namely, length (l), width (b) and thickness (t) were measured using a digital vernier caliper (Model CD-6BS-Mitutoyo Corporation, Japan) with an accuracy of ±0.01 mm.

2.2. Shape

The shapes of sunflower seeds were determined through visual observations and by comparing with the standard shapes. The procedure for recording the shapes of seeds was given by Kachru (1994).

2.3.100 seeds mass

The mass of 100 seeds was measured using an electronic balance (Model PS200/2000/C/2- RADWAG, Poland) with an accuracy of ± 0.001 g.

2.4. True density

The true density of sunflower seeds was measured using toluene displacement method. 50 ml of toluene was taken in a 100 ml measuring jar and weighed, the sample seeds were poured into the jar. The change in the level of toluene in the jar was recorded. The true densities of the samples were calculated using the formula (Mohsenin, 1970).

$$\text{True density } (kg/m^3) = \frac{\text{Weight of seeds (kg)}}{\text{Volume of seeds } (m^3)}$$

$$\text{Volume of seeds} = \left\{\begin{matrix}\text{Final toluene level} \\ \text{in measuring jar}\end{matrix}\right\} - \left\{\begin{matrix}\text{Initial toluene level} \\ \text{in measuring jar}\end{matrix}\right\} \quad \text{…………3.2}$$

2.5 Bulk density

The bulk density was determined as per the method described by Mohsenin (1970). The seeds were filled into a container of standard size 10×10×10 cm upto the top level. The excess seeds were removed so that the top surface was perfectly level and even. Then the seeds in the container were weighed by using an electronic balance. The bulk density was calculated using the following formula:

$$\text{Bulk density } (kg/m^3) = \frac{\text{Weight of seeds (kg)}}{\text{Volume of seeds } (m^3)} \quad \text{…3.3}$$

2.6. Porosity

The porosity is also known as the packing factor and it was determined from bulk density and true density of grains and expressed by the following expression (Mohsenin, 1970)

$$\text{Porosity } (\%) = \frac{\text{True density - Bulk density}}{\text{True density}} \times 100 \quad \text{……3.4}$$

2.7. Angle of repose

The angle of repose indicates the cohesion among the individual units of a material. Higher the cohesion, higher is the angle of repose. The dynamic angle of repose of sunflower seeds was measured by the emptying method. For the emptying method, a bottomless cylinder was used. The cylinder was placed over a plain surface and sunflower seeds were filled in. The cylinder was raised slowly allowing the sample to flow down and form a natural slope. The dynamic angle of repose was calculated from the height and diameter of the pile as:

$$\theta = \tan^{-1}\frac{2h}{D} \quad \text{………3.5}$$

Where, θ = Angle of repose (º),

h = Height of the pile (cm) and

D = Diameter of the pile (cm).

2.8. Co-efficient of static friction

The coefficient of static friction (μ_s) was tested on different material surfaces such as plywood, galvanized steel sheet, and glass. The seed was placed on each of the surface and raised gradually by screw until the seed begin to slide. The angle that the inclined surface makes with the horizontal when sliding of the seed begins was measured. The coefficient of static friction was calculated using:

$$\mu_s = \tan\theta \quad \text{………3.6}$$

Where,

μ_s = Co-efficient of static friction

θ = Angle of inclination of material surface.

2.9. Statistical analysis

The results of the machine performance for different treatments of decortication were analyzed using Fisher's Factorial Completely Randomized Design to determine the significant differences among the treatments. Levels of significance was used in F-test at (P=0.05) for the statistical conclusion.

3. Results and Discussion

3.1. Size

The sizes of sunflower seeds at 10 to 12 per cent moisture content (w.b) were lower than the size of seeds at 14 to 16 per cent moisture content (w.b) (Table 1). The average dimensions of seeds at moisture contents between 10 to 16 percent viz., length, width and thickness varied from 12.54 to 13.19, 5.75 to 6.40, 3.88 to 5.91 mm, respectively.

3.2. Shape

By visual observation and standard chart of shapes, the seeds shapes were recorded. The shapes of seeds were identical and were oblong shaped (Mohesion 1970).

3.3. 100 seeds mass

The mass of 100 seeds at different percentages of moisture content are presented in Table 1. The mass of 100 seeds at 10, 12, 14 and 16 percent moisture content were found to be 6.08, 6.28, 6.36, and 6.38 g respectively.

3.4. True density

The true density of seeds at 10 per cent moisture content (769.2 kg/m^3) was found to be lower than the true density of seeds at 12 per cent moisture content (772.3 kg/m^3) and the true density at 14 percent moisture content was found to be 806.5 kg/m^3. The experimental data was recorded in Table 2.

3.5. Bulk density

The bulk density of seeds significantly varied with moisture content. The bulk density of seeds at 10, 12 and 14 per cent moisture contents were found to be 435 kg/m^3, 434 kg/m^3 and 432 kg/m^3 respectively (Table 2). The bulk density decreased from 435 kg/m^{3}to 432 kg/m^3 found to be in agreement with observations of Aydin (2003).

3.6 Porosity

The porosity of seeds at different moisture contents are presented in Table 4.2. The porosity of seeds at 10 per cent moisture content was found to be 43.5 %, whereas porosity values at 12 and 14 per cent moisture content were found to be 41.0 and 38.7 per cent, respectively.

The moisture content had effect on porosity (Fig.3) also. It was high at 10 percent moisture content and low at 14 per cent moisture content. This might be due to the increase in the size of the seeds due to absorption of moisture. This was also observed that the size of the seeds which was higher at 14 percent moisture compared to 10 percent moisture content (Fig.1). Statistically no significant difference was found among in the values of (43.5, 41.0, and 38.7 %) at different moisture contents of the sunflower seeds.

3.7 Frictional properties

3.7.1. Angle of repose

The angle of repose of seeds at 10, 12 and 14 per cent moisture content are presented in Table 3. The angle of repose of seeds at 10 per cent moisture content was found to be 23.9° and the values at 12 and 14 per cent moisture content were found to be 25.50° and 26.80°, respectively.

3.7.2. Co-efficient of static friction

The co-efficient of friction on different surfaces of materials like wood (ply-wood), galvanized iron sheet, and glass were measured using standard techniques and procedures; analyzed statistically and presented in Table 3. The co-efficient of friction for plywood sheet 22, 20 & 22, galvanized iron 19, 19 & 18 and glass 16, 15 & 15 at 10, 12 and 14 percent moisture content, respectively. Similar observations were recorded by Balasubramaniam (2001). The variation in the co-efficient of friction values for different frictional surfaces indicates the behavior of the surface texture of sunflower seeds. Statistically no significant difference was found for the co-efficient of seeds at different among the different moisture contents on different surfaces.

4. Conclusion

The physical properties of sunflower seeds at different moisture contents were studied by using standard procedures. When the recorded data analyzed statistically, it was observed that the physical properties like size, shape, 100 seeds mass ,true density, bulk density, porosity and frictional properties like angle of repose and co-efficient of static friction were determined. Among these, majority of the physical parameters such as size, true density, bulk density and angle of repose has an influence by the change in the moisture content and some significant differences observed between their readings. Sunflower seeds at 16 % moisture content had the highest dimensions in terms of length, width and thickness with values 13.9, 6.40 and 5.19 mm respectively.

5. Future Scope

Some of the *vivo* studies have been done on physical properties of other seeds but not on the sunflower seeds which are used in the development of power operated sunflower seed decorticator. Therefore further research can be done on aero and hydrodynamic properties of sunflower seeds with respect to moisture contents. These properties could help in separation process with blower. These would help in small scale formers for the decortication of sunflower seeds for confectionary purposes.

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Table 1: Physical dimensions of sunflower seeds

Dimension	Moisture content, % (w.b.)				S.Ed.	F- test	CD
	10	12	14	16	±		(0.01)
Length, mm	12.54	12.71	12.91	13.19	0.0365	100.45**	0.1225
Width, mm	05.57	05.75	05.93	06.40	0.0337	228.42**	0.1130
Thickness, mm	03.88	04.02	04.36	05.19	0.0516	257.35**	0.1733
100 seeds mass, g	06.08	06.28	06.36	06.38	0.0564	11.99**	0.1892

NS – Non Significant, ** - Significant at 1 % level

Table 2: Physical properties of sunflower seeds

Trials	*Moisture Content (% w.b.)*	*Volume (ml)*	*True Density (kg/m^3)*	*Bulk Density (kg/m^3)*	*Porosity (%)*
T1	10.0	65	769.2	435	43.5
T2	12.0	68	772.3	434	41.0
T3	14.0	69	806.5	432	38.7
	S.Ed.	3.6124	28.2830	16.6508	1.5773
	CD (0.05)	9.33	6.92	40.74	3.85

Table 3: Frictional properties of sunflower seeds

Trials	*Moisture Content, % (w.b.)*	*Static Coefficient of Friction (degree)*			*Angle of Repose (degree)*
		Plywood	*G.I. Sheet*	*Glass Sheet*	*Filling*
T1	10.0	22	19	16	23.9
T2	12.0	20	19	15	25.5
T3	14.0	22	18	15	26.8
Mean	**13.1**	**21.3**	**18.6**	**15.3**	**25.4**
S.Ed.		**0.80**	**0.75**	**0.57**	**0.98**
CD (0.05)		**1.96**	**1.84**	**1.40**	**2.40**

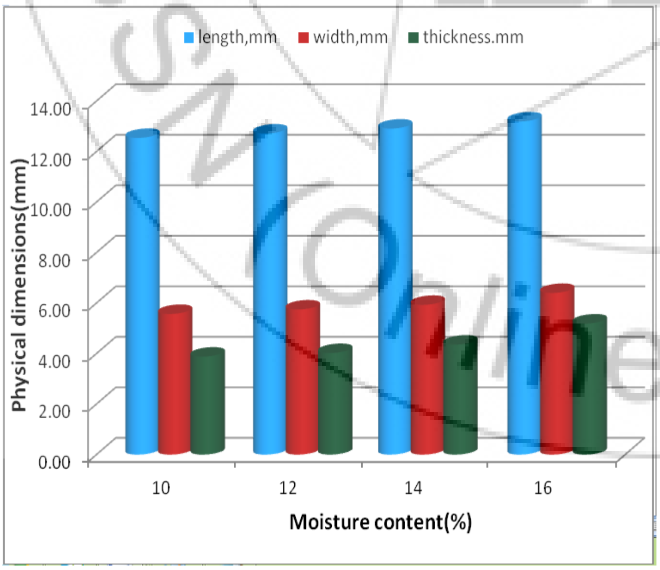

Figure 1: Influence of moisture content on the size of sunflower seeds

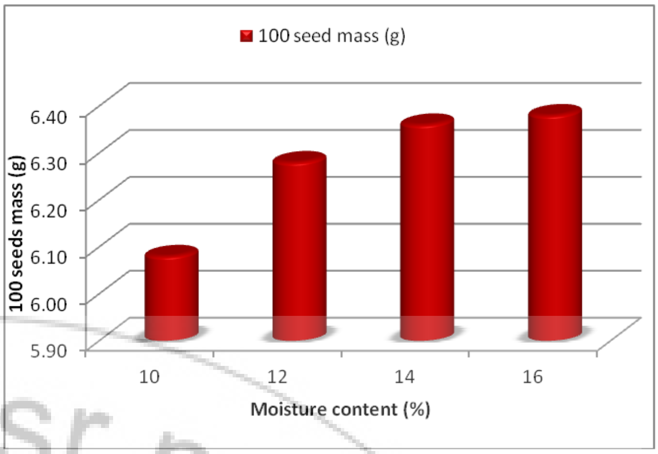

Figure 2: Influence of moisture content on the mass of sunflower seeds

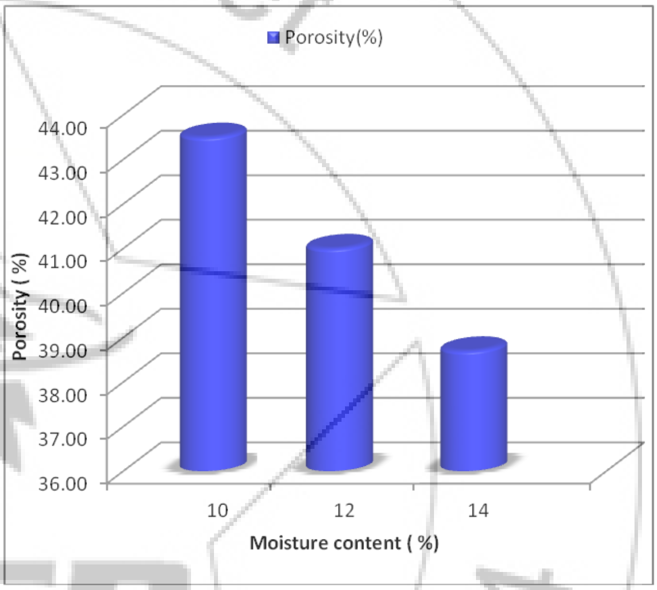

Figure 3: Influence of moisture content on the porosity of sunflower seeds

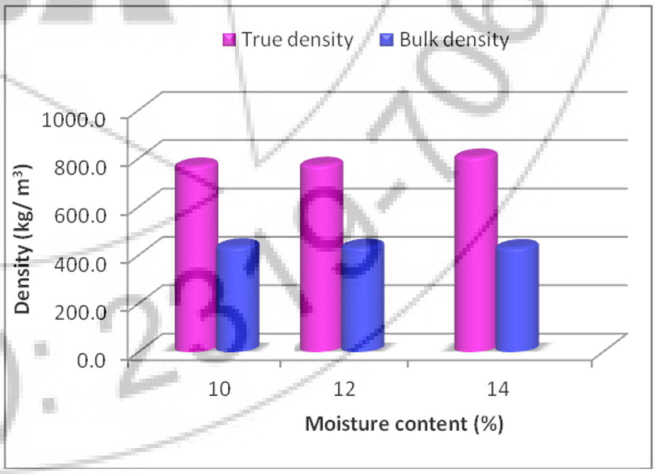

Figure 4: Influence of moisture content on the density of sunflower seeds

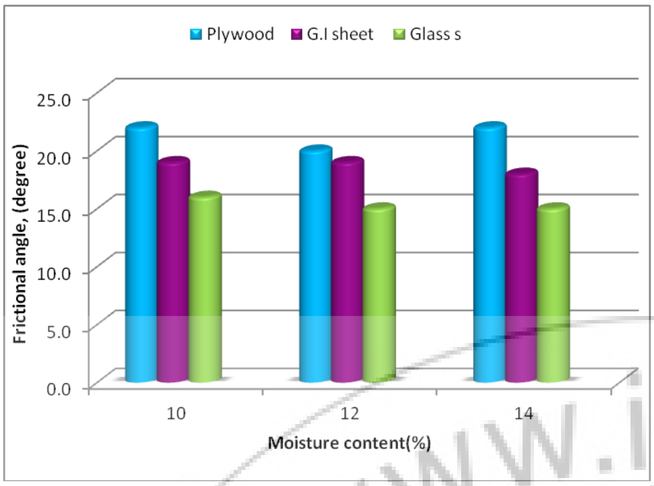

Figure 5: Influence of moisture content on the angle of friction of sunflower

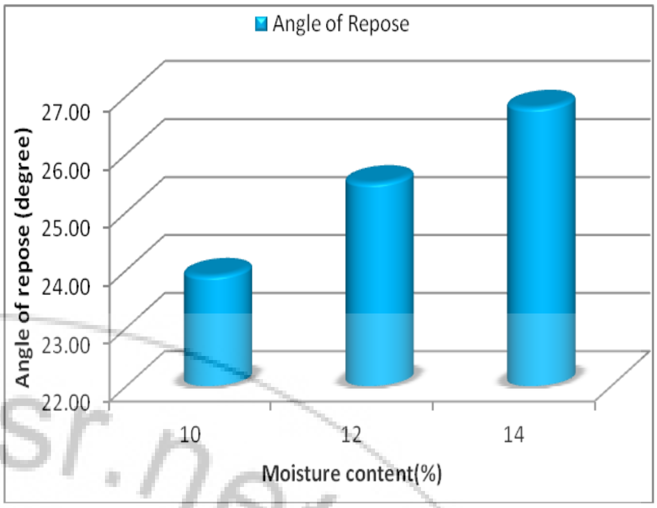

Figure 6: Influence of moisture content on the angle of repose of sunflower seeds