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Study of Physical and Engineering Properties of Wheat Grains

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Abstract

The study was conducted to determine the physical and engineering properties that are very important in many problems associated with the design of seed processing machine. Therefore, the objective of this study was to determine physical and engineering properties of wheat grain (variety UP2526) at three different levels of moisture contents viz. 8, 12 and 16% moisture content (d.b). Some physical properties of wheat (*Triticum aestivum*) grains were determined at 8, 12 and 16% moisture content (d.b). The size, sphericity, surface area, weight of 1000 grains, volume of 1000 grains and bulk density were found to be 5.69 mm, 0.586, 21.50 mm^2, 35.94 g, 3.58 mm^3, 713.58 kg m^{-3} respectively. The frictional characteristics of the wheat grains viz., angle of repose, coefficient of internal friction was also be measured in the post harvest laboratory. The average values of angle of repose at three different moisture content levels were found to be increased from 26.85^0 to 27.65^0 with the increases in moisture content from 8 to 16 % (d.b) respectively with an overall average value of 27.1^0 respectively. The result pertained that terminal velocity of wheat varied from 8.8 to 9.2 m s^{-1}.

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Aspect ratio, bulk density, friction, sphericity, terminal velocity, wheat kernel.

Introduction

Wheat (*Triticum aestivum* L.) is a very important cereal crop grown in the *rabi* season in India, cultivated in almost all the countries of the world. Among major wheat-producing countries, India ranked second next to China with regards to its production in the world. Wheat is the second most important cereal crop after rice in India and is cultivated under diverse agro-climatic conditions zone.

All India the area under wheat crop was 30.28 Mha with a production of 102.59 MT having an average yield of 33.84 q ha^{-1} (GOI, 2022). Physical and engineering properties are important in many problems associated with the design of machines and the analysis of the behaviour of the kernels during agricultural process operations like handling, threshing, cleaning, sorting and drying. Explanations of the problems in these processes involve knowledge of its rheological and engineering properties (Irtawange, 2000). Bulk density, true density, and porosity (the ratio of inter granular space to the total space occupied by the grain) can be useful in deciding the hopper sizes and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes.

Grain bed with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans. Cereal grain kernel densities have been of interest in breakage defencelessness and hardness studies (Ghasemi *et al.,* 2008). Flow ability of agricultural grains is usually measured using the angle of repose. This is a measure of the internal friction between grains and can be useful in hopper design, since the hopper wall's inclination angle should be greater than the angle of repose to ensure the continuous flow of the materials by effect of gravity. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Such information is useful in power requirements for grain transportation and handling (Ghasemi *et al.,* 2008)

Materials and Methods

Physical and engineering properties are very important in many problems associated with the design of machine. Therefore, the objective of this study was to determine physical and engineering properties of wheat grain (variety UP2526) at three levels of moisture contents on dry basis (8, 12 and 16%), such as major dimensions of wheat grain, equivalent and geometric mean diameter, sphericity, surface area, volume and aspect ratio were measured in the laboratory.

Engineering properties

Moisture content

Engineering properties of seeds mainly depend on the moisture content hence, moisture content of seed samples was determined before measuring their properties. ASAE (American Society of Agricultural Engineer) standard oven dry method was selected for determination of moisture content.

Five samples of wheat seed samples were taken of knowing weight and kept in oven at 105^{0}C temperatures for 24 h. Moisture content of wheat seeds was determined by taking difference between the weight before and after drying sample by using the following equation given below as:

$$M.C(d.b), \% = \frac{w - d}{d} \times 100$$

where,

M.C = moisture content, % (d.b)

w = initial weight of sample, g

d = final weight of sample, g

Bulk density of seed

The bulk density of the wheat seed (variety UP2526) was determined by filling the seed in a measuring cylinder having a capacity of 100 ml with the wheat seeds from a height of 63 mm and the base of the cylinder was tapped about more than twelve times on the table (Boumans, 1985). Then the cylinder was refilled again to its maximum reading (100 ml), the samples was weighted by the use of electronic balance (accuracy of ±0.001g). The bulk density was calculated by following relationship was used to determine the bulk density of the seed.

$$\rho = \frac{weight\ of\ seed, g}{volume\ of\ cyclinder, cc}$$

True density of seed

The true density (ρ_t) of the grains is defined as the ratio of the mass of the sample of the grains to the solid volume occupied by the sample (Deshpande *et al.,* 1993).

The volume (V) of wheat grain and true density were determined using water displacement method (Mohensin, 1970).

$$m = \frac{\rho_t}{V}$$

where,

ρ_t= true density, kg m^{-3}

m = Mass of the sample, kg

V = Volume occupied by the sample, m^3

The bulk density is the ratio of the weight of the sample to its total volume of the sample. The bulk density includes void space present in the sample (Mohensin, 1970).

Porosity

The porosity of bulk grains was calculated from bulk and true densities using the relationship given by Mohensin (1970) as follows.

$$\text{porosity} = \left(1 - \frac{\rho}{\rho_t}\right) \times 100$$

Thousand Grain weight (test weight)

Thousand wheat kernel weight were measured randomly from the wheat samples. Five replications were taken at three moisture levels viz. 8,12 and 16 % and the result obtained at three moisture levels viz. 8,12 and 16 % was 34.60, 36.20 and 38.14 g as shown in Table 2 respectively with an overall average of thousand grain weight was 35.94 g respectively.

Physical Properties

The size of wheat seeds was determined in terms of its length (L), width (B) and thickness (T). For this purpose randomly samples of 100 seeds were taken from three samples of wheat at a given three moisture levels (8.12 and 16 %) and the principal dimensions of each seed were measured along all the three major axes with the help of digital vernier caliper (Insize company, resolution :0.01 mm and accuracy: ± 0.02 mm). Thereafter the geometric mean diameter (D_g), arithmetic mean diameter (D_a) and equivalent diameter (D_p) were calculated and the data was averaged out to determine the average size of the wheat grain. The geometric mean diameter (D_g) of the grain was calculated by using the following relationship (Sreenarayanan *et al.,* 1985).

$$D_g = \sqrt[3]{L \times B \times T}$$

$$D_a = (L + B + T)/3$$

where,

D_g = Geometric mean diameter

D_a = Arithmetic mean diameter

L = length of seed, mm

B = width of seed, mm

T = thickness of seed, mm

Aspect ratio of wheat grain

It is the ratio of width of seed to the length of seed. The following formula was used to calculate the aspect ratio of wheat grain.

$$\text{Aspect ratio} = \frac{B}{L}$$

Sphericity

The sphericity of a particle is usually determined by measuring the three linear dimensions of the particle (longest (L), intermediate (B) and shortest (T) diameters). The following equation given below was used to calculate it. According to Mohsenin (1970), the degree of sphericity can be expressed as follows:

$$\emptyset = \frac{(LBT)^{\frac{1}{3}}}{L}$$

Equivalent diameter (D_p)

The equivalent diameter was calculated by considering prolate spheroid shape for a wheat grain and hence the following equation was used to determine its value as given below.

$$D_p = \left[\frac{L}{4}(B+T)^2\right]^{\frac{1}{3}}$$

Volume and surface area of wheat

Bhargava *et al.,* (2013) have regarded as seed volume, V_s and surface area, S_s may be given by:

$$V_s = \frac{\pi B L^2}{6(2L - B)}$$

$$S_s = \frac{\pi B' L^2}{(2L - B)}$$

$$B' = \sqrt{BT}$$

Frictional properties

Angle of repose

The angle of repose is the angle with the horizontal at which the material rests when piled up. Various parameters such as size, shape, moisture content influence it. The angle of repose of materials under study was measured by pouring method. The apparatus consists of a conical hopper for measuring the height of heap above the base plate. The pointer attached to the scale was moved down to the base plate and reading on the scale was noted. It was then moved upward. A sample of material was poured inside the hopper through the funnel which formed a conical heap on the base plate. It was continued until the base of the plate was completely filled and particles had just started to slide down. The pointer was then moved up to the top of the heap and reading on the scale was noted. The difference in these two readings on the scale gave the height of heap, which was used to determine the angle of repose by the equation 10 given below:

$$\theta = \arctan\frac{2H}{d}$$

where,

θ = angle of repose, degree

H = height of the heap, mm

d = diameter of the base plate, mm (330 mm)

Weight of thousand grains (test weight)

Five randomly samples, each comprising of thousand seeds were taken and their weights were determined using electronic balance (having least count of 0.1g). The averages of all five samples were calculated to determine the average weight of thousand seed.

Coefficient of internal friction

The angle of internal friction of wheat seeds were determined by using the inclined plane method (Mohsenin, 1970). The angle of friction was measured on the MS Sheet surface as illustrated in (Fig.1). The static coefficient of friction between frame material and MS sheet was negligible. The MS sheet was fixed on the wooden frame by six clamps.

One end of the surface was hinged and other end was connected with spool through the rope. The material was filled in the rectangular block size (200× 200× 30 mm) resting on the inclined plane which makes an angle θ with the horizontal. When angle θ was increased gradually a stage was reached at which the block just starts sliding down. This angle was calculated by measured the height and base length of the frame and the following equation 11 given below was used to determine the angle of internal friction of wheat grains. The static friction coefficient was determined by equation given below.

$$\theta = \tan^{-1}\frac{h}{b}$$

$$\mu = \frac{h}{b}$$

where,

μ = coefficient of friction

h = height of inclined plane, mm

b = base of the inclined plane, mm

θ = horizontal angle of inclined plane, degree

Aerodynamic property

Terminal velocity

The terminal velocity of wheat grain samples was measured by using an air column (Tabak and Wolf, 1998). Wheat samples were randomly selected and tested. For each experiment the selected wheat grain samples were dropped from the top of a 75-mm diameter, 1m long plexiglass tube as shown in (Fig.2). The air was blown upwards in the tube while its velocity was adjusted by using an inverter– type motor speed control until the major fraction of the sample remained suspended in the air stream. Air velocity was measured by using an anemometer (Make: Windmesser, Germany) and reported as terminal velocity. Five replications were taken for determination of the terminal velocity of the wheat sample

Results and Discussion

The physical, frictional and aerodynamics properties of the wheat grains have the significant role in the design of handling and processing equipment. The results were obtained during studied was discussed below:

Physical properties of wheat seed

Seed parameters are an important parameter to design the metering mechanism of the developed machine. These parameters are also helpful to design the other components like seed hopper, seed pipe and seed metering device respectively. To measure these parameters (UP2526) wheat variety was selected for the study and 100 wheat seeds were selected randomly from the wheat sample and major it's dimensions viz. length, width and thickness were measured with the help of digital vernier caliper with an accuracy of 0.01 mm respectively. The result obtained was pertained in (Table 3). The length of wheat seeds was found to vary from 4.41to 6.54 mm with an average length of 5.69 mm.

The standard deviation and coefficient of variation of length of wheat seed were calculated and found to be 0.42 mm and 7.5 % respectively. Similarly, the width was varied from 1.32 to 2.98 mm with an average value of 2.379 mm. The SD and coefficient of variance of a width of wheat were calculated to be 0.28 g and 12.0 % respectively. The average thickness varied from 1.01 to 2.4 mm with an average value of 1.619 mm for wheat seeds. The SD and coefficient of variance of the thickness of wheat were calculated to be 0.29g and 18.2 % respectively. The mean value of arithmetic diameter (D_a), geometrical diameter (D_g) and equivalent diameter (D_p) were found to be 3.231, 2.766 and 2.827 mm respectively while the average value of sphericity, aspect ratio, surface area and grain volume were found to be 0.5, 0.41, 21.50 mm^2 and 3.584 mm^3 were shown in (Table 3) respectively.

Bulk density and true density of wheat seed

The bulk density of the wheat was measured at three different moisture contents viz. 8, 12 and 16 % and found to be 667.83, 700.72 and 772.28 kg m^{-3} with overall mean bulk density of 713.6 kg m^{-3} respectively as shown in (Table 2). The true density varied from 1105.67 to 1347.0kg m^{-3}and it was found that as the moisture was increased from 8 to 16 %, the true density was linearly increased with it respectively. The data revealed that the average value of SD and coefficient of variation for combined moisture content was calculated 0.43 and 0.06% respectively. The data revealed that the bulk density of wheat was increased with increased in moisture content of wheat seeds because an increase in mass corresponding to moisture increment in the sample was higher than occurred with volumetric expansion of the large quantities of wheat. The bulk density (ρ) of wheat kernel was found to establish the linear relationship with moisture content (M) with a value for R^2 of 0.95 as shown in Fig.3.

Table.1 Physical characteristic of *Triticum aestivum* wheat seed (UP2526)

S. No.	Parameters	Unit	Maximum	Minimum	Average
1	Length	mm	6.54	4.41	5.693
2	Breadth	mm	2.98	1.32	2.379
3	Thickness	mm	2.40	1.01	1.619
4	Surface area	mm^2	31.93	14.40	21.50
5	Grain volume	mm^3	2.403	5.323	3.584
6	Arithmetic diameter	mm	2.73	3.71	3.231
7	Geometrical diameter	mm	2.24	3.33	2.766
8	Equivalent diameter	mm	2.35	3.395	2.827
9	Sphericity	-	0.40	0.585	0.586
10	Aspect ratio	-	0.24	0.544	0.419
11	Angle of repose, degree	deg	26.5	28.5	27.14
12	Coefficient of static friction	-	0.4	0.50	0.50
13	Bulk density	kg m^{-3}	713.20	714.10	713.58
14	Weight of 1000 seeds	g	34.61	38	35.94
15	Moisture content (d.b)	%	8	16	12
16	Shape and size of seed		Prolate Spheroid Shape		
17	Germination	%	85		
18	Variety	-	UP2526		

Table.2 Physical and frictional properties of wheat seeds

S .No	Bulk density, kg m^{-3}	True Density kg m^{-3}	Bulk density, kg m^{-3}	True density kg m^{-3}	Bulk density, kg m^{-3}	True density kg m^{-3}		Angle of repose, deg				Coefficient of internal friction				Thousand seed weight, g			
Moisture level, %	**8**		**12**		**16**		**Mean**	**8**	**12**	**16**	**Mean**	**8**	**12**	**16**	**Mean**	**8**	**12**	**16**	**Mean**
R1	667.91	1105.81	700.79	1167.98	770.85	1342.9	713.2	25.72	27.6	28.48	26.6	0.48	0.5	0.54	0.506	33.0	34.03	39.78	34.616
R2	667.86	1105.72	700.74	1167.9	771.80	1344.5	713.4	25.56	27.5	28.44	26.5	0.46	0.47	0.55	0.465	38.0	38.93	37.07	38.000
R3	666.72	1103.84	700.68	1167.8	772.20	1345.2	713.2	25.72	27.6	28.48	26.6	0.50	0.49	0.52	0.504	35.9	36.49	38.45	36.970
R4	668.86	1107.38	700.74	1167.9	772.80	1346.3	714.1	27.66	27.4	28.50	27.5	0.46	0.48	0.53	0.487	32.9	35.38	37.42	35.233
R5	667.82	1105.66	700.68	1167.8	773.75	1347.9	714.0	29.62	27.5	28.38	28.5	0.53	0.56	0.54	0.543	33.1	36.57	38.02	34.903
Mean	667.83	1105.67	700.726	1167.87	772.28	1345.4	713.58	26.85	27.5	28.45	27.14	0.486	0.5	0.53	0.501	34.5	36.28	38.14	35.944
SD	0.75	1.122	0.046	0.07787	1.08	1.89	0.438	1.771	0.08	0.047	0.861	0.029	0.03	0.01	0.028	2.28	1.804	1.056	1.469
CV,%	0.113	0.101	0.006	0.003	0.14	0.140	0.061	6.59	0.30	0.167	3.176	6.103	7.07	2.12	5.724	6.61	4.973	2.768	4.087
Max	668.86	1107.38	700.79	1167.98	773.75	1347.9	714.1	29.62	27.6	28.5	28.5	0.53	0.56	0.55	0.543	38	38.93	39.78	38.000
Min	666.72	1103.84	700.68	1167.80	770.85	1342.9	713.2	25.56	27.4	28.38	26.5	0.46	0.47	0.52	0.465	32.9	34.03	37.07	34.616

Table.3 Physical properties of the wheat grains

Sl. No	Thickness (T) mm	Width (B) mm	Length (L),mm	Arithmetic diameter, mm $D_a = \frac{L+B+T}{3}$	Geometrical diameter, mm $D_g = \sqrt[3]{(LBT)}$	Eqiuvalent diameter D_p, mm	Sphericity $\emptyset = \frac{\sqrt[3]{(LBT)}}{L}$	Aspect ratio $R = \frac{B}{L}$	$B' = \sqrt{BT}$	Surface area,mm^2 $S_s = \frac{\pi B \cdot L^2}{(2L-B)}$	Grain volume, mm^3 $V = \frac{1}{6}\left(\frac{\pi B l^2}{2L-B}\right)$
1	1.78	2.28	5.37	3.14	2.79	2.80	0.52	0.42	2.01	20.9	3.48
2	1.21	1.98	5.92	3.03	2.42	2.46	0.40	0.33	1.54	16.54	2.75
3	1.44	2.40	5.87	3.23	2.727	2.78	0.46	0.40	1.85	20.35	3.39
4	1.58	2.56	6.24	3.46	2.93	2.99	0.47	0.41	2.01	23.48	3.91
5	1.39	2.26	5.96	3.20	2.62	2.70	0.44	0.37	1.77	19.48	3.24
6	1.53	2.50	5.66	3.23	2.75	2.84	0.48	0.44	1.95	21.00	3.50
7	1.57	2.74	6.33	3.54	2.97	3.08	0.47	0.43	2.07	24.65	4.11
8	1.96	2.71	5.88	3.51	3.11	3.17	0.52	0.46	2.30	26.46	4.41
9	1.65	2.65	5.82	3.37	2.90	2.99	0.49	0.46	2.09	23.29	3.88
10	1.21	2.55	6.17	3.31	2.64	2.79	0.42	0.41	1.75	19.83	3.30
SD	0.29	0.28	0.42	0.23	0.24	0.24	0.04	0.05	0.25	3.98	0.66
Mean	1.61	2.37	5.693	3.23	2.76	2.82	0.48	0.41	1.97	21.50	3.58
CV	0.18	0.12	0.075	0.07	0.09	0.08	0.08	0.12	0.13	0.185	0.18
Max	2.4	2.98	6.54	3.71	3.33	3.39	0.58	0.54	2.64	31.93	5.32
Min	1.01	1.32	4.41	2.73	2.24	2.35	0.40	0.24	1.44	14.4	2.40

Figure.1 Measurement of angle of repose (right) and internal friction of wheat seed (left).

Figure.2 Cross section of vertical wind tunnel. (A) diffuser; (B) wire net; (C) lid hatch; (D) axial fan; (E) flexible section; (F) diaphragm; (G) mesh screens; (H) honeycomb; (I) nozzle; (W) support section

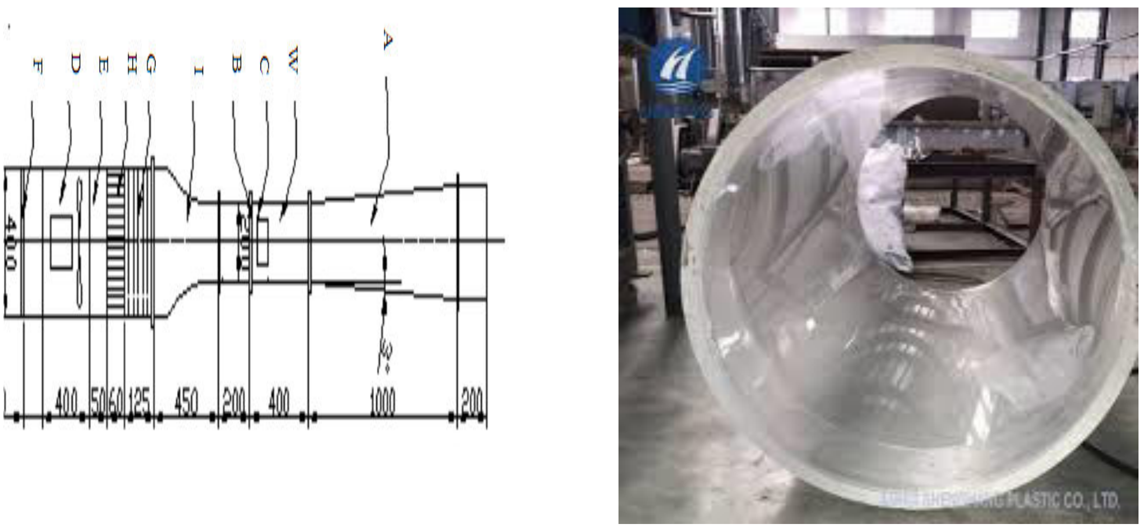


Figure.3 Effect of moisture content on bulk density of wheat grain

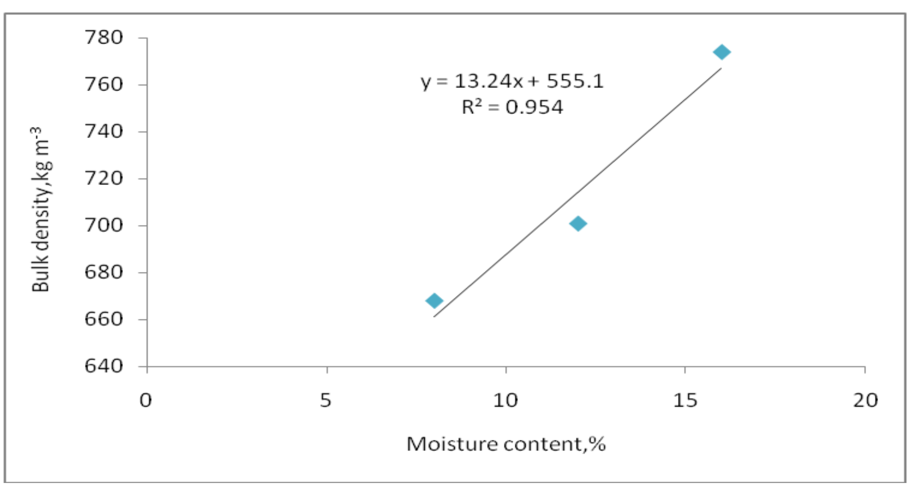


Figure.4 Effect of moisture content on angle of repose of wheat grain

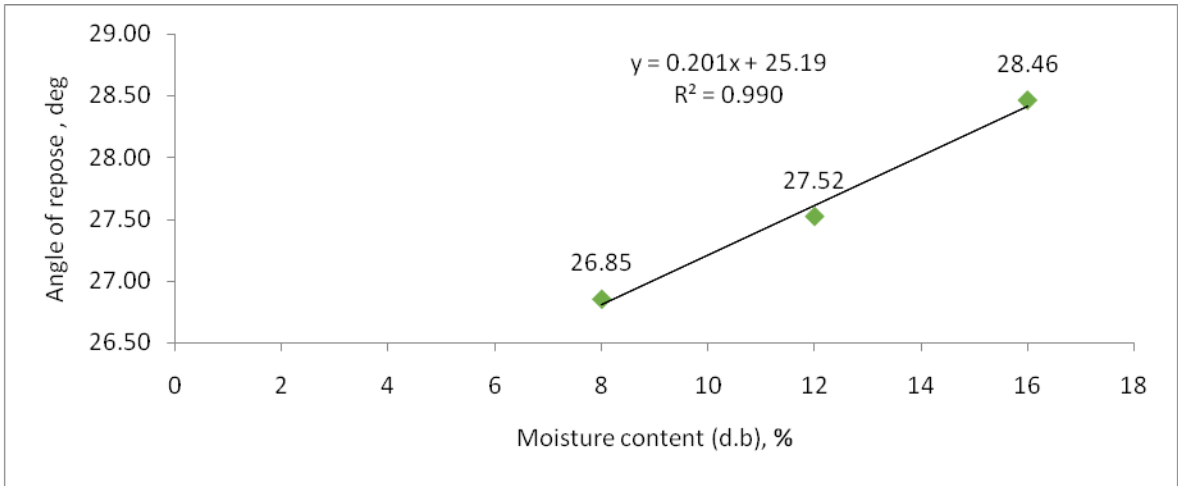


Figure.5 Effect of moisture content on thousand weight of wheat grain

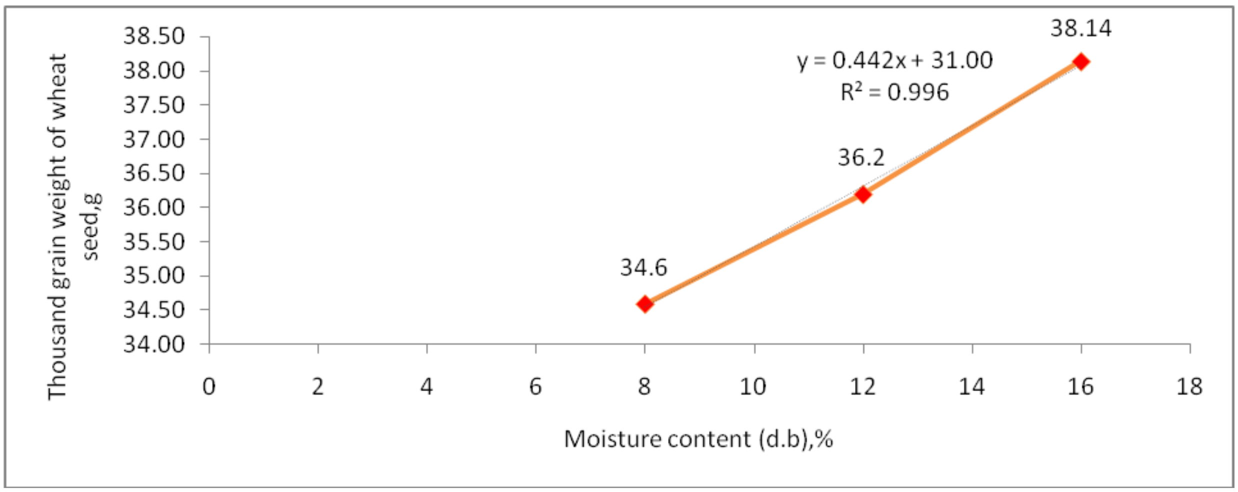
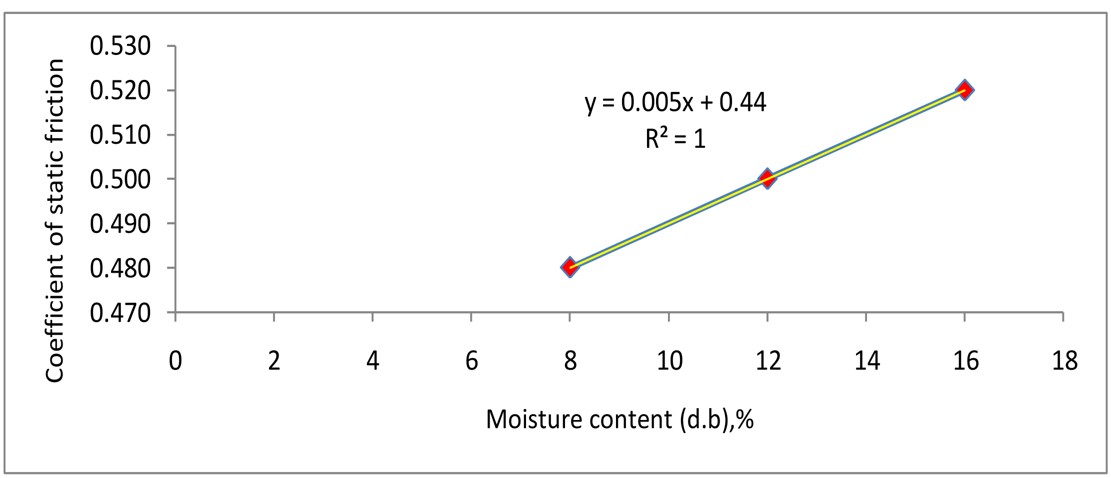


Figure.6 Effect of moisture content on coefficient of static friction of wheat grain



Frictional properties

Angle of repose

The angle of repose is indicated the product ability to flow. The angle of repose of wheat seeds was measured at three moisture levels viz. 8, 12 and 16 %. The average values of angle of repose at three moisture content levels were found to increase from $26.85^0$to 27.65^0 with the increases in moisture content from 8 to 16 % (d.b) respectively with an overall average value of 27.1^0 respectively.

It was shown that the angle of repose of wheat grain was increased with increases in moisture content of grain because surface layer of moisture around the particle hold the aggregate of kernel jointly by the surface tension force.

Coefficient of static friction

The static coefficient of friction of wheat seed was measured on a mild steel sheet. The values of coefficient of static friction were measured at three different moisture levels viz. 8, 12 and 18% and were found to be 0.48, 0.50 and 0.51 with an overall average value of 0.51 respectively.

It was concluded that the coefficient of static friction was increased with an increase in moisture content as shown in Fig. 4.

The reason for the increased static friction coefficient at higher moisture content may be due to the moisture accumulation in the wheat seeds developing a cohesive force between the surfaces of contact.

Conclusion

The study was conducted on wheat variety UP2526 which was very popular in northern Uttar Pradesh. The following conclusions can be drawn from the experiments. The length, breadth and thickness of wheat kernels were varied from 4.41 to 6.54 mm, 1.32 to 2.98 mm and 1.01 to 2.40 mm respectively with average value of length, breadth and thickness are 5.69, 2.37 and 1.61 mm respectively. The surface area varied from 14.40 to 31.93 mm^2 with average value is 21.50 mm^2 and bulk density was 713.20 to 714.10 kg m^{-3} respectively. The average value of arithmetic, geometrical and equivalent diameter was found be 3.23, 2.76 and 2.82 mm respectively. The frictional properties viz. angle of repose was varied from 26.5 to 28.5^0 with average value of 27. 1^0. The terminal velocity of the wheat was varied from 8.8 to 9.2 m s^{-1}. The investigation of various physical and engineering properties of wheat revealed that the linear dimensions (length, width and thickness), geometric mean diameter, sphericity, surface area, volume and thousand grain mass of wheat are linearly related to its moisture content and increase with increase in moisture content within the range of 8 to 16 % d.b. Bulk density and true density of wheat increased linearly with the increase in moisture content in the range of 8 to 16% d.b from 1103.84 to 1347.9 kg m^{-3} respectively.

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