Geometrical properties of underutilized cereal varieties of Himalayan origin for the development of future processing equipments.

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Abstract

This paper presents the database of physical and engineering characteristics of grains and flours of five underutilized cereal varieties viz sorghum, buck wheat, pearl millet, proso millet and barley of Himalayan origin. The results revealed a significant difference in width, length and breadth of these cereals. The sphericity value of cereal grains showed significant difference ($p \leq 0.05$) in the range 97.42 to 137.25.84% which was found to be highest for sorghum grain while as aspect ratio was found highest for proso millet grain. The static coefficient of friction samples was found maximum on corrugated board for the flour and grain. The hausner ratio and compressibility index indicated poor flowability of the sorghum flour. The bulk density, tapped density and porosity values of cereal grains varied significantly for cereal grains as well as flours. ATR-FTIR (attenuated total reflectance-Fourier transform infrared spectroscopy) confirmed the different types of linkages present in the flour samples found within the absorption bands of $3500-993 \text{ cm}^{-1}$.

Introduction

The consumption of whole grain flours in modern world is continuously increasing due to their health benefiting properties¹. Currently, cereals are commonly used as staple food grains and whole grain flours in several parts of the world like Africa, Asia and South America. Apart from some extensively cultivated and consumed cereals like wheat, rice, or maize which are used for the production of different whole grain products there are several underutilised cereals which include millets, sorghum, buck wheat that are found abundantly in the world with well adaptation to harsh climatic conditions of the world. The whole flours of these cereals are mainly used as substrates for manufacturing a different variety of beverages and fermented foods and fodder for animals^{2,3}. However, these can become a potent source of nutrition to the increasing world population, thereby combating food security issues of the world. The cereals are also reported to be the great source of carbohydrates, dietary proteins, minerals, fibre and vitamins⁴. These cereals also contain traces of minerals like calcium, iron, phosphorus, potassium and also great content of oil compared to other main cereals⁵. Various studies have shown presence of different flavonoids and phytochemicals in these minor underutilised grains exhibiting antioxidant, anti-diabetic, anti-cancerous, anti-hypertensive and anti-inflammatory properties⁶. With these promising attributes the minor grains can be viewed as an important ingredient for the development of various whole grain-based food products. However, despite these positive aspects their utilization in current food industry is still restricted by inadequate research efforts and availability of equipment's for processing and handling of such small cereals. The present work is designed to acquire the knowledge regarding the various engineering properties of these cereals such the activities like sorting, cleaning, grading, drying and milling can be done easily⁷. The measurement of different physical characteristics directly influence the handling, processing, packaging and storage conditions in silos and hoppers during transportation properties⁸. The variety of grains in food industries necessitates the information regarding different physical attributes and powder characteristics of these flours due to their complex nature. The current study aims to determine the gravimetric and aerodynamic properties like porosity, bulk density, friction coefficient and angle of repose of these cereal grains and flours which will be helpful for providing guidelines to engineers for the designing and optimisation of different agricultural processing machines. The properties like bulk density, porosity, angle of repose and true density can be helpful for designing the grain hoppers, post harvest handling and storage facilities.

Results And Discussion

2.1. Geometrical properties

The mean results of main geometric parameters of five cereal varieties i.e. sorghum, pearl millet, proso millet, barley and buck wheat are presented in Table 1. Considering the width, length and thickness of five grain varieties, length values were found to be significantly ($p \leq 0.05$) higher for barley followed by buck wheat whereas width was found greater for sorghum grains. Proso millet grain was found to be smallest of all in all respects. Hamdani et al.⁹ reported almost similar results for length, width and thickness values for hulled barley and SKO-20 oats which ranged from 8.57 to 11.31 mm, 2.70 to 3.70 mm and 2.24 to 2.85 mm, respectively. The knowledge of these three important dimensions can be helpful in scheming the aperture sizes of grain handling machineries. The geometric mean diameter varied in the range from 1.88 to 3.86 mm and the arithmetic mean diameter ranged from 1.89 mm to 4.08 (Table 1). Both arithmetic and geometric diameters were found to be significantly ($p \leq 0.05$) higher for buck wheat grains. Adebowale et al.¹⁰ reported similar results for arithmetic and geometric mean diameters for millet grains. The geometric mean diameter helps in the measurement of seeds projected area indicating its pattern of behaviour in both turbulent and non-turbulent flowing systems like air stream. This gives an idea about aerial classification of grains and for removal of undesirable materials by pneumatic means from the sample. The equivalent sphere diameter significantly varied ($p \leq 0.05$) from 1.96 to 1.79 mm and was found to be highest for proso millet grains. The mean result for 1000-grain weight ranged from 97 to 24.4 g with pearl grains showing significantly highest mean result compared to all other varieties. Shah et al.¹¹ reported 1000 grain weight for Sabzaar, SKO20 and SKO90 to be 36.07, 36.543, 36.57 g respectively. Shape is another important parameter for the cleaning and separation of unwanted foreign materials, food materials quality evaluation, mass and heat transfer calculations etc. Also by knowing the size and shape of grains foreign materials can be easily separated from the samples by the help of electrostatic force. The shape of a food grains is determined by its aspect ratio and sphericity. Sphericity values expresses the shape of the grain relative to the sphere of almost same volume. The sphericity values of cereal grain varieties showed a significant difference ($p \leq 0.05$) and was found to be 137.25, 97.42, 121.12, 163.55 and 130.84% for sorghum, proso, pearl, barley and buck wheat, respectively. It implies that some seeds have sphericity and some are elongated. Aspect ratio gives an indication about how oblong a seed is by relating its width and length. The aspect ratio of sorghum, proso, pearl, barley and buck wheat were found to be 97.59, 100.56, 74.09, 34 and 24.4 %, respectively. Higher the values of sphericity and aspect ratio of a seed, higher will be its ability to roll. This property of seed assists in proper designing of processing equipment. The different surface area values lie in the range of 11.09 to 46.78 mm² for different varieties, with buck wheat having the highest surface area. Ramashiaa et al.¹² reported aseptic ratio, sphericity and surface area for finger millet cultivars in the range of 73.55 – 92.21 %, 64.17 - 92.43% and 5.73 -24.81 mm², respectively. Seed volume of the grains was also found significantly ($p < 0.05$) different for five different cereal grains. Adebowale et al.¹⁰ obtained the seed volume of 5.56 mm³ for millet grains, which is almost similar to our results for millet varieties. Aseptic ratio was found within the range of 3.75 to 20.23 mm³ in all the five cereal varieties in which buck wheat and barley grains showed relatively low aseptic ratio determining their more sliding behaviour and less rolling tendency.

2.2. Bulk density, true density and porosity

Bulk density and true density of grains and flour samples of five different cereal varieties are presented in Table 2. The bulk and true density of cereal grains varied in the range of 0.61 to 0.79 g/mL and 1.25 to 1.66 g/mL, respectively. However, for the flour samples it varied significantly ($p < 0.05$) in the range of 0.33 to 0.45 g/mL (bulk) and 0.5 to 0.62 g/mL (true). Bulk density is an important aspect for determining the test weight and grade of the

grains during processing, drying and designing of storage and transportation containers¹⁰. Highly fine particles orient in a compressed manner and results in increased bulk density whereas coarse and rough particles do not orient so easily. The difference in bulk densities can be due to difference in particle properties of samples which mainly include the hygroscopicity, size and form of particles¹³. Samples with high bulk density values indicate that these flours can be used in the preparation of different food products while as of flour samples with low bulk density values indicate its suitability for the preparing food formulations for feeding purpose. Since sorghum flour showed the least bulk density, it can be utilised in the preparation of different complementary foods¹². Moreover, the values of porosity ranged from 49.03 to 57.51 % for five grain samples whereas it ranged from 14 to 43.67% for flour samples. More the difference between true and bulk density of samples, more is the porosity¹¹. The maximum porosity value was found for buck wheat flour, followed by sorghum flour and it was found to be minimum for barley flour. Sangamithra et al¹⁴ reported porosity values ranging from 51.30 to 55.83% for maize grain cultivar.

2.3. Static co-efficient of friction

The static coefficient of friction for grain and flour samples against three different surfaces is presented in Table 2. The highest coefficient of friction for the grains and flour samples was found on corrugated board surface compared to cardboard and glass surfaces. This is attributed to high surface area and force of adhesion between the test surface and sample particles (grain or flour) leading to increased static co-efficient of friction value¹³.

2.4. Compressibility index, Hunsner's ratio

The compressibility index of sorghum, pearl millet, pros millet, barley and buck wheat were found to be 30, 22.22, 27.41, 14 and 24.07 respectively (Table 3). As indicated by the flow ability scale (Table 4), the sorghum flour showed poor ability to flow. Pearl millet, proso millet and buck wheat flour samples were passable while as barley flour showed good flowability as validated using Hausner ratio scale (Table 4). The value of Hunsers ratio were found to be 1.42, 1.28, 1.37, 1.16 and 1.42 for sorghum, pearl millet, proso millet, barley and buck wheat, respectively. The main factors which affect the flow rate of a material are particle properties and methodology related. Different other factors like orifice shape, diameter, container material (PET) and powder bed height were kept constant throughout the study. Shah et al.¹¹ showed oat flour have very poor flow properties.

2.5. Fourier transform-infrared (FT-IR) spectroscopy

ATR-FTIR spectral analysis displayed the presence of important functional groups concentrated in the fingerprint region (900 cm⁻¹ to 3500 cm⁻¹) which correspond to the presence of main chemical constituents of flour samples (Fig. 1). The major peak in the samples is displayed in the range of 3000-3500 cm⁻¹, which correspond to the hydroxyl groups (-OH) present in the samples. Strong characteristic peaks were also found in the range of 2900-2800 cm⁻¹ and 1600-1500 cm⁻¹ which are related to the occurrence of lipids (C-H) and proteins (-NH), respectively¹⁵. Other prominent peaks were present in the carbohydrate absorption region (1200-900 cm⁻¹) confirming the presence of amylose (1076 cm⁻¹) and amylopectin (993 cm⁻¹)¹⁶. Samples revealed almost similar absorption peaks indicating the presence of identical functional groups in every sample. Bhat et al.¹⁷ revealed similar spectral profile of whole wheat flour from three different cultivars (SW-1, SKW-355 and HS-240).

Materials And Methods

3.1. Materials

Five varieties of cereals viz; sorghum, buck wheat, barley, pearl millet and proso millet were purchased from local Srinagar market, Kashmir, India. The sample grains were manually cleaned from any unwanted material and then milled to flour using high speed electric mill, sieved through 60-mesh screen. The flour obtained was kept in air tight jars at ambient room temperature for future use.

3.2. Physical properties

3.2.1. Geometrical properties of cereal grains

3.2.1.1. Dimensional Properties

Length (L), thickness (T) and width (W) of randomly selected 100 grains of five varieties of cereals were measured by a digital Vernier caliper at $\pm 0.01\text{mm}$ accuracy.

3.2.1.2. Aspect ratio

The overall shape of the grain was determined by Aspect ratio (R_a) and was obtained by using the method of Falade and Christopher¹⁸.

$$R_a = (\text{Width} / \text{Length}) \times 100$$

3.2.1.3. Volume

Volume of grains was determined by using the formulae of Jain and Bal¹⁹.

$$V = \pi B^2 L^2 / 6 (2L - B)$$

Where, $B = (WT)^{0.5}$, W and L represents width and length of grains.

3.2.1.4. Sphericity

It was measured by following the formulae of Ramashiaa et al¹².

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

where Φ represents sphericity of the grain.

3.2.1.5. Geometric mean diameter

It was calculated according to method of Shah et al¹¹ as per the formula:

$$D_g (\text{Geometric mean diameter}) = (LWT)^{1/3}$$

3.2.1.6. Arithmetic mean diameter

It was obtained by following the method of Mpotokwane et al²⁰

$$D_a (\text{Arithmetic mean diameter}) = (L+W+T)/3.$$

3.2.1.7. The surface area

The surface area, S (mm^2) of grains was obtained using the formula given by Altuntas et al²¹.

$$S = D_g^2 \cdot \pi$$

3.2.1.8. The diameter of equivalent sphere

It was calculated by following the formula of Gorial and O'callaghan ²².

$$D_e = (W_t/Y_t) (6/\pi)^{1/3}$$

Where, D_e , W_t and Y_t determines the equivalent sphere diameter (mm), seed weight (g) and true density of seed (g/mL), respectively.

3.2.1.9. Determination of 1000-grain weight

Randomly 100 grains were selected and weighed on an electronic balance. The weight obtained was then multiplied 10 times to obtain thousand grain weight (W_{1000}) of the sample¹³.

3.2.2. Gravimetical properties of grains and flour

3.2.2.1. Bulk density

Bulk density of grains/flour of each variety was measured by using a graduated measuring cylinder. The calculation was made using the formulae:

$$\rho_b = M/V_b$$

Where, ρ_b , M and V_b represents the bulk density, mass and volume of the sample seeds/flour, respectively.

3.2.2.2. True density

True density was obtained by the method of Gani et al¹³.

$$\rho_b = M/V_t$$

Where, ρ_t , and V_t represents the true density and toluene volume displaced by the grains/flour mass.

3.2.2.3. Porosity

The porosity (ϵ) of the sample grains/flour was determined by the equation given by Vanrnamkhasti et al ²³.

$$\epsilon = 1 - (\rho_b/\rho_t) \times 100$$

where ϵ , ρ_b and ρ_t represents porosity, bulk density and true density, respectively.

3.2.2.4. Static co-efficient of friction

For the determination of static coefficient of friction (μ) of grain and flour samples of all the five cereal varieties three different test surfaces viz rubber board, corrugated board and glass were attached to a wooden table with adjustable tilting plate. The flour/ grain samples were placed one by one on the test surfaces and the tilting plate was gradually raised until 70 % of the sample slides down the test surface. The angle of inclination (α) was calculated as follows:

$$\mu = \tan \alpha$$

3.2.3. Hausner ratio and Compressibility index of flour

The Hausner ratio and compressibility index of flour samples was obtained by using the formula:

$$\text{Hausner Ratio (HR)} = \rho_t / \rho_b$$

$$\text{Compressibility index} = 100 \times (\rho_t - \rho_b) / \rho_t$$

Where, ρ_t = true density and ρ_b = bulk density.

For determining the Hausner ratio and compressibility index the flowability scale by Carr ²⁴(Table 4).

3.6. Attenuated Fourier transforms infrared (ATR-FTIR) spectroscopy

The major functional groups of flour samples were investigated using an ATR- FTIR Spectrophotometer (Agilent Technologies-CARY 630, USA). The spectra was obtained within the wavelength range of 500– 3600 cm⁻¹ at 4 cm⁻¹ resolution. Powdered flour samples were directly used for the measurement at room temperature.

3.7. Statistical Analysis

For the determination of differences between the means analysis of variance (ANNOVA) was done using Duncan's test with a level of significance of 5% using commercial statistical package (SPSS 16.0). The results reported are averages of triplicate observations.

Conclusion

The study presented different engineering and mechanical characteristics of flour and grains of five underutilised cereal varieties of Himalayan origin. The bulk density, geometric diameter, arithmetic diameter, sphericity and the seed three axial dimensions width (W), length (L) and thickness (T) were determined. These dimensions are considered mainly in selecting and designing the screen perforations. The shape and size grains were significantly different and can be used as a flowability indicator which is an important parameter to be considered during their processing. The lowest bulk density of sorghum flour makes it easy for handling. Grains with high sphericity value need less angle of inclination for flowing during different processing operations. FTIR analysis indicated identical functional groups in all samples. This fundamental knowledge can help in the proper, efficient and economical equipment designing for packaging and processing of these grains and flours. Moreover, these properties of grains play an important role for the selection of proper separating, sorting, and cleaning equipment.

Declarations

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Competing interests statement

The authors declare no competing interests.

Abbreviations

L	Length (mm)
T	Thickness (mm)
W	Width (mm)
D_a	Arithmetic mean diameter (mm)
D_g	Geometric mean diameter (mm)
D_e	Equivalent sphere diameter (mm)
R_a	Aspect ratio
S	Sphericity (%)
Φ	Surface area (mm ²)
V	Volume of grain (mm ³)
W_{1000}	Thousand grain weight (g)
ρ_b	Bulk density (g/mL)
ρ_t	Tapped density (g/mL)
ϵ	Porosity (%)

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Tables

Table 1 Geometrical properties of cereal grains

	Sorghum	Proso millet	Pearl millet	Barley	Buck wheat
L	4.16±0.17 ^c	1.82±0.07 ^a	3.32±0.18 ^b	6.8±0.67 ^e	6.08±0.41 ^d
W	3.99±0.05 ^e	1.92±0.08 ^a	2.43±0.07 ^b	2.96±0.01 ^c	3.33±0.07 ^d
T	2.55±0.27 ^c	1.85±0.06 ^a	2.12±0.01 ^b	2.14±0.01 ^b	2.95±0.05 ^d
D _g	3.5±0.13 ^c	1.88±0.05 ^a	2.58±0.04 ^b	3.5±0.1 ^c	3.86±0.10 ^d
D _a	3.59±0.14 ^c	1.89±0.05 ^a	2.63±0.04 ^b	3.96±0.22 ^d	4.08±0.14 ^d
φ	142.73±1.65 ^d	97.42±3.60 ^a	121.12±1.13 ^b	163.55±2.59 ^c	130.84±1.34 ^d
D _e	1.84±0.73 ^a	1.96±0.00 ^a	1.82±0.02 ^a	1.79±0 ^a	1.92±0.08 ^a
S	38.46±2.31 ^c	11.09±0.63 ^a	20.9±0.64 ^b	38.46±2.31 ^c	46.78±2.56 ^d
R _a	97.59±4.54 ^d	100.56±2.85 ^d	74.09±5.70 ^c	43.52±4.49 ^a	52.96±4.64 ^b
W ₁₀₀₀	26.7±1.98 ^a	38±1.73 ^c	97±2.64 ^d	34±1.15 ^b	24.4±2.25 ^a
V(mm ³)	18.34±2.83 ^d	3.75±0.39 ^a	6.6±0.08 ^b	13.82±0.97 ^c	20.23±1.26 ^d

All the values presented are expressed as Mean ± Standard deviation. Different letters (a, b, c & d) within the same column indicate significant difference (P<0.05).

Table 2 Bulk density, true density, porosity and static co-efficient of friction of cereal grain & flour

		pb	pt	ε	Glass	Corrugated	Card-Board
Grains	Sorghum	0.67±0.02 ^b	1.53±0.34 ^{ab}	57.51±1.17 ^c	1±0.09 ^b	1.19±0.13 ^{ab}	1.19±0.10 ^c
	Proso millet	0.62±0.02 ^a	1.25±0.0 ^a	49.03±3.08 ^a	0.7±0.13 ^a	1.19±0.10 ^a	1±0 ^b ^c
	Pearl millet	0.79±0.02 ^d	1.56±0.06 ^b	50±2.34 ^a	1±0.10 ^b	1.42±0 ^b	0.83±0.15 ^a
	Barley	0.73±0.01 ^c	1.66±0.01 ^b	55.48±0.79 ^{bc}	0.7±0.13 ^a	1±0.18 ^a	0.75±0.04 ^a
	Buck wheat	0.61±0.01 ^a	1.33±0.01 ^b	53.38±1.79 ^{ab}	1±0.10 ^b	1.19±0.20 ^a	1±0.09 ^b
Flour	Sorghum	0.33±0.01 ^a	0.5±0.02 ^a	30±3.67 ^c	1.42±0.13 ^{ab}	11.4±3.30 ^b	2.74±0.58 ^a
	Proso millet	0.45±0.03 ^b	0.62±0.02 ^a	27.41±3.20 ^c	1.42±0.27 ^{ab}	3.73±0.57 ^a	5.67±0.71 ^a
	Pearl millet	0.35±0.00 ^a	0.45±0.00 ^a	22.22±0.28 ^b	1.19±0.10 ^a	5.67±0 ^a	2.74±0.58 ^a
	Barley	0.43±0.00 ^b	0.5±0.02 ^a	14±0.01 ^a	1.73±0.27 ^b	3.73±0.57 ^a	1.73±0.23 ^a
	Buck wheat	0.35±0.04 ^a	0.5±0.20 ^a	43.67±3.11 ^d	1.73±1.19 ^{ab}	5.67±0.71 ^a	1.73±0.23 ^a

All the values presented are expressed as Mean ± Standard deviation. Different letters (a, b, c & d) within the same column indicate significant difference (P<0.05).

Table 3 Compressibility index and Hunsner's ratio of cereal flour

	Compressibility index	Hausner ratio
Sorghum	30±3.67 ^b	1.42±0.07 ^{ab}
Pearl millet	22.22±4.15 ^b	1.28±0.00 ^{ab}
Proso millet	27.41±3.20 ^b	1.37±0.06 ^{ab}
Barley	14±0.89 ^a	1.16±0.06 ^a
Buck wheat	24.07±4.06 ^b	1.42±0.34 ^b

All the values presented are expressed as Mean ± Standard deviation. Different letters (a, b, c & d) within the same column indicate significant difference (P<0.05).

Table 4 Flowability scale

Compressibility index (%)	Hausner ratio	Flow characteristics
10	1.00–1.11	Excellent
11-15	1.12–1.18	Good
16-20	1.19–1.25	Fair
21-25	1.26–1.34	Passable
26-31	1.35–1.45	Poor
32-37	1.46–1.59	Very poor
>38	>1.60	Very, very poor

Figures

Figure 1

FT-IR spectra of flour samples: (A) Sorghum (B) Proso millet (C) Barley, (D) Pearl millet, and (E) Buck wheat.