.06^{h}	6.07 ± 0.06^{h}	0.80 ± 0.08^{d}	1.15 ± 0.02^{bcd}	7.53 ± 0.07^{i}	1.78 ± 0.30^{j}
	DH	4.76 ± 0.05^{g}	3.80 ± 0.10^{f}	0.88 ± 0.06^{g}	1.25 ± 0.05^{de}	4.72 ± 0.12^{g}	1.3 ± 0.58^{f}
	DB	4.2 ± 0.12^{f}	3.2 ± 0.21^{e}	0.93 ± 0.009^{j}	1.32 ± 0.07^{efg}	3.93 ± 0.26^{e}	0.98 ± 0.65^{b}
	% change N to DH	–31.07	–37.4	10	8.7	–37.3	–27
	% change DH to DB	–11.8	–15.8	5.7	5.6	–16.7	–24.6

All the values presented are expressed as mean ± standard deviation. Different superscripts within the same column and row indicate significant difference ($P < 0.05$).

Table 2. Effect of dehusking and debranning on the dimensional features of millets

Name of the millet	Process	Length (mm) (mean ± SD)	Breadth (mm) (mean ± SD)	Thickness (mm) (mean ± SD)	Geometric mean diameter (mm) (mean ± SD)	Arithmetic mean diameter (mm) (mean ± SD)	Aspect ratio (%) (mean ± SD)	Surface area (mm^2) (mean ± SD)	Sphericity (%) (mean ± SD)
Foxtail	N	2.53 ± 0.13^{h}	1.61 ± 0.11^{b}	1.21 ± 0.10^{c}	1.70 ± 0.09^{e}	1.78 ± 0.08^{e}	63.91 ± 5.73^{a}	9.11 ± 0.97^{f}	67.44 ± 4.26^{a}
	DH	2.0 ± 0.09^{f}	1.6 ± 0.09^{ab}	1.1 ± 0.09^{ab}	1.5 ± 0.07^{c}	1.6 ± 0.06^{c}	77.5 ± 4.18^{cd}	7.3 ± 0.63^{d}	75.6 ± 3.24^{bc}
	DB	1.71 ± 0.06^{bc}	1.57 ± 0.06^{ab}	1.1 ± 0.07^{ab}	1.45 ± 0.04^{b}	1.5 ± 0.04^{b}	91.8 ± 5.38^{ef}	6.6 ± 0.40^{b}	84.56 ± 3.56^{de}
	% change N to DH	–20.9	–0.6	–9.1	–11.8	–10.1	21.3	–19.9	2.1
	% change DH to DB	–14.5	–1.9	0	–3.3	–6.3	18.5	–9.6	11.9
Little	N	2.21 ± 0.10^{g}	1.57 ± 0.08^{ab}	1.21 ± 0.08^{c}	1.61 ± 0.06^{d}	1.67 ± 0.05^{d}	71.34 ± 5.60^{b}	8.20 ± 0.59^{e}	73.08 ± 3.71^{b}
	DH	1.78 ± 0.11^{cd}	1.56 ± 0.07^{ab}	1.12 ± 0.05^{ab}	1.46 ± 0.04^{b}	1.5 ± 0.04^{b}	87.7 ± 7.05^{e}	6.7 ± 0.34^{bc}	82.1 ± 3.92^{d}
	DB	1.6 ± 0.12^{a}	1.50 ± 0.04^{a}	1.07 ± 0.05^{af}	1.37 ± 0.05^{a}	1.40 ± 0.05^{a}	94.64 ± 7.88^{g}	5.94 ± 0.42^{a}	86.12 ± 4.63^{ef}
	% change N to DH	–19.5	–0.6	–7.4	–9.3	–10.2	22.9	–18.3	12.3
	% change DH to DB	–10.1	–3.8	–4.5	–6.2	–6.7	7.9	–11.3	4.9
Kodo	N	2.72 ± 0.17^{i}	2.21 ± 0.18^{g}	1.50 ± 0.12^{e}	2.08 ± 0.13^{h}	2.14 ± 0.13^{h}	81.09 ± 5.90^{d}	13.65 ± 1.7^{i}	76.49 ± 3.38^{c}
	DH	1.91 ± 0.13^{e}	1.85 ± 0.14^{e}	1.21 ± 0.13^{c}	1.62 ± 0.10^{d}	1.66 ± 0.10^{d}	96.76 ± 7.24^{g}	8.26 ± 1.09^{e}	84.78 ± 5.36^{de}
	DB	1.7 ± 0.11^{ab}	1.8 ± 0.08^{de}	1.2 ± 0.08^{bc}	1.5 ± 0.06^{c}	1.5 ± 0.06^{c}	109 ± 7.91^{h}	7.2 ± 0.57^{cd}	91.64 ± 5.38^{hi}
	% change N to DH	–29.8	–16.3	–19.3	–22.1	–22.4	19.3	–39.5	10.8
	% change DH to DB	–11	–2.7	–0.8	–7.4	–9.6	2.6	–12.8	8.1
Barnyard	N	2.66 ± 0.28^{i}	1.97 ± 0.15^{f}	1.58 ± 0.13^{f}	2.02 ± 0.13^{g}	2.07 ± 0.14^{g}	74.85 ± 7.12^{bc}	12.87 ± 1.7^{h}	76.41 ± 7.12^{c}
	DH	1.75 ± 0.08^{b}	1.73 ± 0.10^{cd}	1.20 ± 0.08^{c}	1.54 ± 0.07^{c}	1.56 ± 0.07^{c}	98.91 ± 4.31^{g}	7.43 ± 0.66^{d}	87.80 ± 2.26^{fg}
	DB	1.61 ± 0.09^{ac}	1.69 ± 0.09^{c}	1.10 ± 0.07^{a}	1.44 ± 0.44^{b}	1.47 ± 0.04^{b}	105.5 ± 8.81^{h}	6.52 ± 0.37^{b}	89.64 ± 5.06^{gh}
	% change N to DH	–34.2	–12.2	–24.1	–23.8	–24.6	32.1	–42.3	14.9
	% change DH to DB	–8	–2.3	–8.3	–6.5	–5.8	6.6	–12.2	2.1
Proso	N	2.81 ± 0.07^{i}	2.14 ± 0.10^{g}	1.53 ± 0.0^{f}	2.1 ± 0.05^{h}	2.2 ± 0.05^{h}	76.17 ± 4.37^{c}	13.9 ± 0.70^{i}	74.66 ± 2.34^{b}
	DH	2.13 ± 0.10^{g}	2.01 ± 0.07^{f}	1.46 ± 0.06^{de}	1.84 ± 0.04^{f}	1.87 ± 0.04^{f}	94.36 ± 5.65^{fg}	10.67 ± 0.5^{g}	86.43 ± 3.36^{ef}
	DB	1.87 ± 0.08^{de}	1.95 ± 0.14^{f}	1.42 ± 0.07^{d}	1.73 ± 0.06^{e}	1.75 ± 0.06^{e}	104.6 ± 849^{h}	9.39 ± 0.68^{f}	92.75 ± 4.08^{i}
	% change N to DH	–24.2	–6.1	–4.6	–12.4	–15	23.9	–23.2	15.8
	% change DH to DB	–12.2	–3	–2.7	–6	–6.4	10.9	–12	7.3

All the values presented are expressed as mean ± standard deviation. Different superscripts within the same column and row indicate significant difference ($P < 0.05$).

clear that in the case of all the millets, dehusking caused a considerable decrease in the *L*, *B* and *T* values; on the other hand, the differences between the DH and DB millets for the *L*, *B*, *T* values were marginal. This information will be very useful in designing the screens for grading the N and processed millets. According to previous studies[17], the *L*, *B* and *T* values for DH proso are comparable to our study results.

Milling of millets has implications for food and the economic aspects. A study[18] reported that the yield of edible matter (DH millets) from the little, foxtail, finger, barnyard, proso, brown top and kodo was 70%, 70%, 90%, 55%, 67.5%, 55% and 60% respectively. Millet processors have been facing difficulties in the primary processing of these millets, and the yield of the millets has been low due to the lack of appropriate millet processing machinery. Designing appropriate precleaning, dehusking and debranning equipment utilizing these physical properties can help improve the millet yield and reduce the cost of millet. Dehusked grains are nutritionally superior (similar to brown rice), and DB millets are similar to milled rice. However, dehusking grains have poor keeping quality as well as cooking and eating qualities. Also, they have poor consumer acceptability. Given this, the millets were debranned. Undoubtedly, debranning lowers protein, dietary fibre and minerals, and the loss depends on the DOM[5]. The impact of debranning on the nutritional characteristics of these millets is reported in our recent manuscript separately[9].

In addition to the *L*, *B* and *T* parameters, GMD and AMD were determined. GMD is a measure of the overall size of the grain based on the grain primary axis (*L*, *B*, *T*). AMD is computed by averaging the *L*, *B* and *T* of the grains along the axis, which is referred to as the grain's axial dimension. The barnyard and kodo millet showed the highest decrease in GMD of 23.8%, 22.1% on dehusking and 6.5% and 7.4% on debranning respectively; this could be due to the spherical nature of both the grains. On the other hand, the GMD values of foxtail, little and proso millets were decreased by 11.8%, 9.3%, 12.4% on dehusking and 3.3%, 6.2% and 6% on debranning respectively. Relatively lower values could be due to the slightly oval shape of the grains. Barnyard and kodo had the greatest decrease in AMD of 24.6% and 22.4% on dehusking respectively. This may be mainly due to a higher gap between the husk and the millet kernel. AMD values decreased on dehusking and debranning (Table 2). The GMD aids in determining a seed's projected area by demonstrating its behaviour in turbulent and non-turbulent flowing systems such as an air stream. This provides insight into aerial grain classification and pneumatic removal of unwanted components from millets.

Aspect ratio of seeds which compares its *B* and *L*, provides information about how oblong it is. The AR showed differences in the values on DH and DB operations in all the millets studied. Generally, the values for AR increased on DH and DB. It was observed that the AR of N, DH and DB millet values for foxtail millet were the lowest, whereas the highest for kodo millet (Table 2). The kodo millet grains were bigger with larger surface area than other grains, while at least for little millet in N, DH and DB forms respectively. The SA values for DB millets followed the same trend. Removal of the bran (debranning) reduces the SA considerably. The S values represent the shape of the grains, such as spherical, oval, etc. Among the millets studied, N kodo millet was relatively more spherical than all millets. On dehusking and debranning, the sphericity of the grains increased. The S of the proso millet in N, DH and DB forms were the highest, and the least was foxtail millet. A slight increase in the S could be due to removing the husk and bran. Except for kodo and barnyard, all other grains were nearly spherical oval shaped. It was observed that the S values differed considerably not only among the different millets but also in their DH and DB forms. Similarly, AR, SA and S for finger millet cultivars were similar to our results observed for the millets studied in the current study[19].

The information on 1000 kernel weight, 1000 kernel volume, TD, BD, DE, hardness, *L*, *B*, *T*, GMD, AMD, AR, SA and *S*, on the millets (in the N, DH, DB forms) reported study are scanty as compared to the data available on sorghum and pearl millet. The values reported for 1000 kernel volume, BD, TD, DE, *L*, *B*, *T*, AR, GMD, AMD, AR, SA and *S* for proso millet are comparable to our values reported for DH proso millet.

Limitations of our study include different milling parameters for different millets (different duration of milling applied for different millets based on the visual observations for loss of bran) produced millets with different DOM and hence, direct comparison of the parameters analysed in the study between millets could not be made. Only one variety from each of the five millet crops was studied; studying a large number of millet varieties will help industries design millet processing machinery. Research in this direction is needed to understand the changes in the physical and dimensional properties of these millets with similar DOM to draw comparative conclusions between different millets. The strength of the study is that it attempts to bring out the changes in the physical and dimensional properties of these millets upon dehusking and debranning (though not the same DOM between different millets), which are not currently available.

Conclusions

This study shows the changes in physical characteristics in the native, dehusked and debranned millets. To preserve the nutritional value of these millet, food industries ought to explore the possibility of producing a variety of millet-based health-enhancing food products utilizing dehusked millets. Due to the scarcity of studies on the millet dehusking and debranning aspects, the current study will help design millet processing machinery.

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