Effect of moisture content on soybean engineering properties: comparative study of varieties

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Abstract: Interest and research work on soybean has been reinvigorated due to its increasing demand as a cash crop and its being a cheap source of protein. Its production and processing can be improved and maximize with the help of agricultural equipment for handling, transporting, processing and storage of the seeds. The design-related engineering properties of soybean seeds for two varieties TGX 1448-2E and TGX 1835-10E as a function of moisture content in the range of 10.21%-18.37% (d.b) were determined to ascertain the varietal difference and the effect of moisture content. Standard methods were employed in the experimental study. The results of the design-related engineering properties of the soybean were found to be dependent on the moisture content and the soybean variety. The statistical test shows that the varietal difference and the moisture content significantly affect all the design related engineering properties.

Keywords: equipment, physical properties, soybean, moisture content, variety.

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1 Introduction

Soybean (*Glycine max* L.*)* from legume native to Eastern Asia species was known to be an edible oilseed. It was a Golden bean from the 20th century which serves as an energy source to the human body because of its high protein and oil content. It was ranked first among the oil seed production in the world with almost 56% (Soltani et al., 2014; Wandkar et al., 2012). Soybean originates from China where it was grown for almost 5000 years ago this makes it the world's oldest cultured plant. It was also regarded as an important legume crop in America (IITA, 2002). However, its large-scale production which accounts for almost 96% of the world soybean cultivation dominated in some few countries (Singh et al., 2004).

The world soybean production was over 160 million tonnes in the year 1999 (FAO, 2000). In 2018, the production was 362.85 million tons. The leading producer is Brazil which accounted for 36%, followed by United State of America (30%), Argentina (16%), China (5%), India and Paraguay each (3%), Canada (1%), and Nigeria (less than 1%) (Soybean production by country, 2019). The interest and research work on soybean sometimes referred to as meat of the world has reinvigorated to action as a result of its increasing demand as a cash crop and also regarded as the cheapest source of protein and oil (Khalifa, 1987; Mahdi and Abdel-Aziz, 1993; Mukhtar and Naib, 1987). Soybean is among the leading cash crops in the world and also can contribute to the protein needs of a larger population (Mesquita et al., 1997). Its protein content ranges from 30% to 45% and also contains calcium, phosphorus and vitamin B (Sharma and Devnani, 1980; Tandon and Panwar, 1989). Soybeans

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also serve as feed for livestock and aquaculture and biodiesel production (Chinsuwan and Vejasit, 1991; Sharma and Devnani, 1980).

According to Fennel (1996), the introduction of soybeans seeds to Nigeria was in the year 1908. The Malayan variety was used to achieve prosperous cultivation in the year 1973 and it was found to be satisfactorily for commercial production. Most of the lands in Nigeria are fertile; therefore, soybean can be grown with low Agricultural input. The domestic usage, nutritive and economic importance of soybean makes its cultivation dilate in Nigeria (Dugje et al., 2009). In West and Central Africa, Nigeria is the largest producer of soybeans (Ugwu and Nwoke, 2011). It was among the crop that is being consumed routinely in Nigeria and used in large quantities as an ingredient for the preparation of traditional food products.

The engineering properties namely: physical, frictional, mechanical and rheological, are essential while handling and processing of agricultural products. For an efficient operational set up of equipment, the design related engineering properties are the important factors to be considered (Gürsoy and Güzel, 2010; Irtwange and Igbeka, 2002). For the size and shape of the seeds or grains, the characteristic dimensions are used. To separate, sort, grade, calculate the surface area, volume of the grains, investigate the quality evaluation of the agricultural produce, the size, and shape are the foremost (Sahin and Sumnu, 2006). The surface area is beneficial in the determination of the quality and quantity, colour, aerodynamic computations, and respiration measurements of the agricultural materials (Singh and Heldman, 2009). The bulk density determines the conveyor capacity and the produce storage requirement. In materials separation processes, the true density is considered. The porosity is essential for determining the size of grain hoppers and storage equipment. The above are all important properties in drying and ventilation processes because they affect the rate of heat transfer and moisture in the process. The angle of repose and the static coefficient of friction are the main factors to consider in material flow, because they affect the design of the storage structures, seed case, and are used for calculating the grain discharge rates from storage vessels. Designing of such equipments and machines without taking these into considerations may yield poor results. For this reason the determination and considerations of these properties become an important role (Kakade, et al., 2019). The moisture content is a property that influences the other engineering properties of the agricultural materials (Bhise et al., 2014; Degirmencioglu and Srivastava, 1996; Henderson et al., 1997; Sahin and Sumnu, 2006; Singh and Heldman, 2009). The knowledge of the properties of agricultural materials at different moisture levels is needed for efficient, effective and economical equipment design (Bhise et al., 2014; Chhabra and Kaur, 2017). The shape, color, size, physical properties and chemical composition of Soybean seeds differ among its varieties. The seeds are used for different applications, both food and industrial, the knowledge of the design related engineering properties of its varieties is pertinent (Rehal et al., 2019). Recently, study was conducted on two popular cultivars of soybean grown in Punjab, India viz. SL-744 and SL-958 (Rehal et al., 2019). The study revealed the properties of the soybean differ among the two varieties. Studies on the engineering properties of different grains and seeds varieties and the effect of moisture content on their properties were conducted (Bhise et al., 2014; Chhabra and Kaur, 2017; Malik and Saini, 2016; Pohndorf et al., 2018; Ramashia et al., 2018). Reports on the effect of moisture content on Soybean varieties were conducted (Kakade et al., 2019; Wandkar et al., 2012). Hence the present work was carried out to determine the design related engineering properties of two varieties of soybean viz. TGX-1441-2E and TGX-1835-10E at different moisture content levels, because they serve as the important properties for relevant machines and equipment for the processing of the seed.

2 Materials and methods

2.1 Soybean seeds for analysis

The grain sample of two varieties TGX 1448-2E and TGX 1835-10E were procured from the Agronomy Department, Faculty of Agriculture, Bayero University, Kano, Kano Nigeria. The varieties were selected because of their characteristics (high yielding, early maturity, and low shattering) and they are the most commonly planted by farmers in the North-Western part of Nigeria.

2.2 Preparation of sample

Seeds were sorted to remove broken and spoilt seeds before the experimental process. Care was taken to ensure that only good seeds were used. For the two varieties, five levels of moisture content were attained (10.21%, 12.33%, 14.04%, 16.41% & 18.37%). These values are within the normal values at which post-harvest threshing operations are carried out (Mohsenin, 1980). ASTM (ASTM-E871-82, 2013) moisture standard procedure based on a dry basis (Kashani Nejad et al., 2003) was used. A calculated amount of water using Equation 1 (Isik, 2007) was added to the samples to reach the intended moisture levels. The soybean seeds were mixed thoroughly with the calculated amount of water and sealed in a polyethylene bag. It was then kept for 15 days in a refrigerator to have a uniform moisture distribution (Karababa, 2005). The samples' moisture content was then measured before the experiment was carried out.

$$Q = \frac{Wi(M_f - M_i)}{100 - M_f} \quad (1)$$

Where, Q = Quantity of water (g), W_i= Sample initial weight (g), and M_f= Final (dry basis) moisture content (% d.b) and M_i= Initial (dry basis) moisture content (% d.b).

The moisture contents attained for the two varieties were: 10.21%, 12.33%, 14.09%, 16.41% and 18.37%.

2.3 Dimensions

Random selection of 50 soybeans seeds was carried out to determine the dimensions as described by Mohsenin (Mohsenin, 1980). For each variety of soybeans, the dimensions were measured by a vernier caliper with 0.02 mm resolution. Figure 1 illustrates the dimensions length L, the width W, and the thickness T.

The mean diameter (D_g), and sphericity (ϕ) were obtained by Equation 2 and Equation 3 respectively (Mohsenin, 1980) using the soybean length (L), width (W), and thickness (T).

$$Dg = (L \times W \times T)^{\frac{1}{3}} \quad (2)$$

Where: Dg = mean diameter, L = length (mm), W= width (mm), and T = thickness (mm)

$$\phi = \frac{(L \times W \times T)^{\frac{1}{3}}}{L} \quad (3)$$

Where: ϕ = sphericity, L = length (mm), W= width (mm), and T = thickness (mm)

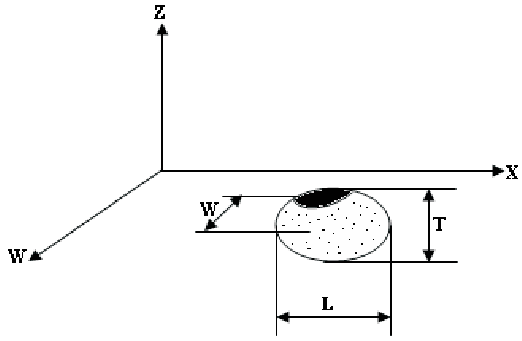

Figure 1 Characteristic dimensions of soybean (Kibar and Öztürk, 2008).

2.4 The bulk and true density, porosity, and thousand-grain mass

The bulk density of a material is the ratio of the sample weight to its total volume. It was calculated by the procedure (Wandkar et al., 2012) given.

$$\rho b = \frac{m}{v} \quad (4)$$

Where: ρb = bulk density (kg m^{-3}), m = seeds weight (kg), and v = seeds volume (m^3)

The method described by Mohsenin (1980) using Equation 5, was used to determine the true density.

$$\rho t = \frac{M_s + M_w}{V_s + V_w} \quad (5)$$

Where: ρt is the true density (kg m^{-3}), M_s, and M_w are the mass of liquid and mass of the air-dried sample in kg, V_s and V_w are the volumes of the liquid and the sample in m^3.

The porosity was expressed by Equation 6 (Mohsenin, 1980). It is the ratio of the internal pores to the bulk volume in the particles.

$$Ps = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (6)$$

Where: P_s is the porosity; ρt and ρb are the true, and bulk density in kg m^{-3}.

The thousand-grain mass of the samples was obtained by an electronic weighing scale (Wandkar et al., 2012).

2.5 The angle of repose and the coefficient of static friction

The angle of repose and coefficient of static friction of the soybean samples were determined as per the standard methods (Nimkar et al., 2005; Sahay and Singh, 1996) against different structural surfaces namely, wood, glass, and metal sheet. Equation 7 was used for (Nimkar et al., 2005) the computation.

$$\mu = tan\alpha \tag{7}$$

Where μ and α are the coefficient of static friction, and the tilt angle (°).

Note that three repetitions were carried out in all the above experiments except for the dimensions where 50 repetitions were made at the stated moisture content.

2.6 Statistical analysis

The results of the design related engineering properties at different moisture content levels were analyzed using analysis of variance SAS/STAT Software package with GLM procedure.

3 Results and Discussion

3.1 The soybean seeds principal dimensions, geometric mean diameter, and sphericity

Results of the mean, minimum and maximum values for the measured properties of the soybean 1448-2E and 1835-10E varieties at different moisture levels in the range of 10.21%-18.37% (dry basis) are presented in Table 1. The ranges of the dimension of 50 grains measured at the stated moisture content levels for 1448-2E variety was 7.08-8.23 mm, 6.02-6.23 mm, 4.98-5.55 mm, 5.96-6.74 mm and 0.84-0.82 for the length, width, thickness, geometric mean diameter, and sphericity respectively. Similarly, the ranges for 1835-10E variety were 6.51-7.99 mm, 5.94-6.02 mm, 4.47-5.13 mm, 5.56-6.26 mm, and 0.85-0.78 for those properties respectively. The results of the two varieties of soybeans indicate that the soybeans increased in length, width, thickness and geometric mean diameter within the stated moisture range.

For the two varieties, there exists a significant difference in the mean values of the properties at a 5% level (Table 2), and they were significantly affected by the moisture content at 5%. A comparison of the mean values of soybean dimensions using t-test LSD (Table 3) shows that 1448-2E has significantly higher values of dimensions than 1835–10E. A similar comparison revealed that the highest value of length was at 18% moisture level. For width, the values at 14.09%, 12.33% and 10.21% moisture levels are statistically similar but significantly lower than the values at 18.37% level. For thickness, the values at 14.09% and 12.33% moisture levels are statistically similar but significantly higher than those at 10.21% and significantly lower than those at 18.37%. The correlation between the dimensions and the moisture content was established with Microsoft excel tool pack for regression. Table 4 shows the linear regression equations. Therefore, dimensions and geometric mean diameter tends to increase with increasing moisture levels. Sphericity, however, decreased with an increase in moisture content. The results agree with similar findings on soybean (Deshpande et al., 1993; Isik, 2007; Kakade, et al., 2019; Mustapha, 2012; Polat et al., 2006; Shirkole et al., 2011; Wandkar et al., 2012), peanut and soybean (Abubakar, 2013), pigeon pea (Baryeh and Mangope, 2003), cowpea and soybean (Huji, 2002) maize (Bhise et al., 2014), lentils seeds (Çarman, 1996).

Table 1 Principal dimensions, geometric mean diameter, and sphericity of the soybean seed at various moisture contents

Variety	Moisture content (% d.b)	*L* (mm)	*W* (mm)	*T* (mm)	*Dg* (mm)	Sphericity
1448-2E	10.21	7.08±0.43	6.02±0.55	4.98±0.4	5.96±0.41	0.84±0.03
		$(8.07)^{max}$	$(6.89)^{max}$	$(5.74)^{max}$	$(6.83)^{max}$	$(0.89)^{max}$
		$(6.20)^{min}$	$(5.10)^{min}$	$(4.08)^{min}$	$(4.84)^{min}$	$(0.76)^{min}$
	12.33	7.24±0.47	6.04±0.40	5.04±0.35	6.04±0.33	0.83±0.04
		$(7.84)^{max}$	$(6.49)^{max}$	$(5.71)^{max}$	$(6.03)^{max}$	$(0.94)^{max}$
		$(6.65)^{min}$	$(5.66)^{min}$	$(4.34)^{min}$	$(5.90)^{min}$	$(0.77)^{min}$
	14.09	7.45±0.34	6.13±0.48	5.39±0.42	6.16±0.32	0.83±0.03
		$(8.00)^{max}$	$(7.14)^{max}$	$(6.22)^{max}$	$(7.08)^{max}$	$(0.89)^{max}$
		$(6.20)^{min}$	$(5.81)^{min}$	$(4.77)^{min}$	$(5.70)^{min}$	$(0.76)^{min}$
	16.41	7.84±0.27	6.46±0.34	5.35±0.33	6.46±0.27	0.82±0.03
		$(8.34)^{max}$	$(7.60)^{max}$	$(6.49)^{max}$	$(7.35)^{max}$	$(0.91)^{max}$
		$(7.37)^{min}$	$(5.89)^{min}$	$(5.00)^{min}$	$(6.06)^{min}$	$(0.78)^{min}$
	18.37	8.23±0.29	6.23±0.19	5.55±0.3	6.74±0.18	0.82±0.02
		$(8.78)^{max}$	$(7.48)^{max}$	$(6.40)^{max}$	$(7.43)^{max}$	$(0.87)^{max}$

		(7.68)^{min}	(6.33)^{min}	(5.05)^{min}	(6.51)^{min}	(0.79)^{min}
1835-10E	10.21	6.51±0.3	5.94±0.51	4.47±0.3	5.56±0.23	0.85±0.04
		(6.98)^{max}	(6.89)^{max}	(5.00)^{max}	(5.93)^{max}	(0.96)^{max}
		(6.00)^{min}	(4.81)^{min}	(88)^{min}	(5.04)^{min}	(0.73)^{min}
	12.33	7.12±0.43	5.95±0.47	4.84±0.42	5.89±0.29	0.83±0.04
		(8.07)^{max}	(6.89)^{max}	(5.74)^{max}	(6.61)^{max}	(0.93)^{max}
		(6.20)^{min}	(4.98)^{min}	(4.01)^{min}	(5.28)^{min}	(0.76)^{min}
	14.09	7.15±0.37	5.96±0.39	4.99±0.29	5.96±0.24	0.84±0.04
		(7.85)^{max}	(6.89)^{max}	(5.74)^{max}	(6.55)^{max}	(0.92)^{max}
		(6.20)^{min}	(5.16)^{min}	(4.42)^{min}	(5.51)^{min}	(0.74)^{min}
	16.41	7.62±0.39	5.99±0.48	5.02±0.36	6.13±0.28	0.79±0.04
		(8.51)^{max}	(6.84)^{max}	(5.81)^{max}	(6.80)^{max}	(0.90)^{max}
		(6.507)^{min}	(5.04)^{min}	(4.15)^{min}	(5.40)^{min}	(0.71)^{min}
	18.37	7.99±0.32	6.02±0.32	5.13±0.4	6.26±0.25	0.78±0.03
		(8.82)^{max}	(7.16)^{max}	(6.09)^{max}	(7.12)^{max}	(0.85)^{max}
		(7.57)^{min}	(5.02)^{min}	(4.42)^{min}	(5.96)^{min}	(0.71)^{min}

Table 2 Analysis of variance result for dimensions of soybean

		F-Value		
SV	df	Length	Width	Thickness
R	49	0.89NS	1.01NS	0.71NS
V	1	74.39**	656**	105.49**
Mc	4	184.33**	12.63**	27.17**
Error	441			
Total	500			

Note: SV: Source of variation, df: Degrees of freedom, R: Replication, V: Variety, Mc: Moisture content, NS: Not significant **: Significant at 1% (highly significant)

Table 3 LSD Comparison for mean values of dimensions at different moisture levels

	Mean Values		
Treatment	Length (mm)	Width (mm)	Thickness (mm)
18.37%	8.11^{a}	6.36^{a}	5.20^{a}
16.41%	7.76^{b}	6.17^{b}	5.19^{a}
14.09%	7.29^{c}	6.07^{b,c}	5.07^{a,b}
12.33%	7.18^{c}	5.99^{c}	5.03^{b}
10.21%	6.80^{d}	5.98^{c}	4.72^{c}
LSD	0.138	0.162	0.1352
1448-2E	7.58^{a}	6.27^{a}	5.21^{a}
1835-10E	7.28^{b}	5.96^{b}	4.87^{b}
LSD	0.0873	0.102	0.0855

Note: Means with the same letters are not significantly different

Table 4 Regression equations for the dimensions of two varieties of soybean

Dimension	1448-2E variety	1835-10E variety
Length	5.45 + 0.144Mc, R2 = 0.962	4.856 + 0.174Mc, R2 = 0.953
Width	5.00 + 0.090Mc, R2 = 0.885	5.838 + 0.009Mc, R2 = 0.992
Thickness	4.205 + 0.071Mc, R2 = 0.945	829+ 0.075Mc, R2 = 0.851
Geometric mean diameter	4.881 + 0.099Mc, R2 = 0.936	4.809 + 0.082Mc, R2 = 0.953
Sphericity	0.868 – 0.002Mc, R2 = 0.978	0.939 – 0.008Mc, R2 = 0.871

Note: R^2 values are significant at p <0.05.

3.2 The densities, porosity, and 1000 grain mass of the soybean seeds

The obtained mean values of the bulk density, true density, porosity and 1000 grain mass for soybean 1448-2E and 1835-10E varieties at different moisture levels 10.21%-18.37% (dry basis) are presented in Table 5. The range of the values obtained at the stated moisture content levels for 1448-2E variety is 128-142 g, 728.47-652.37 kg m^{-3}, 858.78-1016.79 kg $m^{-3}$and 15.16%-35.84% for 1000 grain mass, bulk density, true density, and porosity respectively. Similarly, the range for 1835-10E Variety are 109-121.33 g, 721.28-666.86 kg m^{-3}, 872.38-10133 kg m^{-3}, 17.31%-34.19% for those properties respectively. The properties are dependent on the moisture content level and the variety of the soybean.

There exist highly significant differences in the mean values of the procured soybean seeds properties from the analysis of variance results (Table 6). The mean values of those properties show a highly significant difference at different moisture levels. However, a significant difference between the interaction of the moisture content and the varieties for bulk density and porosity, but surely, no notable difference between the interaction of moisture content and varieties for 1000 grain mass and true density. Comparison of the mean values of the properties using t-test LSD (Table 7) shows that 1448-2E has significantly higher values than 1835-10E for the one thousand mass but for the bulk density, 1835-10E has significantly higher values than 1448-2E. The mean values for the two varieties 1448-2E and 1835-10E of the true density and the porosity are statistically similar. This implies that the moisture content level has no significant effect on the true density and the porosity between the two soybean varieties.

The regression equations are presented in Table 8. The relationship between the design related engineering properties and the moisture content (Mc) was established using the Microsoft excel tool pack for regression. These results corroborate with the findings of various researchers (Abubakar, 2013; Aydın and Özcan, 2002; Isik, 2007; Kakade et al., 2019; Mustapha, 2012; Polat et al., 2006; Shirkole et al., 2011; Wandkar et al., 2012). From this, it could be seen that the true density, one thousand grain mass, and the porosity increases with an increase in the moisture level. Bulk density, however, shows a decreasing trend with an increase in moisture level. This could be due to the increase in mass which results in moisture gain by the sample being lower than the corresponding volumetric expansion of the bulk (Sologubik et al., 2013).

Table 5 Mean values of the properties for the two soybean seed varieties at various moisture levels

Variety	Moisture content % (d.b)	1000 grain mass (g)	Bulk density (kg m^{-3})	True density (kg m^{-3})	Porosity
1448-2E	10.21	128.00	728.47	858.78	15.16
	12.33	132.33	7171	906.86	21.29
	14.09	135.00	695.58	927.27	24.99
	16.41	140.00	672.32	951.63	29.35
	18.37	142.00	652.37	1016.79	35.84
1835-10E	10.21	109.00	721.28	892.38	17.31
	12.33	110.33	711.89	892.67	20.25
	14.09	1133	698.71	919.82	24.04
	16.41	119.00	676.04	9612	29.79
	18.37	121.33	666.86	10133	34.19

Table 6 The analysis of variance results for the true density, bulk density, porosity and 1000 grain mass

		F-Value			
Source variation	Degrees of freedom	1000 grain mass (g)	Bulk density (kg m^{-3})	True density (kg m^{-3})	Porosity
Replication	2	0.08 NS	1.33 NS	0.44 NS	0.92 NS
Variety, V	1	11383*	8.81**	0.00 NS	0.47 NS
Moisture content, Mc	4	630**	8734**	215.99**	459.64**
V*Mc	4	0.44 NS	18.69**	2.41 NS	4.95**
Error	18				
Total	29				

Note: NS: Not significant. **: Significant at 1% (highly significant)

Table 7 LSD comparison for the mean values of true density, bulk density, porosity and 1000 grain mass at different moisture content level

		Mean Values			
Treatment		One thousand mass (g)	Bulk density (kg m^{-3})	True density (kg m^{-3})	Porosity
Moisture content	18.37%	131.67^{a}	659.61^{e}	1015.05^{a}	35.01^{a}
	16.41%	129.50^{a}	674.18^{d}	957.39^{b}	29.57^{b}
	14.09%	125.00^{b}	697.14^{c}	9255^{c}	24.51^{c}
	12.33%	121.67^{c}	712.80^{b}	899.77^{d}	20.77^{d}
	10.21%	118.50^{d}	724.875^{a}	865.58^{e}	16.23^{e}
	LSD	2.7753	7822	15.856	1.3949
Variety	1448-2E	135.53^{a}	692.49^{b}	932.27^{a}	25.33^{a}
	1835-10E	115.00^{b}	694.95^{a}	932.26^{a}	25.12^{a}
	LSD	1.7553	2.3921	10.028	0.8822

Note: The mean values with the same letters are not significantly different.

Table 8 Regression equation for the 1000 grain mass, true density, bulk density, and porosity

Dimension	1448-2E variety	1835-10E variety
One thousand mass	110.5 + 1.783Mc, R^2 = 0.986	91.26 + 1.666Mc, R^2 = 0.958
Bulk density	828 – 9.679Mc, R^2 = 0.993	795.7 – 7.206Mc, R^2 = 0.977
True density	679.7 + 18.04Mc, R^2 = 0.957	685.6 + 17.61Mc, R^2 = 0.967
Porosity	-9.27 + 2.471Mc, R^2 = 0.990	-4.44 + 2.118Mc, R^2 = 0.981

Note: R^2 values are significant at p<0.05.

3.3 The angle of repose and coefficient of static friction on three surfaces

The mean values obtained for 1448-2E and 1835-10E varieties at different moisture levels 10.21%-18.37% d.b were shown in Table 9. The range of the values for the angle of repose and the static coefficient of friction was found to be 27.35°-31.50° and 0.55-0.65 (Plywood), 18.20°-24.70° and 0.39-0.51 (Glass) and 14.50°-21.97° and 0.37-0.44 (Steel) for 1448-2E variety. Similarly, the range for 1835-10E variety are 24.53°-28.10° and 0.54-0.68, 18.63°-22.77° and 0.49-58.84, 14.27-18.73 and 0.45-0.51 for those properties.

There exists a highly significant difference in the mean values for the angle of repose and the coefficient of static friction between the two varieties as shown by the analysis of variance result (Table 10). Also, the mean values of those properties show highly significant differences at different moisture content levels and different surfaces. A comparison of the mean values of the properties using t-test LSD (Table 11) shows that glass has significantly higher values of these properties than steel but significantly lower values than plywood. For the angle of repose, a similar comparison revealed that the maximum value obtained was at 18.37% moisture level. The values at 12.33% and 10.21% moisture level are statistically similar but lower than the values at 14.09%, 16.41% and 18.37% for the coefficient of static friction.

The correlation of the obtained properties and the moisture content (Mc) against three surfaces was established using the Microsoft excel tool pack for regression. The linear regression equations are presented in Table 12. The results of the properties obtained increase linearly with increasing moisture levels. The trend could be a result of the increased adhesion in the soybean seeds and the tested materials at a high moisture level (Izli, 2015). The values for each property obtained were highest against the plywood surface and least against the steel surface at the stated moisture level. A similar increasing trend was reported in different studies on agricultural products (Abubakar, 2013; Huji, 2002; Isik, 2007; Kakade et al., 2019; Mustapha, 2012; Polat et al., 2006; Shirkole et al., 2011; Wandkar et al., 2012).

Table 9 Mean values of the properties of soybean seeds at various moisture levels

Variety	Moisture content (% d.b)	Plywood (°)		Glass (°)		Steel (°)	
		Angle of repose	Co-efficient of static friction	Angle of repose	Co-efficient of static friction	Angle of repose	Co-efficient of static friction
1448-2E	10.21	27.35	0.55	18.20	0.39	14.50	0.37
	12.33	25.29	0.57	28.08	0.42	16.73	0.38
	14.09	29.27	0.59	21.80	0.44	18.07	0.40
	16.41	31.07	0.61	22.83	0.47	19.13	0.43
	18.37	31.35	0.65	24.70	0.51	21.97	0.45
1835-10E	10.21	24.53	0.54	18.63	0.49	14.27	0.45
	12.33	25.43	0.59	19.73	0.50	15.23	0.46
	14.09	26.60	0.62	20.60	0.51	16.67	0.48
	16.41	27.10	0.66	21.70	0.55	17.93	0.50
	18.37	28.10	0.68	22.77	0.58	18.73	0.51

Table 10 Analysis of variance

Source of variation	Degrees of freedom	Angle of repose	Static co-efficient of friction
Replication	2	2.48NS	2.44NS
Variety (V)	1	430.33**	575.78**
Moisture content (Mc)	4	406.23**	201.74**
Material (Mat)	2	4978.81**	1611.04**
V*Mc	4	13.95**	0.37NS

V*Mat	2	58.00**	43.08**
Mc*Mat	8	5.19**	5.23**
V*Mc*Mat	8	3.04**	3.94**
Error	58		
Total	89		

Note: NS: Not significant, **: Significant at 1% (highly significant)

Table 11 LSD comparison for the mean values of the properties at various moisture levels

Mean values			
Treatment		Angle of repose	Co-efficient of static friction
Moisture content (% d.b)	18.37	24.62[a]	0.56[a]
	16.41	229[b]	0.53[b]
	14.09	22.17[c]	0.51[c]
	12.33	20.89[d]	0.49[d]
	10.21	19.58e	0.46[d]
	LSD	0.3694	0.0102
Variety	1448-2E	23.02[a]	0.48[b]
	1835-10E	21.20[b]	0.53[a]
	LSD	0.2336	0.0064
Surface	Plywood	27.90[a]	0.60[a]
	Glass	21.11[b]	0.48[b]
	Steel	17.32[c]	0.44[c]
	LSD	0.2861	0.0079

Note: The means with the same letters are not significantly different.

Table 12 Regression equation for angle of repose and static coefficient of friction

Treatment		1448-2E variety	1835-10E variety
Angle of repose	Plywood	23.98 + 0.361Mc, R^2 = 0.643	20.19 + 0.44Mc, R^2 =0.989
	Glass	14.27 + 0.473Mc, R^2 = 0.6996	152 + 0.511Mc, R^2 = 0.998
	Steel	10.73 + 0.467Mc, R^2 = 0.696	8.423 + 0.581Mc,R^2 = 0.992
Static coefficient of friction	Plywood	0.426 + 0.012Mc, R^2 = 0.973	0.373 + 0.017Mc, R^2 = 0.981
	Glass	0.259 + 0.010Mc,R^2 = 0.975	0.368 + 0.008Mc, R^2 = 0.984
	Steel	0.243 + 0.014Mc, R^2 = 0.987	0.365 + 0.011Mc, R^2 = 0.924

4 Conclusion

Some physical properties of soybean were determined at different moisture contents in the range of 10.21% - 18.37% dry basis for two varieties (1448-2E and 1835-10E). All the physical properties of the soybean varieties were dependent on moisture content. For the studied soybean seed varieties, the length, width, thickness, geometric mean diameter, 1000 grain mass, porosity, and true density increased with increase in moisture content. Also, the mean values for the angle of repose and static coefficient of friction tested on the plywood, glass and steel materials increased linearly. Sphericity and bulk density, however, decreases with a rise in the moisture level. The mean values of all the properties for the two soybean varieties show the existence of high significant differences from the results of the analysis of variance. A comparison of the mean values of the properties using t-test LSD shows that 1448-2E has significantly higher values of dimensions than 1835-10E. The linear relationship between the length, width, thickness, true density, porosity, angle of repose, mass, bulk density, coefficient of friction, porosity and the moisture content were established using Microsoft excel tool pack for regression. Therefore, these properties can be used to design equipment for handling soybean seed for its processing.

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