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Moisture-Dependent Some Physical Properties of Selected Food Grains

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ABSTRACT

The design of post-harvest equipment is centered on the physical characteristics of agricultural food grains, which are dependent on their moisture content. The physical and engineering properties of materials are decisive in addressing various challenges related to machine design and evaluating how products perform during agricultural processes like handling, planting, harvesting, threshing, cleaning, sorting and drying. In the recent study, numerous physical properties (Bulk density, True density, Porosity, GMD, Sphericity and Surface area) of different food grains (wheat paddy, gram, pigeon pea and pea) were determined at five levels of moisture content i.e. 10%, 13%, 16%, 19% and 22% on wet basis. As the moisture content of food grains increases, their average length (mm), width (mm), thickness (mm), bulk density (kg/m^3), true density (kg/m^3), porosity (%), geometric mean diameter (mm), sphericity, and surface area (mm^2) all show an upward trend.

Keywords Moisture content, True density, Bulk density, Sphericity, Surface area.

INTRODUCTION

Engineering properties are those that are helpful and required for the design, manufacture, and use of various machinery used in the field of agricultural processing. The size, shape, and physical characteristics of food grains play a crucial role in the manufacturing of equipment's for harvesting, separating, sizing, grinding, and oil extraction. Bulk density (Pb), true density (Pt), and porosity (ε) (which refers to the ratio of the space between grains to the total volume they occupy) are key factors in designing storage bins and silos, as well as in separating impurities, cleaning and grading, and evaluating product quality. Moisture-dependent physical properties and mechanical behavior of food grains. (Buenavista *et al.* 2024).

The most extensively grown cereal crop in the world is wheat, covering approximately 237 million hectares each year and contributing around 420 million tonnes in total production (Isitor *et al.*1990, Langer and Hill 1991, Olabanji *et al*. 2004). It pro-

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vides at least one-fifth of the caloric intake for humans (Ohiagu *et al.*1987). Wheat is an annual grass with a tall stalk that ends in a densely packed cluster of plump kernels surrounded by a beard of bristly spikes. It can grow to a height of ½ to 1 ¼ meters (Smith 2010). The early domestication of wheat likely involved selecting plants with larger kernels to maximize the nutrients obtained from each stalk. Wheat has been grown in Nigeria for centuries (Ohiagu *et al.*1987). There is substantial evidence that wheat has been cultivated in Nigeria as far back as 200 BC, although the varieties grown today were introduced more recently (Olabanji *et al.* 2004). Even though the demand for wheat is rising, Nigeria's domestic production has remained low. Factors limiting wheat cultivation in many of the country's wheat-growing regions include climate conditions, suitable agronomic practices, and a preference for vegetable farming (Ohiagu *et al.*1987).

Paddy is one of the highest essential food crops of the world and is the second emerging crop in India after wheat. (Razavi and Milani 2006). Rice is a grain belonging to the grass family. Every year, more than 3 billion people rely on rice as a vital source of nourishment. Every year, 680 million tons of rice are grown, making it the second most produced food in the world behind wheat (Foo and Hameed 2009). Globally, India stands first position in paddy area and second in paddy production, after China. It contributes 21.5% of global paddy production. It feeds morethan 50% of the world's population (Sinha 2017).

Chickpea belongs to the family Fabaceae, within the tribe Cicerae. It is a self-pollinated, diploid, annual grain legume crop. The global production of chickpea is nearly 11 million tonnes and India is the major producer accounting for 64% of the total chickpea production (FAOSTAT 2019). Kabuli type chickpea is mostly grown in the temperate regions, while the Desi type chickpea is grown in the semi-arid tropics (Muehlbauer *et al*. 2004, Malhotra *et al*.1996). However, several early-maturing Kabuli chickpea varieties have been acquired recently, which can be cultivated in tropical regions (Gaur and Singh 1996).

Pigeon pea is a versatile leguminous crop commonly grown in Nigeria. It serves multiple purposes for small-scale farmers engaged in subsistence agriculture, providing food, fuelwood, and fodder. Pulses along with cereals play a vital role in human nutrition, especially for the vegetarian population as a cheap source of protein. Pigeon pea (*Cajanus cajan*) is the most consumedpulse in the Indian subcontinent.

Pea is a member of the family Fabaceae, is an important cool-season and nutritious leguminous vegetables. India is fifth on the list of top pea producers, behind France, and is one of the world's largest pea producers. India produces 7.8 lakh tons of produce annually, which accounts for about 7% of global production. In India peas are mainly grown in Uttar Pradesh, Madhya Pradesh, Himachal Pradesh, Jharkhand, Punjab, Haryana, and Uttarakhand (Ganjloo *et al*. 2018).

Therefore, the primary goal of this study was to examine the mechanical and physical characteristics of food grains that are dependent on moisture, such as their size, sphericity, surface area, bulk density, true density, porosity, and linear dimension on a variety of surfaces at varying moisture content levels.

MATERIALS AND METHODS

The development of experimental setup to find out the physical properties of grains and experimental work were carried out in the Department of Processing and Food Engineering, Mahamaya College of Agriculture Engineering and Technology, Ambedkar Nagar.

It is needed to determine conditions for most favorable processing of grains, their physical properties have to be measured on a regular basis for different food grains. Conventional standard methods for moisture content and bulk density determination are both energy and time consuming. The conventional way to determine the bulk density is to weigh a given volume of material. Test weight, a measure of static bulk density determined under specific conditions (USDA 1953) for a particular moisture content, continues to serve as an indicator for quality control. Determination of moisture content, the ASAE Standards (ASAE 2003) specify oven-drying three ground samples for 2h at 130°C for different food grains and for 2 h at 103°C for corn.

The samples with the required moisture content were created by adding a calculated amount of distilled water based on the following relationship (Coskun *et al.* 2005):

$$Q = \frac{W i\,(M f - M i)}{100 - M f}$$

Where Q = Added water to sample, (kg), W_i = Initial weight of the sample, (kg), M_i =Initial moisture content of sample, (wb) %, M_f= Final moisture content of sample, (wb) %.

Measurement of physical properties of the various food grains

The various physical properties measured included length (L), width (W), thickness (T), thousand grain mass, geometric mean diameter (GMD), aspect ratio, surface area, sphericity, volume, bulk density, true density, and porosity. A sample of 100 grains was erratically picked, and their three main dimensions (length, width, and thickness) were measured with a vernier calliper, achieving an accuracy of 0.02 mm. The mass of 1,000 grains was determined by manually counting and weighing different sets of grains using a digital balance that has an accuracy of 5g. The average value of three replications was taken.

Bulk density

The bulk density of grain was measured by filling a circular container with a volume of 442.4 m³, without any manual compaction. The mass of the grain was then recorded using an electronic weighing scale with a precision of 5 grams. The bulk density was determined using the following formula

$$Pb \frac{W}{V}$$

P_b = Bulk density, kg/m³, W = Weight of material, kg, V = Volume of the container, m³

True density

Liquid displacement technique was used to determine the true density of multi food grains. The true density was determined by calculating the ratio of the mass of the grains (in kg) to the volume of water displaced (in m³), using the following formula:

$$P t = \frac{W}{V}$$

P_t = True density, kg/m³, W = Mass of the grains, kg, V = Volume of water displaced, m³

Porosity

The porosity was determined from the measured values of bulk density and true density using the given relationship (Mohsenin 1986):

$$\varepsilon = \left(\frac{P g - P b}{Pb}\right) \times 10$$

ε = Porosity, %, Pb - Bulk density, kg/m³ , Pt - True density, kg/m³,

Geometric mean diameter (GMD)

A vernier calliper with a minimum count of 0.02 mm was used to measure the three principal dimensions: Major diameter (length), minor diameter (thickness), and intermediate diameter (width). The equivalent diameter of grain samples is another name for the geometric mean diameter (GMD). The following formulae were used to calculate the geometric mean diameter (GMD) and sphericity (Mohsenin 1986):

$$GMD = (LWT)^{1/3}$$

L= Length, mm, W= Width, mm, T= Thickness, mm

Sphericity, (ϕ)

In relation to a sphere of the same volume, the sphericity is a measure of shape character. In order to determine the sphericity, the following formula was used, assuming that the diameter of the circumscribed sphere matched the biggest intercept (a) of the tri-axial ellipsoid and that the solid's volume matched that of the ellipsoid with intercepts a, b, and c:

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

ϕ = Sphericity, L= Length, mm, W= Width, mm, T= Thickness, mm

Surface area

The following formula was used to determine the surface area

$$S = \pi \, Dg^2$$

Dg or GMD = Geometric Mean Diameters, mm, S = Surface Area, mm^2

RESULTS AND DISCUSSION

The results of various experiments conducted to find out the physical properties for instance true density, bulk density, porosity, GMD, surface area and sphericity on grains wheat, paddy, pigeon pea, gram and pea to see the effect of different moisture content levels (10%, 13%, 16%, 19%, 22%).

Effect of moisture contact on physical properties of wheat size dimensions

The data obtained on size of wheat is depicted in Tables 1–2. The length (L), width (W), thickness (T) and geometric diameter of the wheat grain varied from 6.08 to 6.92 mm, 4.06 to 4.48 mm, 3.36 to 3.82 mm and 4.42 to 4.72 mm respectively. Dimension of wheat grain increased with increased the moisture content from 10%, 13%, 16%, 19% and 22% (wb).

Bulk density (Pb), true density (Pt), and porosity (ε)

The interrelationship between bulk density (Pb), true density (Pt), and porosity (ε) to different levels of the moisture content for wheat grains shown in Table 2. It was observed that bulk density (Pb), true density (Pt), and porosity (ε) of the wheat grains increased with the increases the moisture content. The bulk density (Pb), btrue density (Pt), and porosity (ε) of wheat grains varied from 867 to 1073 kg/m^3, 1041to 1388 kg/m^3 and 16 to 22% respectively at the moisture content ranging from 10% to 22% on wet basis.

Table 1. Axial dimensions of wheat grains.

Sl. No,	Length (mm)	Width (mm)	Thickness (mm)	GMD (mm)	Sphericity	Surface area mm^2
1	6.92	4.24	3.36	4.61	0.66	66.9
2	6.18	4.48	3.64	4.65	0.75	67.9
3	6.08	4.42	3.68	4.62	0.76	67.1
4	6.18	3.86	3.64	4.42	0.71	61.5
5	6.82	4.06	3.82	4.72	0.69	70.2
Avg	6.43	4.21	3.62	4.60	0.71	66.7

Table 2. Physical properties of wheat grains at 10%, 13%, 16%, 19% and 22% moisture content.

Moisture content (%)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	GMD (mm)	Sphericity	Surface area mm^2
10	867	1041	16	4.61	0.66	66.9
13	926	1136	18	4.97	0.71	77.7
16	930	1190	19	4.99	0.71	78.6
19	990	1250	20	5.03	0.72	80.4
22	1073	1388	22	5.15	0.73	83.2

GMD, Sphericity, Surface area

The relationship between GMD, sphericity, surface area to different levels of moisture content for wheat grains shown in Table 2. It was observed that GMD, sphericity, surface area of the wheat grains increased with the increases the moisture content. The GMD, sphericity, surface area of wheat grains varied from 4.61 to 5.15 mm, 0.66 to 0.73 and 66.9 to 83.2 mm^3 respectively at the moisture content ranging from10% to 22% on wet basis.

Effect of moisture contact on physical properties of paddy size dimensions

The data obtained on size of paddy is presented in Tables 3 and 4. The length (L), width (W), thickness (T) and geometric diameter of the paddy grain varied from 7.08 to 8.7 mm, 2.84 to 3.38 mm, 2.7 to 2.8 mm and 3.85 to 4.19 mm respectively. As we increased the amount of moisture content from 10%, 13%, 16%, 19% and 22% wb, our length (L), width (W), thickness (T) and geometric mean diameter also increased.

Bulk density (Pb), true density (Pt), and porosity (ε)

The interrelationship between bulk density (Pb), true

Table 3. Axial dimensions of paddy grains.

Sl. No,	Length (mm)	Width (mm)	Thickness (mm)	GMD (mm)	Sphericity	Surface area mm^2
1	7.08	3.28	2.8	4.02	0.56	50.7
2	7.06	3.06	2.7	3.87	0.54	47.2
3	8.7	3.02	2.8	4.19	0.48	55.1
4	7.48	2.84	2.7	3.85	0.51	46.6
5	7.68	3.38	2.8	4.17	0.54	54.6
Avg	7.6	3.11	2.76	4.02	0.53	50.8

density (Pt), and porosity (ε) to different levels of the moisture content of the paddy grains shown in Table 4. It was observed that bulk density (Pb), true density (Pt), and porosity (ε) of the paddy grains increased with the increases the moisture content. The bulk density (Pb), true density (Pt), and porosity (ε) of paddy grains varied from 867 to 1073 kg/m^3 , 1041 to 1388 kg/m^3 and 43 to 47 % respectively at the moisture content ranging from 10% to 22% on wet basis.

GMD, sphericity, surface area

The interaction between GMD, sphericity, surface area to different levels of moisture content of the paddy grains shown in Table 4. It was observed that GMD, sphericity, surface area of the paddy grains increased with the increases the moisture content. The GMD, sphericity, surface area of paddy grains varied from 4.02 to 5.50 mm, 0.56 to 0.63 and 50.7 to 95.1 mm^2 respectively at the moisture content ranging from 10% to 22% on wet basis.

Effect of moisture contact on physical properties of pigeon pea size dimensions

The data obtained on size of pigeon pea is presented in Tables 5–6. The length (L), width (W), thickness (T) and geometric diameter of the pigeon pea grain varied from 6.28 to 6.8 mm, 5.08 to 6.38 mm, 4.08 to 4.74 mm and 5.21 to 5.83 mm respectively. As the moisture content increased from 10%, 13%, 16%, 19% and 22% wb. As we increased the amount of moisture content of pigeon pea grain the length (L), width (W), thickness (T) and geometric mean diameter of grain increased as well.

Bulk density (Pb), true density (Pt), and porosity (ε)

The interrelationship between bulk density (Pb), true

Table 4. Physical properties of paddy at 10%, 13%, 16%, 19% and 22% moisture content.

Moisture content (%)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	GMD (mm)	Sphericity	Surface area mm^2
10	644	1130	43	4.02	0.56	50.7
13	666	1250	46	4.41	0.59	61.2
16	670	1260	46	4.78	0.60	72.2
19	680	1290	47	4.99	0.61	83.2
22	689	1310	47	5.50	0.63	95.1

density (Pt), and porosity (ε) to different levels of the moisture content of the pigeon pea grains shown in Table 6. It was observed that bulk density (Pb), true density (Pt), and porosity (ε) of the pigeon pea grains increased with the increases the moisture content. The bulk density (Pb), true density (Pt), and porosity (ε) of pigeon pea grains varied from 870 to 983 kg/m^3 and 1041 to 1562 kg/m^3 and 16 to 36 % respectively at the moisture content ranging from 10% to 22% on wet basis.

GMD, sphericity, surface area

The interaction between GMD, sphericity, surface area to different levels of moisture content of the pigeon pea grains shown in Table 6. It was observed that GMD, sphericity, surface area of the pigeon pea grains increased with the increases the moisture content. The GMD, sphericity, surface area of pigeon pea grains varied from 4.02 to 5.50 mm, 0.56 to 0.63 and 50.7 to 95.1 mm^2 respectively at the moisture content ranging from 10% to 22% on wet basis.

Effect of moisture contact on physical properties of gram size dimensions

The data obtained on size of gram is presented in Tables 7–8. The length (L), width (W), thickness (T)

Table 5. Axial dimensions of pigeon pea grains.

Sl. No.	Length (mm)	Width (mm)	Thickness (mm)	GMD (mm)	Sphericity	Surface area mm^2
1	6.8	6.3	4.64	5.83	0.85	106.9
2	6.56	6.38	4.66	5.79	0.88	105.5
3	6.28	5.08	4.58	5.26	0.83	87.0
4	6.86	5.48	4.74	5.62	0.82	99.4
5	6.84	5.08	4.08	5.21	0.76	85.3

Table 6. Physical properties of pigeon pea at 10%, 13%, 16%, 19% and 22% moisture content.

Moisture content (%)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	GMD (mm)	Sphericity	Surface area mm^2
10	870	1041	16	5.83	0.85	106.9
13	924	1136	18	5.99	0.86	112.6
16	942	1250	24	6.00	0.87	115.3
19	970	1388	30	6.12	0.88	119.5
22	983	1562	36	6.19	0.88	120.2

Table 8. Physical properties of gram at 10%, 13%, 16%, 19% and 22% moisture content.

Moisture content (%)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	GMD (mm)	Sphericity	Surface area mm^2
10	836	1086	23	7.36	0.88	170.4
13	870	1190	26	7.47	0.93	175.4
16	899	1315	31	7.50	0.93	176.3
19	922	1470	37	7.60	0.94	180.1
22	983	1666	40	7.63	0.94	183.2

and geometric diameter of the gram grain varied from 8.18 to 8.56 mm, 6.28 to 7.84 mm, 6.08 to 6.58 mm and 6.78 to 7.48 mm respectively. As the moisture content increased from 10%, 13%, 16%, 19% and 22% wb. As we increased the amount of moisture content of gram grain the length (L), width (W), thickness (T) and geometric mean diameter of grain increased as well.

Bulk density (Pb), true density (Pt), and porosity (ε)

The interrelationship between bulk density (Pb), true density (Pt), and porosity (ε) to different levels of the moisture content of the gram grains shown in Table 8. It was observed that bulk density (Pb), true density (Pt), and porosity (ε) of the gram grains increased with the increases the moisture content. The bulk density (Pb), true density (Pt), and porosity (ε) of gram grains varied from 836 to 983 kg/m^3 and 1086 to 1666 kg/m^3 and 23 to 40 % respectively at the moisture content ranging from 10% to 22% on wet basis.

GMD, sphericity, surface area

The interaction between GMD, sphericity, surface area to different levels of moisture content of the gram grains shown in Table 8. It was observed that GMD, sphericity, surface area of the gram grains increased with the increases the moisture content. The GMD, sphericity, surface area of gram grains varied from 7.36 to 7.63 mm, 0.88 to 0.94 and 170.1 to 183.2 mm^2 respectively at the moisture content ranging from 10% to 22% on wet basis.

Table 7. Axial dimensions of gram grains.

Sl. No,	Length (mm)	Width (mm)	Thickness (mm)	GMD (mm)	Sphericity	Surface area mm^2
1	8.32	7.58	6.34	7.36	0.88	170.4
2	8.18	6.28	6.08	6.78	0.82	144.5
3	8.34	7.84	6.42	7.48	0.89	176.0
4	8.48	7.08	6.58	7.33	0.86	169.0
5	8.56	7.08	6.38	7.28	0.85	166.6
Avg	8.37	7.17	6.36	7.24	0.86	165.3

Effect of moisture contact on physical properties of pea size dimensions

The data obtained on size of pea is presented in Tables 9 –10. The length (L), width(W), thickness (T) and geometric diameter of the pea grain varied from 7.28 to 7.84 mm, 6.46 to 6.88 mm, 6.08 to 6.48 mm and 6.58 to 6.86 mm respectively. As the moisture content increased from 10%, 13%, 16%, 19% and 22% wb. As we increased the amount of moisture content of pea grain the length (L), width (W), thickness (T) and geometric mean diameter of grain increased as well.

Bulk density (Pb), true density (Pt), and porosity (ε)

The interrelationship between bulk density (Pb), true

Table 9. Axial dimensions of pea grains.

Sl. No,	Length (mm)	Width (mm)	Thickness (mm)	GMD (mm)	Sphericity	Surface area mm^2
1	7.36	6.88	6.4	6.86	0.93	148.1
2	7.28	6.48	6.38	6.70	0.92	140.9
3	7.54	6.54	6.48	6.83	0.90	146.7
4	7.84	6.48	6.08	6.75	0.86	143.4
5	7.28	6.46	6.08	6.58	0.90	136.2
Avg	7.46	6.56	6.28	6.74	0.90	143.0

Table 10. Physical properties of pea at 10%, 13%, 16%, 19% and 22% moisture content.

Moisture content (%)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	GMD (mm)	Sphericity	Surface area mm^3
10	870	1230	29	6.86	0.93	148.1
13	926	1360	31	7.68	0.94	185.1
16	940	1440	34	7.70	0.94	185.1
19	950	1550	38	7.71	0.95	186.1
22	994	1680	40	7.72	0.96	187.1

density (Pt), and porosity (ε) to different levels of the moisture content of the pea grains shown in Table 10. It was observed that bulk density (Pb), true density (Pt), and porosity (ε) of the pea grains increased with the increases the moisture content. The bulk density (Pb), true density (Pt), and porosity (ε) of pea grains varied from 870 to 994 kg/m^3 and 1230 to 1680 kg/m^3 and 29 to 40% respectively at the moisture content ranging from 10% to 22% on wet basis.

GMD, Sphericity, surface area

The interaction between GMD, sphericity, surface area to different levels of moisture content of the pea grains shown in Table 10. It was observed that GMD, sphericity, surface area of the pea grains increased with the increases the moisture content. The GMD, sphericity, surface area of pea grains varied from 6.89 to 7.72 mm, 0.93 to 0.96 and 148 to 187 mm2 respectively at the moisture content ranging from 10% to 22% on wet basis.

CONCLUSIONS

This study covers the effect of moisture content on physical properties such as wheat, paddy, pigeon pea, gram and pea food grains at different level of moisture content i.e. 10%, 13%, 16%, 19% and 22% on wet basis. The average length (L), width (W), thickness (T), bulk density, true density, porosity, geometric mean diameter, sphericity and surface area increased as the increases the moisture content. This study would also be useful to design and develop the agro processing equipments/ technologies used during post harvest operational activities.

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