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Effect of moisture content on engineering properties of some wheat varieties for post-harvest processing or designing grain storage bins

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Abstract
The purpose of this study was to investigate the effect of moisture content and wheat variety on some engineering properties of wheat grain widely cultivated in India. In the present investigation, three varieties of wheat namely MP-1106, UP-2554 and WH-542 with moisture content ranging from 8 – 14% (w.b) were selected. The length, width and thickness of wheat varieties were in the range of 5.19 (UP-2554) to 6.80mm (WH-542), 2.68 (MP-1106) to 3.65mm (UP-2554) and 2.30 (WH-542) to 2.96mm (MP-1106) respectively. Principal component analysis showed that porosity, true density, angle of repose and thousand kernel weight were positively correlated with the increase in moisture content, whereas **b**ulk density, hardness and initial cracking force were negatively correlated. Data on flow properties indicated that wheat of low moisture content will have better flow characteristics. The data obtained will be very useful in evolving design for storage bins and post-harvest equipment.

Keywords: wheat, moisture content, correlation matrix, physical properties

1. Introduction

In India, 70% of its population depends upon agriculture and allied activities for their livelihood. Wheat and rice are the two major cereal crops and wheat alone covers ~25% of the area under cereal crops. In India wheat is mostly consumed in the form of *Chapati* and bread (Singh *et al*, 2007) [35]. After harvesting, wheat grain is subjected to various types of loads during handling, cleaning and storage (Bargale *et al*., 1995) [5]. Wheat is considered as free-flowing material and the bulk behavior during all the operations is totally dependent on physical and flow properties of grains (Schulze, 2008; Bian *et al* 2015) [29, 6]. Knowledge of bulk density, true density, porosity and angle of repose is important for the design of grain hoppers and storage facilities as these properties are important flow indicators. The angle of repose decides the movement between the grains (Train, 1958; Bian et.al.2015) [7, 40]. Compressibility index and Hausner ratio, which is derived from bulk and tapped densities measure the ability of a material to compress and interact (Carr, 1965; Hausner 1967) [10, 14]. The capacity of storage bins is dependent on the bulk density of the grains. (Bhise *et al* 2014; Train, 1958; Sologubik *et al*. 2013) [40, 38, 5]. The rate of heat and mass transfer and aeration is also dependent on the porosity of the grain bed (Nelson, 1980) [24].These properties not only help in proper designing of post-harvest equipment but the efficiency of machines is also dependent on them. Also, the quality of the final product depends upon these properties that also help in classifying and distinguishing between different varieties or different kinds of kernels, grains, and seeds (Markowski *et al* 2013) [22].

Post-harvest losses in India amounts to about 12 to 16 million metric tons of food grains each year (Singh, 2010) [37] therefore the study of the engineering properties of grains is necessary to design efficient processing equipment and storage facilities (Simonyan *et al*. 2007) [34]. It is reported that physical, engineering and mechanical properties of the improved paddy varieties were significantly affected by variety and moisture content. Almost all the properties positively correlated with the increase in moisture content, but bulk density and true density were found to be negatively correlated. In other studies properties of wheat, spelt varieties in comparison with the common wheat (Markowski *et al*. 2013) [22], physical and mechanical properties of Osmancık-97 rice cultivated in Turkey (Kibar *et al*, 2010) [20], properties of jatropha seeds (Karaj and Muller, 2010) [18], tung seeds (Sharma *et al*., 2011) [33] etc. have been reported.

Literature review reveals that study of the above-mentioned properties of grains and their behavior with the increase of moisture content is of great significance. However, in developing countries like India studies regarding engineering properties of wheat grains are highly scanty. Therefore, in the present study selected engineering properties of three varieties of wheat procured from three different states (Uttar Pradesh, Haryana, and Madhya Pradesh) and their relation to the moisture content have been investigated.

2. Material and Methods

2.1 Materials

Three varieties of wheat MP-1106 (Dwarf variety, 23.25°N 77.417°E), UP-2554 (Bread wheat, 26.85°N 80.91°E) and WH-542 (Double-dwarf variety, salt-sensitive, 28.8909°N 76.5796°E) were obtained from different farms in three states as mentioned above. These samples were packed in LDPE bags, that are properly sealed and stored in a refrigerator maintained at temperature 5±1^{0}C. To determine different properties method of random sampling was adopted.

2.2 Moisture content and sample preparation

The initial moisture content of the samples was determined according to ASAE standard (2002) by drying 10 gm of sample in an oven at 130 ^{0}C for 19 h. After determining the initial moisture content, the wheat samples were then conditioned to different required percentage moisture contents (8, 10, 12 and 14) by direct addition of a predetermined amount of distilled water and gently thorough mixing of the grains. Amount of water to be added is determined by the equation (i).

Moisture conditioning of wheat samples

$W_w = W_d \frac{(M2-M1)}{(1-M1)(1-M2)}$ ………. (i) (Basediya et al., 2013)

Where,
W_w = Wt of water to be added
W_d = Bone dry wt.
M_1 = Initial moisture content
M_2 = Desired moisture content
All the samples were then packed in airtight LDPE bags and stored in a refrigerator at 5± 1^{0}C for 3 days to allow the moisture to equilibrate.

2.3 Physical properties

Geometrical properties: Relevant geometrical properties have been determined. To determine the dimensions of the grain 50 individual grains of each variety were selected randomly and their three principal linear dimensions namely length (L), width (W) and thickness (T) were measured using a digital vernier caliper reading to an accuracy of 0.01 mm and following parameters were calculated using different methods (Jain & Bal, 1997; Sharma *et al*., 1985; Omobuwajo *et al*. 1999) [16, 26, 32].

Geometric mean diameter (D_g)
$D_g = (LWT)^{1/3}$
Arithmetic mean diameter (D_a)
$D_a = (L + W + T) / 3$
Degree of sphericity Φ
$\Phi = \frac{(LWT)1/3}{L} * 100$
Seed volume V
$V = \pi B^2 L^2 / [6(2L-B)]$
$B = (WT)^{0.5}$
Surface area S
$S = D^2_g . \pi$
Aspect ratio R_a
$R_a = (W/L) * 100$

1000 grain weight

To find out the thousand grain weight (W_{1000}), 1000 grains were selected randomly and weighed using an electronic balance (Shah *et al*., 2016) [31].

2.4 Gravimetrical properties

Bulk density (ρ_b), True density (ρ_t) and porosity (ε) was calculated by using the following equations:

$\rho_b = M/V_b$ (Singh *et al*., 1996) [36]

Where, ρ_b is the bulk density of the bulk seeds and V_b is the bulk volume of the weighed sample of bulk seeds.

$\rho_t = M/V_t$ (Gani *et al*., 2015) [12]

Where, ρ_t is the true density of wheat seeds and V_t is the volume of toluene displaced by grains.

$\varepsilon = [1 - (\rho_b/\rho_t)] * 100$ (Mohsenin, 1986) [23]

Where, ε is the porosity.

2.5 Frictional properties

Angle of repose (Θ) is defined as the angle with the plane horizontal at which bulk granular materials will stand when piled and was calculated by using following relationship (Ozguven and Kubilay, 2004): [27]

$\Theta = \arctan(2H/D)$

where H and Dare the height and average diameter of the pile. Hardness and initial cracking force at different moisture content were evaluated using a Texture analyzer (TA-XT2i model, Stable Micro Systems). (Bourne, 1990) [9]

2.6 Bulk flow properties

Tapped density (ρT) determination was done in the measuring cylinder very carefully until no further decrease in the level was observed at the graduation mark. The results were expressed in kg/m^3 (Gani *et al*. 2015) [12]. The CI and HR indicate the property of being sticky and densification that occur during handling of grains as a result of vibration that sometimes result in crushing. These are calculated by following formula (Carr, 1965; Bian *et al*, 2015) [6, 10]

$CI = 100 * (\frac{\rho T - \rho b}{\rho T})$

$HR = \rho T / \rho_b c$

2.7 Statistical analysis

All the experiments were done in triplicate. All data were analyzed using one way ANOVA SPSS 10.1 (USA), and Duncan's multiple range test were used to determine the differences between the means.

3. Results and Discussion

3.1 Geometrical properties

Physical properties play an important role in determining the quality of grains. These properties changes during storage as affected by the storage conditions like temperature, moisture content etc. Grading depends upon geometrical properties of grains, and an important aspect deciding the market value of grains. Also, it has been reported that functional properties of wheat depend on geometrical parameters (Serna-Saldivar, 2016) [30]. Data obtained on various geometrical properties of wheat grains are presented in table 1. The average length, width and thickness of three varieties at 8% moisture content were in the range of 5.33 to 6.53, 2.73 to 3.64 and 2.13 to 2.96 respectively. The results are in accordance with the data reported by Markowski *et al*, (2013) [22] and Gekas *et al*, (2010). Considering the dimensional features, it was observed that wheat grains procured from Madhya Pradesh were longer as compared to other varieties. With the increase in moisture content, these dimensions of grain increases. This trend was due to the filling of capillaries and voids upon absorption of moisture (Kheiralipour *et al*., 2008). The geometric mean diameter was found to be in the range of 3.23 to 4.13 mm. The sphericity was in the range of 52.14 to 69.32%. Sphericity for most of the agricultural material fall in the range of 32–100% as mentioned by Mohsenin (1986) [23]. Knowledge of linear dimension of grains helps in the design of cleaners and separators for quality control.

By doing the multivariate analysis using SPSS between the dependent variables and the independent variables (variety and moisture content) it was found that there was no significant difference between the dimensions due to variety. Therefore, one wheat variety (WH-542) was selected for detailed investigation. Physical and engineering properties like thousand grain weight, bulk density, true density, etc. important for designing post-harvest processing equipment and machinery were determined. Results are presented in tables 2-4 and figure 1-5.

3.2 Thousand kernels weight (TKW)
Thousand kernel weight is an important parameter determining the health and quality of grains (Warechowska *et al*., 2013). With the increase in moisture content from 8 to 14% (w.b.) thousand kernel weight increased linearly from 37.21g to 42.24 g as shown in figure 1. Based on this data the linear relationship between the two can be represented by the equation

$$TGW = 1.53\,MC + 36.31 \text{ with a value of } R^2 = 0.98.$$

The results showed similar behavior to the TKW of green wheat, cumin seeds, green gram and chickpeas (Al-Mahasneh *et al*, 2007; Singh and Goswami, 1996; Nimkar and Chattopadyay, 2001 and Dutta *et al*., 1988) [17].

3.3 Bulk density
It was found that bulk density decreased with the increase in moisture content from 785.5 to 623.21 kg/m^3 as shown in Fig. 2. The relationship between bulk density and moisture content is presented by the equation:

$$\rho_b = 844.46 - 45.81\,MC \text{ value of } R^2 = 0.93$$

The decrease in the value of bulk density with increase in moisture content was mainly due to the increase in the volume of kernels as compared to the mass i.e. the volume of air entrapped between the grains is less in drier grains. Similar results were also reported by other researchers (Tabatabaeefar, 2003; Dutta *et al*. 1988; Kheiralipour *et al*. 2008; Sologubik *et al*. 2013) [38]

3.4 True density
True density was found to vary from 1232.12 to 1315.78 kg/m^3. It was found that true density increases with the increase in moisture content from 8 – 14% as shown in Fig. 3. The relationship between the two is described by the following equation:

$$\rho_t = 24.07MC + 1212.2 \text{ value of } R^2 = 0.99$$

Similar results were shown by Bishe *et al*. (2014).

3.5 Porosity (%)
Fig. 4 shows the increase of porosity with the increase in moisture content from 36.64 to 50.34%. The porosity of a grain bed is dependent on the bulk density and true density of grains and kernel bed with low porosity will have greater resistance to water vapor requiring higher power to drive the aeration fans (Markowski *et al*., 2013) [22]. The following equation was developed showing the relationship between porosity with the increase in moisture content.

$$\varepsilon\,(\%) = 4.66\,MC + 30.84 \text{ value of } R^2 = 0.96$$

3.6 Other properties
Data on other properties like the angle of repose (AOR), hardness, Initial cracking force (ICF) is given in table 2. The angle of repose increased from 23.76 to 30.32 ^{0}C with the increase in moisture content. With the increase in moisture content, kernels of wheat become less smooth that leads to difficulty in sliding on one another resulting in a higher value of angle of repose. Markowska *et al*., (2016) observed that the angle of repose increased from 30.5 to 37.6 ^{0}C with the increase in moisture content from 14-24%. In present study, the angle of repose shows the following equation with moisture content.

$$\Theta = 0.63\,MC + 23.40 \text{ with a value of } R^2 = 0.90$$

Tabatabaeefar (2003) observed the same pattern for angle of repose with the increase in moisture content. The angle of repose reflects the shape of grains heap. Increasing moisture content had the opposite effect on hardness and initial cracking force i.e. both decreased. Hardness decreases from 124.54 to 98.01 N and initial cracking force decreased to 38.54 from 66.94 N.

The Pearson correlation matrix was calculated among some important traits of wheat that are dependent on moisture content and is shown in Table 3. Results reveal that most of the traits are negatively correlated with each other. The strong positive correlation at 1 % level was observed between the angle of repose and true density with the value of correlation matrix r = 0.98. Porosity and bulk density was found to be highly negatively correlated (r = -0.99). Also, the PCs plot of these same properties as affected by the increased moisture content is presented in Fig 5. The scatter diagram shows that there was a high level of diversity. The first principal component (PC1) was positively related to porosity, true density, the angle of repose and thousand kernel weight with a variance of 50.43%. Bulk density, hardness, and initial cracking force were negatively related to increasing moisture content with a variance of PC2 = 47.83%.

Table 1: Geometrical properties of wheat grains of different varieties at different moisture content.

Moisture	8 %			10%			12%			14%		
Variety	MP-1106	UP- 2554	WH-542	MP-1106	UP- 2554	WH-542	MP-1106	UP- 2554	WH-542	MP-1106	UP- 2554	WH-542
L (mm)	6.23 ±0.30	5.59±0.40	5.85±0.52	6.49±0.31	5.67±0.24	5.93±0.39	6.30±0.32	5.57±0.19	6.03±0.25	6.37±0.41	5.63±0.37	6.45±0.35
W (mm)	3.10±0.46	3.41±0.23	3.04±0.31	2.76±0.29	3.52±0.25	3.26±0.26	2.86±0.20	3.51±0.20	3.13±0.31	2.82±0.19	3.41±0.17	3.42±0.29
T (mm)	2.73±0.23	2.66±0.14	2.57±0.44	2.64±0.26	2.76±0.17	2.63±0.30	2.81±0.22	2.65±0.30	2.45±0.30	2.66±0.16	2.72±0.17	2.60±0.39
Dg (mm)	3.74±0.29	3.70±0.26	3.56±0.33	3.61±0.19	3.80±0.17	3.70±0.26	3.70±0.20	3.72±0.19	3.59±0.27	3.63±0.16	3.74±0.18	3.85±0.28
Da (mm)	4.02±0.27	3.89±0.24	3.82±0.32	3.97±0.16	3.98±0.16	3.94±0.25	3.99±0.20	3.91±0.16	3.87±0.23	3.95±0.17	3.92±0.19	4.16±0.22
Φ (%)	60.02±3.55	66.33±1.16	61.04±4.59	55.67±3.53	67.10±2.51	62.47±3.48	58.75±2.57	66.51±2.85	59.52±4.20	57.15±3.40	66.63±2.69	59.83±5.22
S (mm2)	44.29±6.92	43.24±5.14	40.30±7.14	41.08±4.44	45.56±4.00	43.28±6.16	43.11±4.81	43.64±4.50	40.68±6.10	41.51±3.64	44.04±4.27	46.90±6.75
Ra	49.68±6.78	61.17±1.87	52.18±0.57	42.63±4.95	62.15±4.26	55.15±4.87	45.46±3.31	63.06±3.82	52.07±5.37	44.59±4.60	60.70±3.29	53.33±6.18
V (mm3)	18.31±4.57	18.40±3.10	16.07±4.19	15.75±2.87	20.03±2.82	17.97±4.03	17.29±3.08	18.78±3.11	16.08±3.90	16.11±2.18	18.93±2.68	19.95±4.63

For determining L, W & T each value is mean of 30 replications ± standard deviation.
Dg = Geometric mean diameter, Da = Arithmetic mean diameter, Φ= Degree of sphericity, S= Surface area, Ra = Aspect ratio & V= Seed volume.

Table 2: Properties of Wheat (WH-542).

Moisture (%)	8	10	12	14
BD	783.92±2.01c	771.47±7.79 c	713.94±7.04 b	650.39±5.04 a
TD	1237.29±5.59 a	1259.54±2.89 b	1282.68±3.38 c	1309.83±6.7 d
Porosity	36.64±0.34 a	38.75±0.48 b	44.34±0.46 c	50.34±0.06 d
AOR	24.31±0.55 a	26.88±0.23 b	28.39±0.40 c	30.60±0.54 d
Hardness	124.88±0.30d	119.47±1.51c	112.76±1.47 b	97.99±0.13 a
ICF	66.34±0.87 d	53.97±0.67 c	43.88±0.30 b	38.85±0.26 a
TKW	37.66±0.39 a	39.54±0.45 b	41.05±0.21 c	41.82±0.42 c

BD bulk density, TD true density, AOR angle of repose, ICF initial cracking force, TKW thousand kernel weight.
All the values are Mean ± SD. Values within the same column with different letters are significantly different ($p < 0.05$)

Table 3: Correlation matrix for traits of wheat (WH-542).

	BD	TD	Porosity	AOR	Hardness	ICF	TKW
BD	1						
TD	-0.94**	1					
Porosity	-0.99**	0.97**	1				
AOR	-0.93**	0.98**	0.95**	1			
Hardness	0.95**	-0.96**	-0.96**	-0.93**	1		
ICF	0.89**	-0.96**	-0.92**	-0.97**	0.90**	1	
TKW	-0.89**	0.94**	0.91**	0.96**	-0.87**	-0.98**	1

**$P < 0.01$. BD bulk density, TD true density, AOR angle of repose, ICF initial cracking force, TKW thousand kernel weight

Table 4: Flow indicating properties of wheat (WH-542) at different moisture content**.**

Moisture content	Tapped density kg/m^3	CI	HR
8	852.04±0.23d	7.99±0.90a	1.08±0.01a
10	843.97±1.40c	8.58±1.06a	1.09±0.02a
12	811.58±0.62b	12.03±0.90b	1.13±0.01a
14	797.62±1.99a	18.45±0.15c	1.22±0.04b

CI - compressibility index; HR - Hausner ratio. Values ± standard deviation. Different letters in column indicates significant difference. (p<0.0)

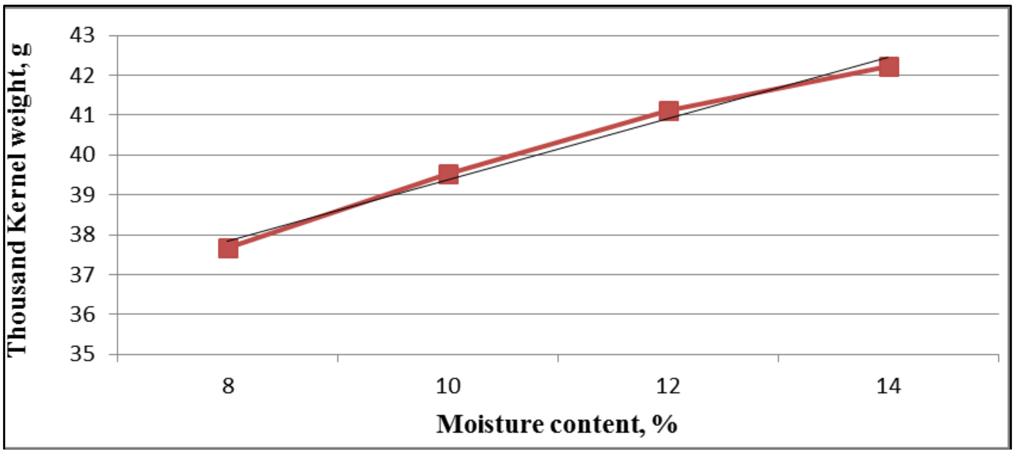

Fig 1: Variation of mass of 1000 kernels (WH-542) with moisture content.

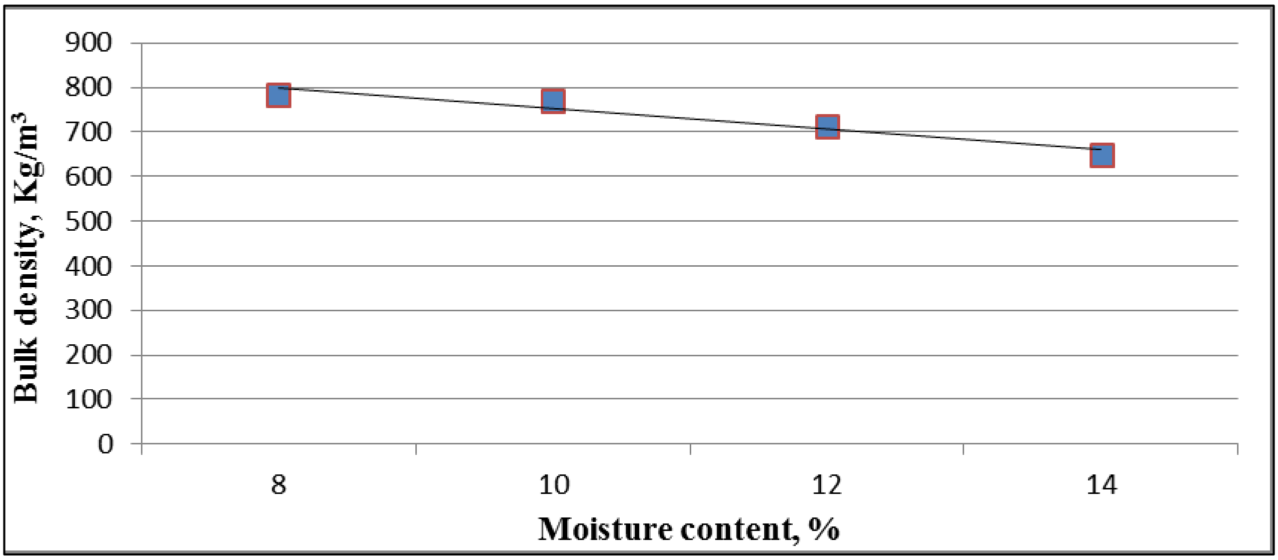

Fig 2: Effect of moisture content on bulk density (WH-542).

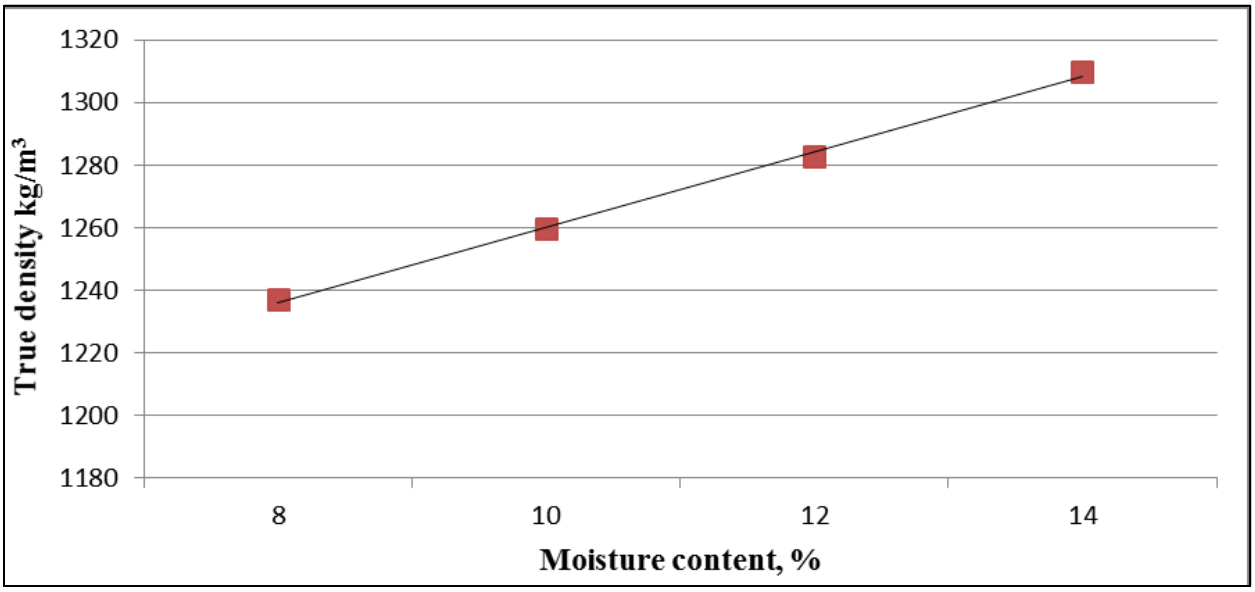

Fig 3: Effect of moisture content on true density (WH-542).

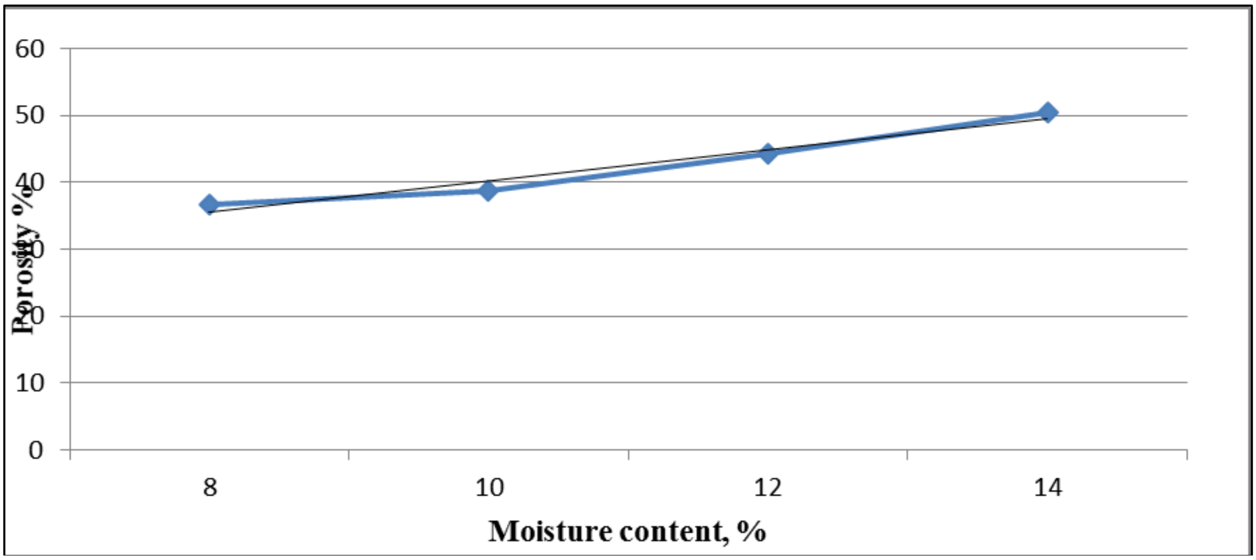

Fig 4: Effect of moisture content on porosity (WH-542).

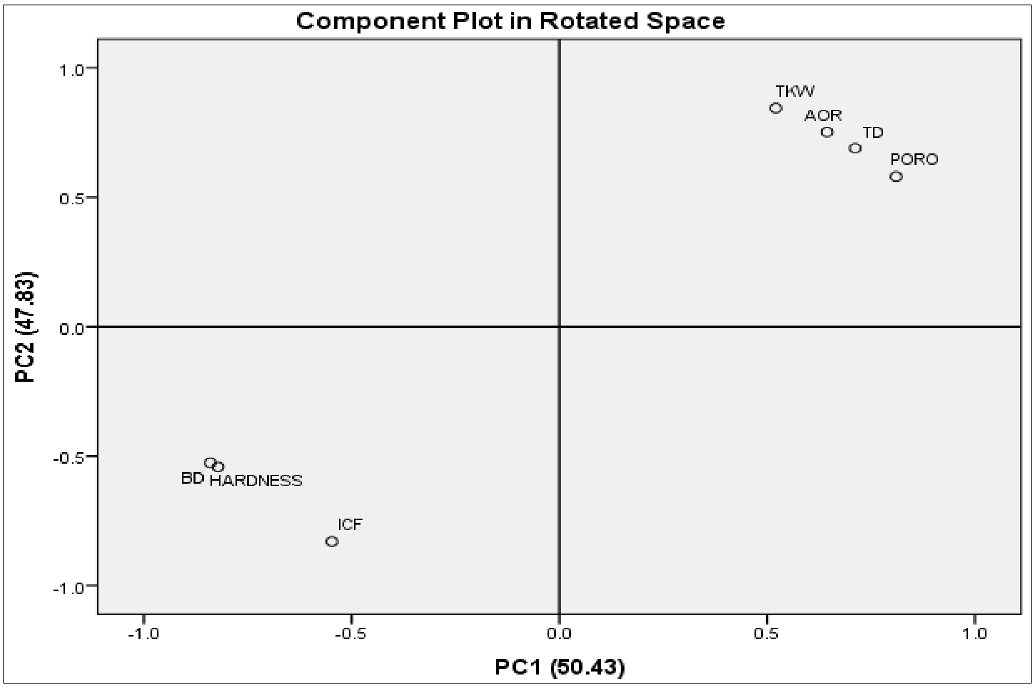

Fig 5: Principal component analysis (PCA) projections on the first and second components: BD bulk density, TD true density, AOR angle of repose, ICF initial cracking force, TKW thousand kernel weight.

3.7 Flow Properties
Tapped density decreases with the increase in moisture content from 852.23 to 795.43 kg/m^3 details are given in Table 4. Negative trend in tapped density was due to the reason that high moisture wheat can easily stick together and form a curve. A similar trend was observed by Bian et.al, (2015) [7] who found that tapped density not only depend on moisture content but also varies with the insect-pest infestation. Compressibility index (CI) shows cohesion and flow ability of grains were higher for high moisture content wheat, suggesting that low moisture content wheat will have better flow characteristics. HR indicated the ratio between densities when grains are packed. HR was found between 1.08 to 1.22 i.e. below 1.3 so wheat even at high moisture content falls under free-flowing material (Santomaso *et al*., 2003; Bian *et al*., 2015) [6].

4. Conclusion
In this study, some engineering properties of three varieties of wheat widespread cultivated and consumed in India were investigated in the range of moisture contents from 8 to 14% (w.b). The following conclusions are drawn from this investigation:

- Length, width and thickness increased from 5.19-6.80mm, 2.68- 3.65mm and 2.30-2.96mm with the increase in moisture content from 8 to 14%. The bulk density decreased from 785.5 – 623.21 kg/m^3 while true density and porosity increased from 1232.12-1315.78 kg/m^3 to 34.64-50.34%.
- Study on flow properties indicates that compressibility index was higher for high moisture wheat as compared to low moisture wheat indicating that low moisture wheat will have better flow characteristics.
- Engineering properties of wheat not only vary with the variety but also with the change in moisture content. Forexample, cracking force decreased from 67.21 to 38.54 N with the increase in moisture content.

Overall, the data obtained regarding moisture dependent properties would prove useful prior to designing post-harvest processing equipment and storage bins under Indian agro-climatic condition.

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