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EFFECT OF MOISTURE CONTENT ON SOME PHYSICAL AND MECHANICAL PROPERTIES OF SESBANIA SEEDS

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ABSTRACT

This study was carried out to determine the effect of moisture content on some physical and engineering properties for *Sesbania*. Four levels of moisture content ranging from 12.4 to 25.03% d.b. (dry basis) were used. The average length, width, thickness, and geometric main diameter ranged from 3.342±0.016 mm to 3.50±0.020 mm, 1.898±0.013 mm to 1.953±0.018 mm, 1.847±0.015 mm to 1.916±0.017 mm and 2.269±0.012 mm to 2.373±0.016 mm, respectively. The average sphericity and roundness ranged from 68.0±0.4% to 66.4±0.4% and 18.1±0.2% to 17.5±0.2% respectively. The average surface area ranged from 16.212±0.169mm^2 to 17.746±0.232mm^2. The average bulk density, true density, porosity and repose angle ranged from 781.227±0.875 kg/m^3 to 737.355±1.511 kg/m^3, 1232.065±2.384 kg/m^3 to 1206.255±7.594 kg/m^3, 36.592±0.052% to 38.866±0.264%, and 26±0.447o to 36±0.707o respectively. The average static coefficient of frication against wood, stainless steel, galvanized iron, iron, rubber and lather surfaces and ranged from 0.450±0.008 to 0.596±0.009, 0.325±0.006 to 0.36±0.007, 0.380±0.013 to 0.501±0.005, 0.582±0.014 to 0.675±0.008 and 0.606±0.009 to 0.690±0.010, respectively. The average terminal velocity ranged from 7.823±0.095 m/s to 11.176±0.475 m/s. The average hardness was determined as engineering property, and generally decreased in magnitude with an increase in moisture content and ranged from 10.035±0.057 kg to 3.578±0.036 kg.

Keywords: *Sesbania; Physical and Mechanical Properties.*

INTRODUCTION

Sesbania is a leguminous crop widely available in many tropical countries of Asia and Africa. Thought to be originally from Egypt, this short nitrogen fixing tree is great for animal fodder and fuel wood. Legume seeds can form a valuable fish feed component since most legume seeds are rich in protein, lipid and carbohydrates. Leguminous seeds, mainly soybeans, have been widely used as feed ingredients due to their high protein content despite their antinutritional factors and low levels of sulphur-containing amino acids **(Wilson and Poe, 1985; Robaina et al., 1995)**. It can grow in poor and degraded soil. The major use of *Sesbania* crop has been as fodder for livestock and green manure to improve the fertility of the land. The *Sesbania* seed contains 30–36% crude protein and is at present not being used for other agricultural or industrial purposes. The average seed yield is 0.36 t/fed. The price of *Sesbania* seed is much lower than any other legumes or cereals. The seeds have considerable potential as an ingredient in animal feed including fish. **FAO, (2005).**

Physical properties data of agricultural materials are required in the design of machines for planting, harvesting and various post-harvest operations such as cleaning, conveying and storage. Limited earlier research works reported some important physical properties of various cultivars of *Sesbania* seeds. The threshing is usually carried out on a hard floor with home made threshing machine. In order to optimize various factors, threshing efficiency, pneumatic conveying and storage pertaining to *Sesbania* seed, the physical properties are essential. However, detailed measurements of the principal dimensions of *Sesbania* seed and variations in physical properties at various levels of moisture content have not been investigated. The objective of this study was to investigate some moisture levels dependent physical and engineering properties of the *Sesbania* seed, namely linear dimensions, unit weight for individual seed and thousand seeds, sphericity, density, porosity, surface area measured and calculated, projected area, angle

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of repose, terminal velocity, penetration depth and coefficient of static friction against five structural surfaces.

MATERIALS AND METHODS

1. Sample preparation

This study was conducted at Department of Agricultural Engineering, Shibin El-kom, Egypt. *Sesbania* seeds were collected from the El-Serw Research Station. The initial moisture content was (12.4%) determined by drying *Sesbania* sample in an air ventilated oven at 103 0C for 72 h (ASAE, 1993). Four levels of moisture contents of *Sesbania* seeds were selected 12.4%,18.4%, 21.6% and 25.03% (on dry basis).The samples at the selected moisture contents were prepared by adding a calculated amount of distilled water and sealing them in separate polethene bags and storing them in a refrigerator at 7 0C for 72 h. Before each experiment, the required sample was taken out from the refrigerator and kept sealed in an ambient environment for 24 h to equilibrate the water and temperature throughout the sample. The sample is kept in the ambient environment in sealed conditions so there is no chance for change moisture. Static coefficients of friction were determined at the moisture contents of 12.4%, 18.4%, 21.6% and 25.03% (on dry basis). According to the present investigation aims and the work plan sequences, the following instruments, equipments, and materials were used.

2. Determination of physical properties

A random sample of one hundred seeds at four moisture content. The dimensions of major (L), intermediate (W), and minor (T), diameter of all particles in the sample, which means length, width, and thickness respectively, were measured using digital caliber. Fig (1) shows the shape and the three mutually perpendicular diametrical dimensions L, W, and T of seed of *Sesbania*. The obtained data of seeds were studied in terms of geometric mean diameter (D_g), percent of roundness of seed (R %) and sphericity (S%), of individual seed.

The geometric mean diameter, D_g is given by **Sreenarayana et al., (1985)** as: $D_g = (LWT)^{1/3}$ .... (1).

According to **Mohsenin (1986)**, the degree of sphericity (S) can be expressed as equation (2).

$$S = \frac{(LWT)^{1/3}}{L} \qquad (2).$$

Where L is seed length, W seed width, and T seed thickness.

According to **Mohsenin (1986)**, the degree of roundness (R) can be expressed as equation (3).

$$R = \frac{A_P}{A_C} \qquad (3).$$

Where A_P : the largest projected area, A_C : the smallest circumscribing circle.

According to **Mohsenin (1986)**, the surface area calculated, S_A, can be expressed as follows:

$$S_A = \pi D_g^{\,2} \qquad (4).$$

True density was measured for five randomly samples of seeds for each variety of the investigated crops as follows:

$$\rho_t = M / V_t \quad ,Kg/m^3 \qquad (5)$$

Where:

ρ_t is the true density of the bulk seeds, Kg/m^3;

M weight of the bulk seeds, Kg;

V_t real volume of the bulk seeds, m^3.

Bulk density was calculated for the seed of the investigated crop varieties, by dividing the weight of a quantity of seeds of each variety on its volume, which measured by using graduate cylinder as follows:

$$\rho_b = M / V_b \quad ,Kg/m^3 \qquad (6)$$

Where:

ρ_b is the bulk density of the bulk seeds, Kg/m^3;

M weight of the bulk seeds, Kg;

V_b volume of the weight sample of bulk seeds, m^3.

Porosity of the investigated crop varieties was determined as the percentage of densities of bulk seeds according to (**Mohsenin, 1986**) as follows:

$$P = \frac{\rho_t - \rho_b}{\rho_t} 100, \% \qquad (7)$$

Where:

P is the porosity of seeds, %;

ρ_r the real density of the bulk seeds, Kg/m^3;

ρ_b is the bulk density of the bulk seeds, Kg/m^3.

The terminal velocity of the investigated crops was measured where the particles under study were placed at the front of the blower at the net inlet side of the transparent tube. After operating the blower, increasing the blower speed by opening the gate slowly, until the floating air suspend the particle in the vertical active part of the transparent tube, the measured air velocity represents the terminal velocity of the particles.

Seed friction angle was measured on six surfaces (stainless steel, galvanized steel, iron, plywood, rubber and lather) at four different moisture content. Seed samples were placed in a tray over the tested surface. At the operating, the tray, which has the seed sample, was tilted up around its side pivot, the angle of frication was recorded when 75% of the seeds reached the bottom and the tray was stopped. The coefficient of friction for the mentioned samples was obtained from the equation (8). The friction angle of the seed samples was the average of five replications.

According to **Singh and Gowswami (1996)**, static coefficient of friction (μ) was calculated as the following formula:

$$\mu = \tan \Phi \qquad (8).$$

Where: Φ = The angle of tilt.

A quantity of seed was used to determine repose angle. The seed was then poured under gravity from a suitable height to form a cone at the same spot. More seed was let to be fallen on the top of the formed cone until the angle between the cone surface and the horizontal plan become constant. The angle between the cone surface and the horizontal plan was recorded to represent repose angle of seed. The recorded angle was the average of five replicates.

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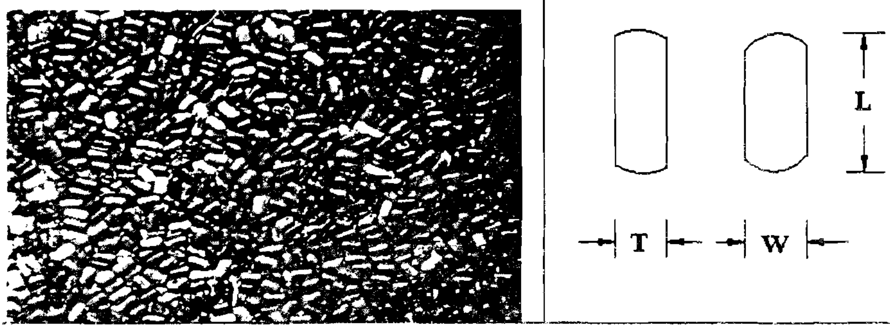

Fig. (1). The shape of *Sesbania* seed.

Statistical analysis.

The Data analysis of this experiment was carried out by using the Statistical Analysis System GLM procedures (SAS) **(2003).** This system was a one-way analysis of variance with the following model:

$$y_{ijk} = \mu + A_i + e_{ik} \quad (9).$$

Where: yijk = An individual observation.

μ = Overall mean

Ai = Effect due to moisture content jth = 12.4, 18.4, 21.6, and 25.03 %(d.b)

eik = Random effect.

Furthermore the simple correlation coefficients were calculated. The differences between the mean values of physical and mechanical *Sesbania* seeds characteristics were tested for significance using Duncan test **(Duncan, 1955).**

The coefficient of multiple determinations (R^2) and the mean square error (MSE) of models and the variation of predicted values with respect to measured values as well as the distribution of the residuals with respect to the estimated coefficients were used to evaluate the fit of the models to the experimental data.

RESULTS AND DISCUSSION

3.1. Influence of moisture content on physical measurements of individual *Sesbania* seeds.

Mean square values for measured and calculated variables for *Sesbania* seeds are presented in Table 1. There were highly significant differences among moisture content for thickness, geometric mean diameter, and surface area. Similar results were found by **Mohamed, (2005) and Eissa, (2006).** The mean values and standard error for length, width, thickness, geometric mean diameter, and surface area are presented in Table 2.

Table (1): Mean square and F Value and Probability of physical properties of *Sesbania* seeds.

Length L (mm)	Width W (mm	Thickness T (mm)	Geometric diameter D_g (mm)	Sphericity S (%)	Roundness R. (%)	Surface area S_a (mm^2)
Mean Square						
1.027	0.058	0.084	0.194	0.005	0.001	42.331
F Value and Probability						
31.683	2.210	3.359	9.847	2.611	2.718	10.163
**	N.S.	*	**	N.S.	*	**

(**), Significant at level P≤ 0.01, (*), significant at level P≤ 0.05, (N.S.) no significant.

Table (2): Mean and stander error of physical properties of Sesbania seeds.

Items	Length L (mm)	Width W (mm)	Thickness T (mm)	Geometric diameter D_g (mm)	Sphericity S (%)	Roundness R. (%)	Surface area S_a (mm^2)
12.4%	3.342± 0.016^C	1.898± 0.013	1.847± 0.015^b	2.269± 0.012^C	0.680± 0.004	0.181± 0.002^a	16.212± 0.169^C
18.4%	3.407± 0.017^C	1.908± 0.016	1.876± 0.015^{ab}	2.300± 0.014^{BC}	0.675± 0.004	0.179± 0.002^{ab}	16.675± 0.206^{BC}
21.6%	3.473± 0.018^B	1.928± 0.017	1.893± 0.016^{ab}	2.329± 0.014^{AB}	0.672± 0.005	0.177± 0.002^{ab}	17.085± 0.204^{AB}
25.03%	3.580± 0.020^A	1.953± 0.018	1.916± 0.017^a	2.373± 0.016^A	0.664± 0.004	0.175± 0.002^b	17.746± 0.232^A

3.2. Influence of moisture content on physical measurements of bulk *Sesbania* seeds.

Mean square values for measured and calculated variables are presented in Table 3 according to moisture content of *Sesbania* seeds. There were significant differences for true density, and porosity, had highly significant difference (P≤0.01). The mean values and standard error for these variables are presented in Table 4.

Table (3): Mean square and F Value and Probability of physical properties of *Sesbania* seeds.

Mean Square				
Bulk density ρ_b *(kg/m³)*	*True density* ρ_t *(kg/m³)*	*Porosity* *P. (%)*	*Terminal velocity* *T.V. (m/s)*	*Angle of repose* *A.R. (deg)*
2028.45	606.4612	8.410868	10.21933	88.73333
F Value and Probability				
246.6769	6.983757	79.04093	23.04	54.60513
**	**	**	**	**

(**), Significant at level P≤ 0.01, (*), significant at level P≤ 0.05, (N.S.) no significant.

Table (4): Mean and stander error of physical properties of bulk *Sesbania* seeds.

Items	*Bulk density* ρ_b *(kg/m³)*	*True density* ρ_t *(kg/m³)*	*Porosity* *P. (%)*	*Terminal velocity* *T.V. (m/s)*	*Angle of repose* *A.R. (deg)*
12.4%	781.227± 0.875^{A}	1232.065± 2.384^{A}	36.592± 0.052^{C}	7.8232± 0.095^{D}	26± 0.44721^{4}D
18.4%	744.765± 1.749^{B}	1225.228± 1.543^{A}	39.214± 0.076^{AB}	8.7376± 0.152^{C}	29.2± 0.583^{C}
21.6%	742.120± 0.686^{B}	1224.070± 1.935^{A}	39.372± 0.083^{A}	9.652± 0.311^{B}	31.6± 0.510^{B}
25.03 %	737.355± 1.511^{C}	1206.255± 7.594^{B}	38.866± 0.264^{B}	11.176± 0.475^{A}	36± 0.707^{A}

3.3. Influence of moisture content on engineering measurements of bulk *Sesbania* seeds.

Mean square values for measured and calculated variables are presented in Table 5 according to varieties of *Sesbania* seeds. There were highly significant differences among for coefficient of static friction (P≤0.01). For the other traits there were no significant differences among moisture content. Similar results were found by **Essa, (2006).** The mean values and standard error for engineering properties of bulk *Sesbania* seeds were presented in Table 6.

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Table (5): Mean square and F Value and Probability of engineering properties of *Sesbania* seeds.

Mean Square					
Wood μ_W *(tanΦ)*	*Galvanized iron* μ_{Gi} *(tanΦ)*	*Stainless steel* μ_S *(tanΦ)*	*Rubber* μ_r *(tanΦ)*	*Lather* μ_L *(tanΦ)*	*Hardness* *H (kg)*
0.022158	0.012719	0.001239	0.009662	0.007733	802.046
F Value and Probability					
68.84487	30.87545	5.900732	19.97625	23.82838	2476.684
**	**	**	**	**	**

(**), Significant at level P≤ 0.01, (*), significant at level P≤ 0.05, (N.S.) no significant.

Table (6): Mean and stander error of physical properties of *Seshania* seeds.

Items	***Wood*** μ_W ***(tanΦ)***	***Galvanized iron*** μ_{Gi} ***(tanΦ)***	***Stainless steel*** μ_S ***(tanΦ)***	***Rubber*** μ_r ***(tanΦ)***	***Lather*** μ_L ***(tanΦ)***	**Hardness H (kg)**
12.4%	0.450± 0.008^{D}	0.380± 0.013^{C}	0.325± 0.006^{C}	0.582± 0.014^{C}	0.606± 0.009^{C}	10.035± 0.057^{A}
18.4%	0.484± 0.008^{C}	0.441± 0.008^{B}	0.333± 0.005^{CB}	0.582± 0.009^{C}	0.515± 0.006^{C}	8.233± 0.056^{B}
21.6%	0.554± 0.007^{B}	0.462± 0.008^{B}	0.348± 0.007^{BA}	0.625± 0.008^{B}	0.659± 0.006^{B}	5.708± 0.073^{C}
25.03%	0.596± 0.009^{A}	0.501± 0.005^{A}	0.360± 0.007^{A}	0.675± 0.008^{A}	0.690± 0.010^{A}	3.578± 0.036^{D}

3.4. Correlation coefficients of evaluating sesbania traits.

Phenotypic correlation coefficients among the individual seeds of sesbania traits are presented in Table 7. Concerning sesbania dimensions (length, width and thickness) relationships with other studied traits, it was noticed that some features can be detected from these illustrated correlations. First feature is that length of sesbania had positive and significant correlations with width (0.159), thickness (0.139), geometric mean diameter (0.440), and surface area (0.448), and had negative and significant correlations with sphericity (-0.473), roundness (-0.462) and hardness (-0.432). Width of sesbania also had positive and significant correlation with thickness (0.980), geometric mean diameter (0.951), sphericity (0.787), roundness (0.783) and surface area (0.949), and had negative correlation with hardness (-0.135). Concerning sesbania thickness relationships with other studied traits, it had positive and significant correlations with geometric mean diameter (0.946), sphericity (0.799), roundness (0.942) and surface area (0.942), and negative relationship with hardness (-0.158). These results mean that increasing dimensions (length, width and thickness) was associated with increasing in these traits.

These results indicate that dimensions of sesbania can be utilized to predict some other traits without damage the sesbania seeds. Geometric mean diameter showed highly significant relationships with other studied traits, positively with surface area (0.999), sphericity (0.579), and roundness (0.570), and negative with hardness (-0.265). Concerning sphericity and its correlations with other traits it was noticed that most of these correlations were positive and significant, as with roundness (0.979), surface area (0.570), and hardness (0.130). It was also noticed that roundness trait had significant and positive correlations with surface area (0.562), and hardness (0.134).

Surface area is highly correlated with some studied traits, negatively with hardness (-0.269).Similar results were been reported by **Gupta and Das (1997), Balasubramanian (2001), Gezer (2002) and Ebubekir and Yildiz (2007).**

Table (7): Correlation between properties of individual seeds of sesbania.

Items	Length (mm)	Width (mm)	Thickness (mm)	Geometric mean diameter (mm)	Sphericity (%)	Roundness (%)	Surface area (mm^2)
Width (mm)	0.159 **						
Thickness (mm)	0.139 **	0.980 **					
Geometric mean diameter (mm)	0.440 **	0.951 **	0.946 **				
Sphericity (%)	-0.473 **	0.787 **	0.799 **	0.579 **			
Roundness (%)	-0.462 **	0.783 **	0.777 **	0.570 **	0.979 **		
Surface area (mm^2)	0.448 **	0.949 **	0.942 **	0.999 **	0.570 **	0.562 **	
Hardness (kg)	-0.432 **	-0.135 **	-0.158 **	-0.265 **	0.130 **	0.134 **	-0.269 **

Phenotypic correlation coefficients among bulk seeds the sesbania traits are presented in Table 8. Concerning sesbania static coefficient of friction with rubber relationships with other studied traits, it had positive and significant correlations with static coefficient of friction with terminal velocity (0.966), repose angle (0.973) and true density (0.617), and it had negative significant correlation with static coefficient of friction with lather (0.536). Sesbania static coefficient of friction with lather relationships with other studied traits, it had negative and significant correlations with terminal velocity (0.521), repose angle (0.446), bulk density (0.717) and true density (0.498). Terminal velocity showed highly significant relationships with other studied traits, positively with repose angle (0.981) and true density (0.635). Concerning repose angle and its correlations with other traits it was noticed that most of these correlations were negative and significant, but positive with true density (0.595).

It was also noticed that bulk density trait had significant and positive correlations with true density (0.598).

Table (8): Correlation between bulk seeds properties for sesbania seeds

Items	μ_W (tan Φ)	μ_{GI} (tan Φ)	μ_S (tan Φ)	μ_r (tan Φ)	μ_L (tan Φ)	Terminal velocity m/sec	Repose angle (θ°)	Bulk density (kg/m³
μ_{GI} (tan Φ)	0.898 **							
μ_S (tan Φ)	0.796 **	0.929 **						
μ_r (tan Φ)	-0.630 **	-0.846 **	-0.931 **					
μ_L (tan Φ)	0.832 **	0.762 **	0.722 **	-0.536 *				
Terminal velocity m/sec	-0.599 **	-0.812 **	-0.944 **	0.966 **	-0.521 *			
Repose angle (θ°)	-0.557 *	-0.781 **	-0.913 **	0.973 **	-0.446 *	0.981 **		
Bulk density (kg/m³	-0.745 **	-0.725 **	-0.567 *	0.357 N.S.	-0.717 **	0.317 N.S.	0.234 N.S.	
True density (kg/m³	-0.594 *	-0.688 **	-0.693 **	0.617 *	-0.498 *	0.635 **	0.595 *	0.598 *

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3.5. Physical properties of *Sesbania* seeds.

3.5.1. Linear dimensions.

The variations of length, width, thickness and geometric diameter of the seeds with seed moisture content are displayed in Fig. 2. All the dimensions increase with increasing seed moisture content up to 25.03% moisture content.

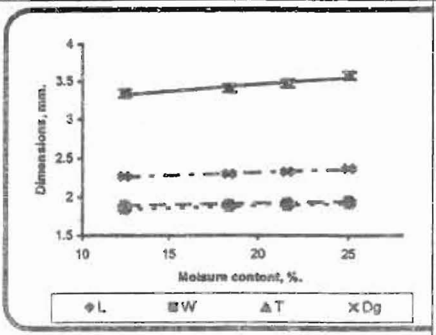

Fig. (2). Linear dimensions versus moisture content.

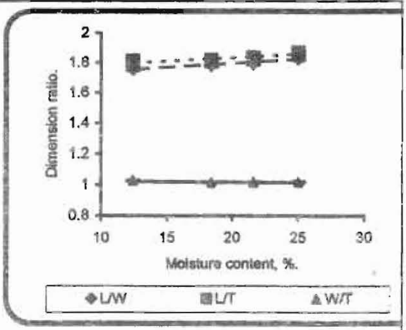

Fig. (3). Effect of moisture content on dimensions ratio for *Sesbania* seeds.

Very high correlation was observed between these dimensions and seed moisture content. This indicates that, on moisture absorption, the seeds expand in length, width, thickness and geometric diameter within the moisture range 12.4% to 25.03% (d.b.). **Konak et al., (2002)** also found the linear dimensions of *chickpea* to increase in liner manner with moisture content up to 16.5% d.b. The total average expansions from 12.4% to 25.03% moisture content were largest along the seed width and least along its length. **Mohamed, et al., (2007)**, however, found the expansion of chickpea seeds to be largest along their width and least along the seed thickness. This could be due to the different cell arrangements in the seeds. The (L/W, L/T and L/Dg) ratio variations with moisture content are shown in Fig. 3. L/W exhibits the highest ratios, followed by L/T and L/D_g in descending order. The relationship for principle dimensions (L, W, and T) and geometric mean diameter with seed moisture can be represented as follows:

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L	= 0.0186M.C. + 3.0899	R^2 = 0.938........(10)
W	= 0.0043M.C. + 1.8383	R^2 = 0.898.......(11)
T	= 0.0055M.C. + 1.7764	R^2 = 0.9959......(12)
Dg	= 0.0081M.C. + 2.16	R^2 = 0.9546......(13)

3.5.2. Surface area

The variation of surface area of the seeds with seed moisture content is shown in Fig. 4. The figure indicates that the calculated surface area increases linearly with seed moisture content up to 25.03% (equation 4). The relationship between seed moisture content and calculated surface area can be represented as follows:

$$SA = 14.644 + 0.1181\ M.C. \qquad (R^2 = 0.95).....(14)$$

Linear increase in surface area with increase in moisture content has been observed by **Oje and Ugbar, (1991)** for oil bean seed.

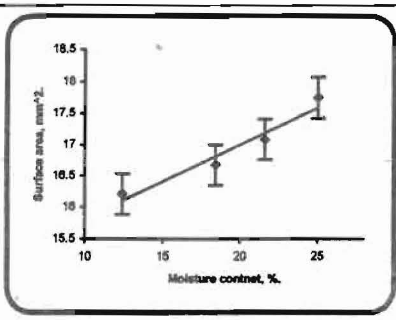

Fig. (4). Effect of moisture content on surface area for sesbania seeds.

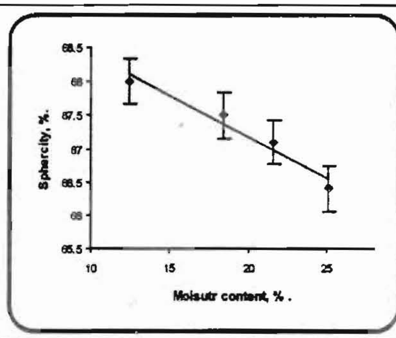

Fig. (5). Effect of moisture content on sphericity for *Sesbania* seeds.

3.5.3. Sphericity

The sphericity variation with the seed moisture content is shown in Fig. 5. Sphericity decreased with increasing seed moisture content up to 25.4% moisture content. The sphericity of *Sesbania* seeds ranged from 68 to 66.4% when the moisture content ranged from 12.4 to 25.03% d.b., using equation (2). The relationship between sphericity and seed moisture can be represented as follows:

$$S = 69.625 - 0.1227M.C. \qquad R^2 = 0.9506.....(15)$$

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3.5.4. Roundness

The variation of roundness of the seeds with seed moisture content is displayed in Fig. 6. Roundness decreased with increasing seed moisture content up to 25.03%. The roundness of *Sesbania* seeds ranges from 18.1 to 17.5%, when the moisture content ranges from 12.4 to 25.03%, d.b. The relationship between roundness and seed moisture can be represented by following equation:

$$R = 18.875 - 0.0565M.C. \qquad R^2 = 0.9586.....(16)$$

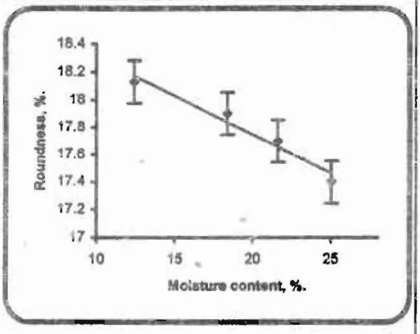

Fig. (6). Effect of moisture content on roundness for *Sesbania* seeds.

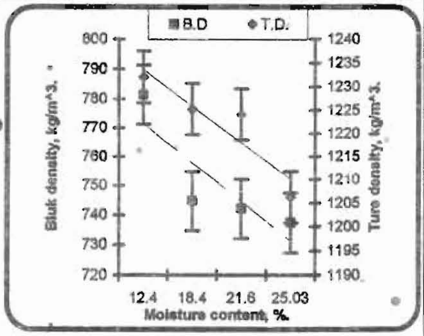

Fig. (7). Effect of moisture content on bulk and true density for *Sesbania* seeds.

3.5.5. Bulk and true densities

The experimental results of the bulk and true densities for *Sesbania* seed at different moisture levels are presented in Fig. 7. As the moisture content increased from 12.4 to 25.03% d.b., the bulk and true densities decreased from 781.227 to 737.355 kg/m^3 and from 1232.065 to 1206.255 kg/m^3, respectively.

The relationship between bulk and true densities were found to be linear with the moisture content and the relationship between them can be expressed as follows:

$$\rho_b = 784.93 - 13.426M.C. \qquad R^2 = 0.7406.....(17)$$

$$\rho_t = 1241.6 - 7.8588M.C. \qquad R^2 = 0.8486.....(18)$$

The decrease indicates that there is a small increase in the seed weight in comparison to its volume increase as its moisture content increases. This similar with the findings of **Essa (2006)** for flax seed, however, the bulk and true densities at different moisture levels ranged from 5.2 to 16.5% d.b., varied from 800 to 741.4kg/m^3 and 1428 to 1368 kg/m^3, respectively.

The bulk density decreases as the moisture content increases. These discrepancies could be due to the cell structure and the volume and the weight increase characteristics of the seeds and seeds as moisture content increases.

3.5.6. Porosity

Since the porosity depends on the bulk as well as true densities, the magnitude of variation in porosity depends on these factors only. The porosity of *Sesbania* seeds increased with increase in moisture content from 12.4 to 21.6% then decreased up to 25.03% as shown in Fig. 8. The relationship exiting between moisture content and porosity isn't linear relationship and relationship between them can be represented as follows:

$$P = 22.695 + 1.5885M.C. - 0.0377M.C.^2 \qquad R^2 = 0.9989.....(19)$$

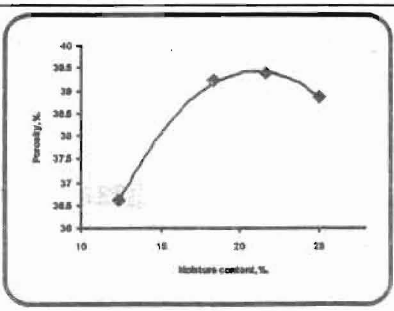

Fig. (8). Effect of moisture content on porosity for *Sesbania* seeds.

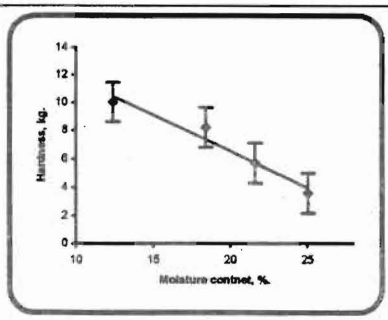

Fig. (9). Effect of moisture content on hardness for *Sesbania* seeds.

3.6. Engineering properties of *Sesbania* seeds.

3.6.1. Hardness

The variation of hardness (H.) of the *Sesbania* seeds with seed moisture content is presented in Fig. 9. The graph shows that hardness decreased with increasing seed moisture content up to 25.03%. The lower hardness at higher moisture content might have resulted from the fact that the kernel tended to be very soft in high moisture content. The relationship between the seeds hardness and seed moisture can be expressed by following equation:

$H = 16.867 - 0.5155M.C. \qquad R^2 = 0.9556$.....(20)

3.6.2. Coefficient of friction.

The coefficient of static friction variation with seed moisture content is displayed in Fig. 10 for surfaces of different materials.

The coefficient of friction for all moisture contents considered is highly for lather followed by, rubber, plywood, galvanized iron, and then stainless steel surface. Coefficient of static friction was increased with increasing seed moisture content up to 25.03%, for lather, rubber, plywood, galvanized iron, and then stainless steel. It was observed that the moisture content had a more significant on coefficient of static friction than effect the material surface. This owing to the increased adhesion between the seed and the surface at higher moisture values. The largest coefficient of static friction was the coefficient of internal friction (the coefficient of static friction between the seeds and a surface of the same seeds at the same moisture content). Following equations represented the relationship between coefficient of static friction for wood, stainless steel, galvanized iron, iron, and surface of seed at same moisture content and seed moisture:

$\mu_W = 0.012M.C. + 0.2894 \qquad R^2 = 0.9313$....(21)

$\mu_{Gi} = 0.0094M.C. + 0.264 \qquad R^2 = 0.9943$....(22)

$\mu_S = 0.0028M.C. + 0.286 \qquad R^2 = 0.9275$....(23)

$\mu_r = 0.0072M.C. + 0.477 \qquad R^2 = 0.7646$....(24)

$\mu_{th} = 0.0068M.C. + 0.5108 \qquad R^2 = 0.8654$....(25)

Similar results were found by **Carman (1996)** for lentil seeds, **Mohamed et al., (2007)** for chickpea seeds.

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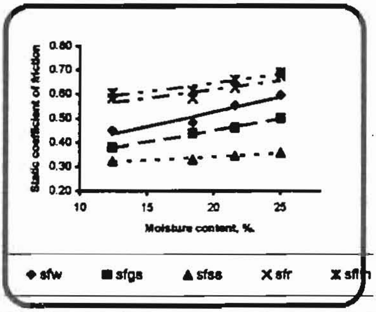

Fig. (10). Effect of moisture content on coefficient of static friction for *Sesbania* seeds.

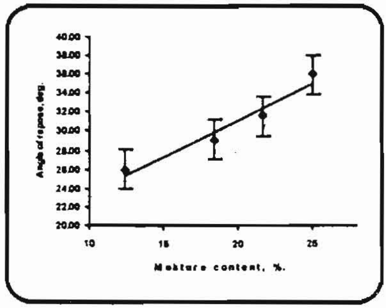

Fig. (11). Effect of moisture content on angle of repose for *Sesbania* seeds.

3.6.3. Angle of repose

The variation of angle of repose of the seed with seed moisture content is displayed in Fig. 11. The angle of repose increases linearly with increasing seed moisture content form 26 ° at 12.4% to 36° at 25.03% moisture content.

The variation is somewhat similar to pumpkin seeds **(Joshi et al., 1993)**, oilbean **(Oje and Ugbor, 1991) and Essa, (2006)** flax seeds. Following equation represented the relationship between angle of repose and seed moisture:

$\theta = 0.7653M.C. + 15.886 \qquad R^2 = 0.9518.....$ (26)

3.6.4. Terminal velocity.

The variation of terminal velocity of the seeds with seed moisture content is displayed in Fig. (12). Terminal velocity was increased with increasing seed moisture content up to 25.03%. The increase in terminal velocity with increase in moisture content can be attributed to the increase of individual seed weight per unit frontal area represented to air stream. Following equation can be represented the relationship between terminal velocity with seed moisture:

$T.V. = 0.0178M.C.2 - 0.4026M.C. + 10.084 \qquad R^2 = 0.9995....$(27)

The figure reveals a linear increase in terminal velocity from 5.18m/s to 9.14m/s when increasing seed moisture content from 11.06 to 25.4%, d.b.

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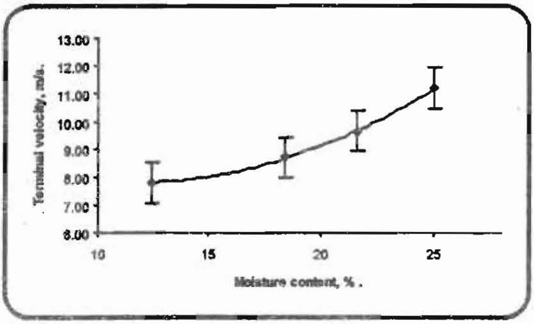

Fig. (17). Effect of moisture content on terminal velocity for *Sesbania* seeds.

Konak et al., (2002), Mohamed et al., (2007) for chickpea seeds reported a linear increase in terminal velocity for chickpea with increasing seed moisture content.

CONCOLUSIONS

The average static coefficient of frication against wood, stainless steel, galvanized iron, iron, rubber and lather surfaces and ranged from 0.450±0.008 to 0.596±0.009, 0.325±0.006 to 0.360±0.007, 0.380±0.013 to 0.501±0.005, 0.582±0.014 to 0.675±0.008 and 0.606±0.009 to 0.690±0.010, respectively.

The porosity of *Sesbania* seeds increased with increase in moisture content from 12.4 to 21.6%, then decreased up to 25.03% and terminal velocity linearly increased with the increase in moisture content.

The increases of seed moisture content from12.4 to 25.03% increase the angle of repose from 26° to 36°.

The results show positive relationships between the moisture content and length, width, thickness, geometric main diameter, surface area, mass of 1000 grains, angle of repose, terminal velocity and static coefficient of friction. While there were negative relationships between the moisture content and hardness, bulk density, kernel density and porosity.

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الملخص العربي

تأثير المحتوي الرطوبي علي بعض الخصائص الطبيعية والميكانيكية لبذور السيسبان

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تمت دراسة بعض الخواص الطبيعية وتأثير المحتوي الرطوبي علي بعض الخواص الطبيعية والهندسية لبذور السيسبان. والخواص الطبيعية التي تم دراستها مع تغير المحتوي الرطوبي هي الطول والعرض والسمك والحجم ومساحة السطح والصلابة للحبة والكثافة الظاهرية والحقيقية والمسامية وزاوية المكوث وكذلك تم دراسة السرعة الحرجة ومعامل الاحتكاك الاستاتيكي للحبوب للأسطح المختلفة (الخشب – الحديد – الأستانليس أستيل – الحديد المجلفن – المطاط – الجلد). وهذه الدراسة من الناحية التطبيقية لها أهمية استراتيجية في تصميم المعدات الزراعية التي تستخدم في الزراعة والحصاد والنقل والتخزين وكذلك في التصنيع الغذائي نظراً للإحتياج لمعرفة هذه الخواص.

وكانت النتائج كالتالي:

– حيث تراوح متوسط الطول من 3.342 ± 0.016مم إلي 3.580 ± 0.020مم، والعرض من 1.898 ± 0.013مم إلي 1.953 ± 0.018، والسمك من

1.847 ± 0.015مم إلي 1.916 ± 0.017مم، والقطر الهندسي من 2.269 ± 0.012مم إلي 2.373 ± 0.016. وتراوح متوسط الكروية والاستدارة من 68 ± 0.4% إلي 66.4 ± 0.4%، و 18.1 ± 0.2% إلي 17.5 ± 0.2%، علي الترتيب.

- وكان متوسط المساحة السطحية 16.212 ± 0.169مم^2 إلي 17.746 ± 0.232مم^2. كما تراوحت الكثافة الظاهرية والكثافة الحقيقية والمسامية وزاوية المكوث من 781.227 ± 0.875كجم/م^3 إلي 737.355 ± 1.511كجم/م^3، و 1232.065 ± 2.384كجم/م^3 إلي 1206.255 ± 7.594كجم/م^3، و 36.592 ± 0.052% إلي 38.866 ± 0.264%، و 26 ± 0.447 ^{5} (درجة) إلي 36 ± 0.707 ^{5} (درجة)، علي الترتيب.
- وتراوح متوسط معامل الاحتكاك مع أسطح من الخشب والاستانلس استيل والحديد المجلفن والحديد و المطاط والجلد من 0.450 ± 0.008 إلي 0.496 ± 0.009، و0.325 ± 0.006 إلي 0.360 ± 0.007، و0.380 ± 0.013 إلي 0.501 ± 0.005، و0.582 ± 0.014 إلي 0.675 ± 0.008، و0.606 ± 0.009 إلي 0.690 ± 0.010، علي الترتيب. - وتراوح متوسط السرعة الحرجة من 7.8232 ± 0.095م/ث إلي 11.176 ± 0.475م/ث. كما تراوح صلابة البذرة من 10.35 ± 0.057 إلي 3.578 ± 0.036كجم. عند محتوي رطوبي من 12.4% إلي 25.04% (علي أساس جاف).
- ولقد وجد من النتائج أن هناك علاقة خطية طردية بدرجة عالية المعنوية بين المحتوي الرطوبي لحبوب السيسبان وخصائص الطول والعرض والسمك والقطر الهندسي والكروية ووزن البذرة ومساحة السطح ومعامل الاحتكاك الاستاتيكي للأسطح المختلفة والسرعة الحرجة. وكانت العلاقات خطية تناقصية لخصائص الكثافة الظاهرية والحقيقية والصلابة والمسامية.