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Effect of processing on the physico-chemical parameters of minor millet grains

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Abstract
In order to diversify the uses on minor millets, the study was undertaken to understand the changes caused due to processing on the selected physico-chemical parameters. Results indicated significant difference (at 5% level of significance) for all the minor millets at physical and chemical levels. The physical parameters i.e. length, width, thickness, geometric mean diameter, arithmetic mean diameter, surface area were observed highest in case of puffed grain (3.75 mm, 3.38 mm, 2.31 mm, 3.08 mm, 3.15 mm, 30.58 mm^2 respectively and lowest for dehulled grain (2.05 mm, 1.72 mm, 1.18 mm, 1.60 mm, 1.63 mm, 9.59 mm respectively). Proximate composition expressed high values for protein and low values for ash, moisture and fat content when compared to raw millet grains, making processed Ready to Eat (RTE) product viable for snacking purpose.

Keywords: minor millets, physical parameters, chemical parameters, dehulling, puffs

Introduction
Minor millets, also referred to as small millets, includes several grain crops namely barnyard millet, foxtail millet, kodo millet, little millet and proso millet. They contain 9–14% protein, 70–80% carbohydrates and are rich source of dietary fibre (Malleshi and Hadimani, 1993) [14]. These treasure trove of nutrition, have received far less attention, due to cultural attachments and non-availability of processed millet products similar to rice or wheat. Generally, millets, before consumption are preferred to be processed, to improve their edible, nutritional, and sensory properties (Lestienne *et al.* 2005; Shobana and Malleshi 2007) [11, 23].
Millets have high potential for processing at traditional and industrial levels, involving small, medium and large scale entrepreneurs (Obilana and Manyasa, 2002; Hamad, 2012) [19, 9]. The processing of the grain involves primary (wetting, dehulling and milling) and secondary (fermentation, malting, extrusion, flaking, popping, roasting etc.) operations, however limited information exists on the comparison of physico-chemical changes in minor millets, due to processing.
The physical properties of millet i.e., size, shape, geometric mean diameter, surface area, volume, sphericity, 1000 seed mass, bulk density, porosity, play an important role in selecting the proper separating and cleaning equipment whereas the main dimensions are considered in selecting and designing the suitable size of the screen perforations, for their handling, storing and processing (Balasubramanian and Vishwanathan, 2010; Ojediran *et al.* 2010; Swami and Swami, 2010; Singh *et al.*, 2010; Ramappa *et al.*, 2011) [4, 20, 28, 25, 22]. Such basic information should be of value not only to engineers but also to food scientists and processors who may exploit these properties and set grading standards on millets like we have for rice and wheat. Although, the information on physico-chemical properties for many food grains is available, but the information of these properties for minor millets is lacking and hence this study was undertaken.

Materials & Methods
Procurement and preparation of sample
Raw grains (barnyard, foxtail, kodo, little and proso millets) were procured from the stores of Indian Institute of Millets Research, Rajendranagar, Hyderabad. The grains were evaluated for their pre-formulation studies namely, bulk density, tapped density, sphericity and roundness. In the case of puffing, the grains were de-hulled to ensure the removal of inedible part i.e. husk and darker grains like barnyard, kodo and little were even polished to get pearl white products for consumer appeal.

Afterwards, the engineering properties like, length, width, thickness, slenderness ratio, aspect ratio, geometric mean diameter (GMD), arithmetic mean diameter (AMD), thousand kernel/puff weight were evaluated for raw and processed (dehulled and puffed) grains. On the basis of preliminary research trials, 18% moisture content at 1.0 MPa pressure was considered best for secondary processing like puffing, and hence comparison study on the basis of chemical parameters like, moisture content, fat content, protein content and ash content for raw and puffed grains were evaluated.

Physical properties of raw grain

Bulk density and tapped density

The term bulk density and tapped density is used to measure anatomy and packing of grains. The tapped density was calculated by manually tapping, and hence tapped grain was considered for calculation. Thereafter, both the densities were calculated as a ratio between the kernel weight and the volume of the cylinder (Singh; Goswami, 1996) [24] as shown in equation.

$$\text{Bulk density} = \frac{\text{Weight of grain (kg)}}{\text{Volume of container } (\text{m}^3)}$$

Sphericity (Φ)

Sphericity measures the degree to which a particle approaches a spherical shape. The sphericity was calculated as (Geankoplis, 1999) [8]:

$$\Phi = \frac{(\text{LWT})^{1/3}}{\text{L}}$$

Roundness (R)

Roundness refers to the sharpness of the corners and edges of a grain. It was calculated using the relationship given by Mohsenin (1980) [17]:

$$\text{R} = \frac{\text{A}_\text{p}}{\text{A}_\text{c}}$$

Where, A_p= largest projected area of object in natural rest position, mm^2

A_c= area of the smallest circumscribing circle, mm^2

Determination of different Engineering Properties of the millet grain

Grain size

The length (L), width (W) and thickness (T) were measured on randomly selected 100 grains for each minor millet i.e. barnyard, foxtail, kodo, little and proso. The measurements were taken using a digital vernier calliper having least count of 0.05 mm.

Slenderness Ratio (Sr)

The slenderness ratio (the ratio of grain length to width) was determined by the following equation (Bagheri *et al.*, 2011) [3].

$$\text{Sr} = \frac{L}{W}$$

Aspect Ratio (Ar)

The aspect ratio was calculated as given by (Maduako and Faborode, 1990) [13].

$$\text{Ar} = \frac{W}{L}$$

Geometric mean diameter (D_g)

The geometric mean diameter of maize grain was calculated by using the relationship (Mohesnin, 1986) [16]:

$$\text{D}_\text{g} = (\text{LWT})^{1/3}$$

Arithmetic mean diameter (D_a)

The geometric diameter of maize grain was calculated by using the relationship (EL–Raie *et al.*, 1996) [7]:

$$\text{D}_\text{a} = \frac{\text{L} + \text{W} + \text{T}}{3}$$

Surface area

The surface area, S, was found by using the following relationship (McCabe *et al.*, 1993) [15]

$$S = \pi D_g^2$$

1000 kernel/puff weight

It gives an idea about the density of the grains or puffs and is directly related to bulk density. 1000 no. of sound kernels or puffs were counted and the weight is measured using a four point sensitive electronic weighing balance. Average of three such reading is taken and is expressed as "g".

Determination of proximate composition of raw and puffed grain

The parameters like moisture content, fat content, protein content and ash content were determined using standard methods as discussed under:

Moisture content

The initial moisture content of kernels was measured by standard air oven method (AOAC 2000). The kernels were kept in the oven at 130ºC for 4 hr; the loss in weight was noted down and the moisture content was determined using the following equation:

$$\text{M.C.}(\%\,\text{wb}) = \frac{W_1 - W_2}{W_1} \times 100$$

Where, W_1 = Weight of original sample (g), W_2 = Weight of dry sample (g)

Protein content

Protein in food samples is determined as a function of free nitrogen released. It is measured using micro-Kjeldhal method (AACC 46-13, 1986) [1] which consists of three predominant steps namely, digestion, distillation or neutralization and titration. The average of three measurements was calculated, protein content is then expressed using the following formula.

$$N_2 = \frac{(\text{blank titre} - \text{sample titre}) \times \text{Normality of HCl} \times 14 \times 100}{\text{weight of sample taken} \times 1000}$$

And Protein (%) = 6.25×Nitrogen (N_2) content (%).

Crude fat content

Crude fat in food samples is determined as the change in weight recorded after exhaustively extracting the food sample with a non-polar solvent. The conventional AACC method (AACC Method 30 - 25.01, 1999) [1] involves the use of the Soxhlet apparatus which has three parts – the reactor, where the food sample is added, a condenser and the lower chamber (usually a flat bottomed or round bottomed flask) that contains the reservoir for the organic solvent. The average of three measurements was calculated, crude fat content is then expressed using the following formula.

$$\text{Crude fat (\%)} = \frac{\text{weight of fat(g)} \times 100}{\text{weight of sample}}$$

Ash content
About 5g of samples were taken in crucibles. These were burnt on the hot plate and then placed in an electric muffle furnace at 600°C for 6 hours as shown in Fig. 3.11. After cooling the crucibles to room temperature, the residue left (Ash) in crucibles were weighed (AOAC, 2000) [1].
The following formula was used to calculate the ash content percentage.

$$\text{Ash content (\%)} = \frac{\text{Weight of ash (g)}}{\text{Weight of sample (g)}} \times 100$$

Statistical Analysis: The data obtained from the experiments were analyzed using the analysis of variance (ANOVA) (Panse and Sukhatme, 1985) [21]. Means comparison were performed using Tukey's studentized range test to determine the significance of moisture content and pressure on the following product characteristics, puffing yield, expansion volume, bulk density and thousand puff weight. The data was analysed for significance at ($P \leq 0.05$) using SPSS 20.0.

Results & Discussion
A summary of the results for all the parameters measured and determined is shown in Table 1 to 5 and comparison has been expressed in terms of figures (Fig. 1 to 4).

Physical characteristics of Minor millet grains
In order to understand the changes due to processing, selected physical parameters of grain were studied. The variations among minor millets for bulk density, tapped density, roundness and sphericity are shown in Fig 1. & 2. The bulk density and tapped density varied in the range from 814 to 837 kg/m^3 and 833 to 867 kg/m^3 respectively, whereas roundness and sphericity varied from 0.73 to 0.92 and 0.74 to 0.90 respectively for all the minor millets (Table 1). A similar relationship was reported by Baryeh, 2002 [5]; Subramanian and Viswanathan, 2007 [4], for selected minor millets.

Table 1: Selected physical characteristics of raw minor millet grains

Minor millets	Bulk density (kg/m^3)	Tapped density (kg/m^3)	Roundness	Sphericity
Barnyard	825±1.00^b	837±0.79^c	0.92±0.01^a	0.84±0.03^a
Foxtail	821±0.97^c	839±0.88^c	0.75±0.03^c	0.74±0.02^c
Kodo	814±0.95^c	845±1.00^b	0.92±0.02^a	0.90±0.08^a
Little	821±1.00^d	833±0.97^d	0.73±0.04^c	0.79±0.03^c
Proso	837±0.94^a	867±1.00^a	0.85±0.07^b	0.85±0.06^b

Values are based on mean ± standard deviation using Tukey's b standardized range test
& Values with different letters differ significantly (P<0.05)

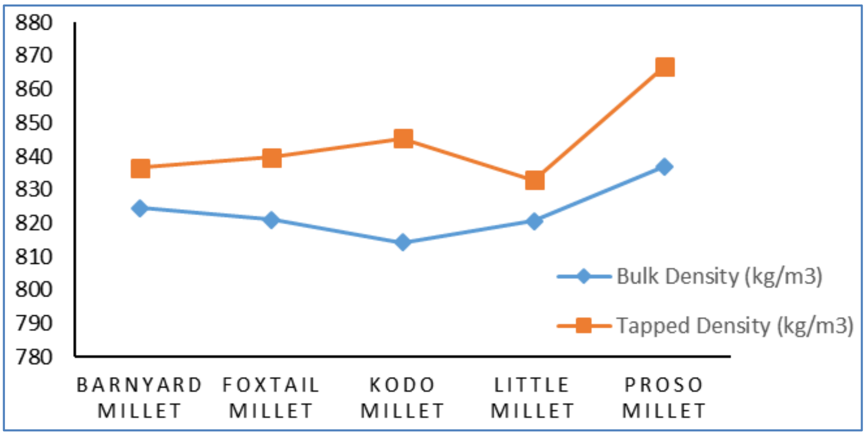

Fig 1: Bulk density and Tapped density of minor millets

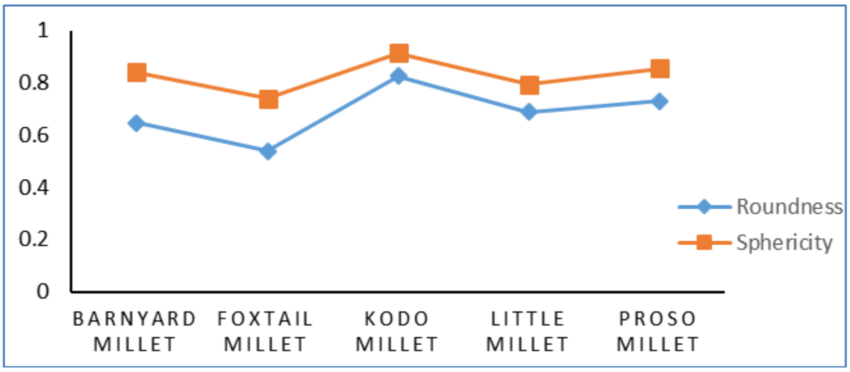

Fig 2: Roundness and Sphericity of minor millets

Engineering properties of minor millet (Raw/Dehulled/ Puffed) grains

Significant differences were observed in all the minor millets ($p<0.05$), for raw, dehulled and puffed grains (Table 2). The parameters like length, width, thickness, geometric mean diameter, arithmetic mean diameter, surface area were highest in case of puffed grain, and lowest for dehulled grain. This may be attributed to the fact that dehulling operation removed the outer layer, whereas in puffing operation, high temperature and pressure expanded the grain, hence the grain dimensions might change due to these processing operations. All the minor millets (raw, dehulled and puffed) differed significantly ($p<0.05$), wherein kodo millet expressed maximum geometric mean diameter (2.49 mm), arithmetic mean diameter (2.55 mm), surface area (22.43), followed by proso, barnyard, foxtail and little millet. Slenderness ratio showed no significant difference among Barnyard (1.20) and little (1.22), whereas foxtail, kodo and proso differed significantly ($p<0.05$) (Table 3). The comparison among minor millets has also been explained graphically for better understanding (Fig. 3). Similar studies has been conducted by Srivastava and Batra (1998), Jones *et al.*, (2000), Chen and Yeh, (2001); Balasubramanian S. and Viswanathan R. (2010) [26, 10, 6, 4] which are connected with the compositional characteristics of the grain.

Table 2: Physical characteristics of Minor millets

Type of millet	Length (mm)	Width (mm)	Thickness (mm)	Slenderness ratio	Aspect ratio	Geometric Mean Diameter	Arithmetic Mean Diameter	Surface Area	Thousand kernel/ puff weight
Raw grain	2.73^c	1.80^b	1.29^b	1.55^a	0.66^c	1.85^b	1.95^b	10.92^b	3.29^a
Dehulled grain	2.05^b	1.72^c	1.18^c	1.21^b	0.84^b	1.60^c	1.63^c	9.59^c	2.81^b
Puffed grain	3.75^a	3.38^a	2.31^a	1.11^c	0.91^a	3.08^a	3.15^a	30.58^a	2.45^c

Values with different letters differ significantly ($P<0.05$)

Table 3: Overall physical characteristics of Minor millets

Minor millets	Length (mm)	Width (mm)	Thickness (mm)	Slenderness ratio	Aspect ratio	Geometric Mean Diameter	Arithmetic Mean Diameter	Surface Area	Thousand kernel/puff weight
Barnyard	2.73^c	2.34^c	1.60^c	1.20^a	0.85^b	2.17^c	2.23^c	17.97^c	2.74^c
Foxtail	2.74^c	1.91^d	1.42^e	1.53^a	0.68^d	1.95^d	2.02^d	13.52^d	2.37^d
Kodo	3.10^b	2.78^a	1.79^a	1.12^d	0.90^a	2.49^a	2.55^a	22.43^a	3.13^b
Little	2.21^d	1.87^e	1.44^d	1.22^c	0.84^b	1.81^e	1.84^e	10.87^e	1.83^e
Proso	3.39^a	2.51^b	1.64^b	1.41^b	0.73^c	2.40^b	2.48^b	19.06^b	4.38^a

Values with different letters differ significantly ($P<0.05$)

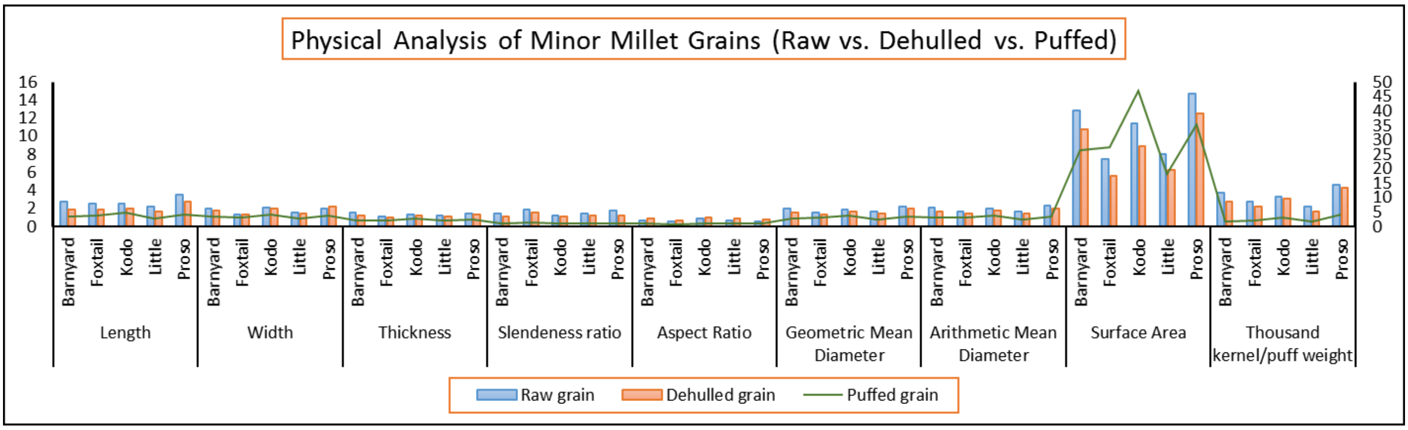

Fig 3: Comparison among physical characteristics of Minor millets

Chemical properties of the minor millet (Raw/ Dehulled /Puffed) grains

Results indicated high ash and moisture content and low fat and protein for raw millets when compared to puffed grains (Table 4) for all the minor millets. The higher protein percentage may be due to the inactivation of enzymes while puffing, which increases the protein digestibility (Muralikrishna *et al.*, 1986; Subramanian *et al.*, 1986) [18, 27]. Overall it was observed all the minor millets, differed significantly ($p<0.05$) in terms of proximate composition (Table 5, Fig. 4.). Low moisture, fat, ash and high protein content makes these puffs, viable ready to eat (RTE) healthy snack product, incorporating which can add value to the health as well as to the grain as whole. The changes observed can be compared with the unprocessed minor millet grains (Longvah *et al*; 2017) [12].

Table 4: Chemical characteristics of Minor millets

Type of millet	Ash content (%)	Moisture content (%)	Fat content (%)	Protein content (%)
Raw grain	1.70 ± 0.05	10.89 ± 0.06	3.04 ± 0.20	10.05 ± 0.57
Puffed grain	1.02 ± 0.04	4.37 ± 0.06	2.48 ± 0.20	11.54 ± 0.56

Values are based on mean ± standard deviation using Tukey's b standardized range test.

Table 5: Overall chemical characteristics of Minor millets

Minor millets	Ash content (%)	Moisture content (%)	Fat content (%)	Protein content (%)
Barnyard	1.39^b	7.53^b	2.53^c	8.96^d
Foxtail	1.53^a	7.59^c	3.77^a	12.48^b
Kodo	1.30^d	7.94^a	2.32^d	9.74^c
Little	1.25^e	7.41^e	3.33^b	8.76^e
Proso	1.35^c	7.68^b	1.85^e	14.04^a

Values with different letters differ significantly (P<0.05)

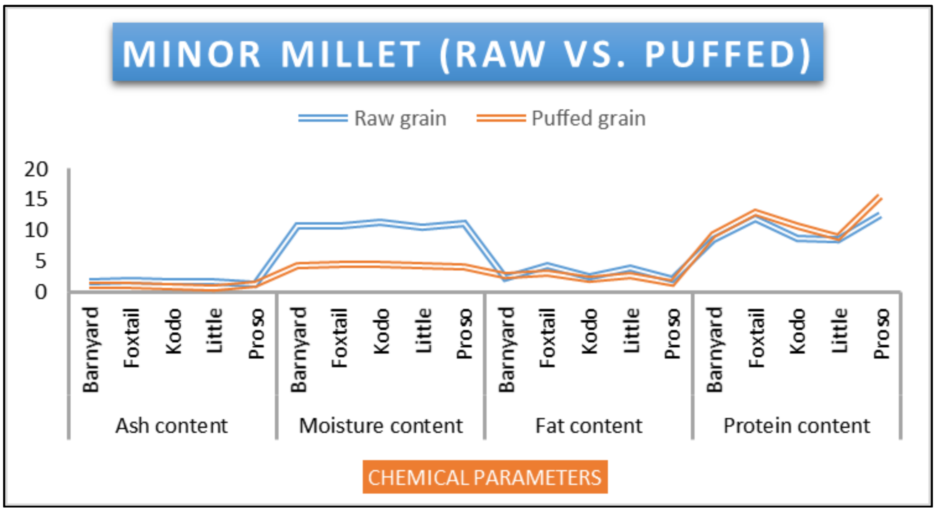

Fig 4: Comparison among chemical characteristics of minor millets

Conclusion

Overall it can be concluded from the study that the physico-chemical parameters showed significant result (p<0.05) for all the minor millets. The outcome is likely to be useful for anyone who wants to understand effect of processing on these grains. The physical parameters can help in understanding the grain quality, henceforth future works could be undertaken to set specific standards for grains like rice and wheat. The proximate analysis of the final product, indicated high protein content and low moisture, fat and ash (0.71-1.27%) contents, making millet puffs as one of the healthy convenient snack option.

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