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SELECTED PROPERTIES OF SESAME AS A FUNCTION OF VARIETIES AND MOISTURE CONTENTS

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Knowledge of the physical properties of sesame (*Sesamun indicum *L.) is necessary for the design of equipment for harvesting, transporting, sorting, cleaning, separating, crushing, extracting, and processing it for use in different food products. In this study, the effects of different moisture contents on the physical properties of two sesame mutants, cc6 and cc7, were investigated at three (8.1, 12.3, and 15.8% w.b) moisture contents. At moisture contents from 8.1 to 15.8% w.b., the length, width, thickness, and geometric mean diameter of the cc6 sesame mutants varied from 21.00 to 23.80 mm, 6.54 to 7.99 mm, 5.2 to 6.00 mm, and 8.89 to 10.45 mm, respectively. In the cc7 sesame mutants, the length, width, thickness, and geometric mean diameter were found to be 22.17 to 24.78 mm, 7.12 to 7.80 mm, 5.15 to 6.30 mm, and 9.33 to 10.83 mm, respectively, within the same moisture range. Increased moisture content of the sesame mutant's capsules resulted in their terminal velocity increasing from 4.72 to 5.27 m/s. The static and dynamic coefficients of friction were measured at the different moisture contents on three different surfaces, and results varied between 0.446–0.528 and 0.436–0.498, respectively, for the two mutants. The rupture force of the sesame capsules was measured in the horizontal and vertical planes. All rupture forces decreased with increased moisture content of the shell. However, the rupture force of capsules increased above 12.3% w.b moisture content. Analysis of variance was carried out on two closed capsule sesame varieties, and differences between the mean values were investigated by Duncan's test.

Keywords: ***Sesame, Handling, Physical structure, Mechanical structure.***

INTRODUCTION

According to some archaeological findings, sesame (*Sesamun indicum* L.) is thought to be the first oil seed used by humans, and its cultivation can be dated back to 2130 B.C.[1] More than 90% of global vegetable tallow breeding has been produced from 13 different oil plants. Within this group of oil plants, sesame ranks 8th or 9th, according to situation or yield of the plants. Sesame processing has traditionally been done by hand throughout the world. This situation gives rise to leeway and seed loss. There is a need for new mutants, to address this situation.

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The International Atomic Energy Agency (IAEA) has initiated various new mutation projects in order to develop new sesame types and to eliminate the negative characteristics of the natural sesame body. Closed capsule mutants; determined mutants; sterile mutants, which are used to develop the hybrid mutants; and plant mutations, which have different agronomic features, have been successfully produced.[2] The only available recessive genes for indehiscent capsules were found in the Venezuelan gene in the early 1940s. However, to date, it was unsuitable for the development of new varieties, due to many negative pleiotropic effects on agronomic performance of the resulting progenies.[3,4] Closed capsule sesame mutants induced in Turkish sesame cultivars[5] have introduced new germplasm to plant breeders and designers of agricultural machinery. Many studies have reported on the physical properties of fruits, grains and seeds, such as orange,[6] wheat,[7] hazelnut,[8] chickpea,[9] cotton seed,[10] peanuts,[11] gram,[12] mung bean,[13] soybean,[14] pumpkin,[15] and pear.[16]

In Turkey, harvesting and handling of sesame is performed manually. The threshing is usually carried out on a hard floor with a homemade threshing machine. In order to optimize the threshing performance, pneumatic conveying, storage, and other aspects of sesame processing, their physical properties must be known. There were two specific objectives of this study. The first was to investigate the effects of different moisture contents on the physical properties of sesame, such as linear dimensions, porosity, sphericity, bulk density, surface area, angle or repose, terminal velocity, coefficient of static friction, and rupture force. The second was to produce a convenient reference table with physical information suitable for sesame mechanization and food processing.

MATERIAL AND METHODS

Material

Two types of the sesame genotype were used for all experiments in this study, cc6 and cc7, where the designation "cc" indicates closed capsule. It was identified by Mutation Research Group Breeders. The term "capsule" refers to the shell of the sesame. When the sesame is grown, the capsule is closed and the seeds do not molder in the field. Sesame type cc6 was obtained to be applied to the gamma rays on the Çamdibi genotype and also cc7 sesame type was obtained to be applied to the gamma rays on the Muganlı-57 genotype. Sesame capsules were obtained from cultivars grown in 2006 following regular practices and harvested manually at experimental sites of the Mutation Research Group, Agriculture Faculty at Akdeniz University, Antalya, Turkey.

Methods

The moisture contents of the sesame capsules were determined by the oven-drying method.[17] The three linear dimensions, length L, width W, and thickness T, of 100 capsules of each mutant were measured with a digital caliper with a sensitivity of 0.001 mm. Geometric mean diameter (Dg) and sphericity (ϕ) were calculated using the following equations:

$$D_g = (LWT)^{1/3}, \tag{1}$$

$$\phi = D_g/L. \tag{2}$$

Capsule mass (M) and thousand capsule mass (M1000) were measured by an electronic balance with a sensitivity of 0.001 g. The capsule mass was determined using 100 randomly selected capsules, and then converted to a thousand capsule mass measurement. Bulk density (ρ_b) was determined with a weight per hectoliter tester, which was calibrated in kg per hectoliter. The porosity (ε) of the capsules was determined by the following equation:

$$\varepsilon = 1 - \rho b/\rho f, \tag{3}$$

where ρb is the bulk density and ρf is the capsule density. Surface area (S) was calculated using the following equation:

$$S = \pi D_g^2. \tag{4}$$

The equations used to calculate the geometric mean diameter, sphericity, porosity, and surface area followed the methods reported in previous studies within the literature.[18–20]

To determine the angle of repose (θ) of the capsules, the study used a funnel tube (smallest diameter 45 mm, biggest diameter 200 mm, and height 350 mm) and discharge gate at the bottom of the box. The box was filled with the samples and then the front panel was quickly removed. The height of the capsule pile above the floor (h) and the diameter of the heap (r) were measured and used to determine the angle of reponse. The angle of reponse was calculated with the measurement of the height (h) of the conical shape at the center and the radius (r) of the free samples over the surface.

$$(\theta) = \tan^{-1}(\mathrm{h/r}). \tag{5}$$

Terminal velocity (V_t) at different moisture levels was measured using an air column. For each test, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material in the air stream. The air velocity at the position at which the capsule was suspended was measured by an electronic anemometer that could register a minimum air speed of 0.001 m/s.[21]

The static coefficient of friction (μ) was determined for three different structural materials, namely galvanized steel, rubber, and plywood sheet. For this measurement, one end of the friction surface was attached to an endless screw. The capsule was placed on the surface and was gradually raised by the screw. Vertical and horizontal height values were recorded when the seed started sliding over the surface. Then, using the tangent value of that angle, the coefficient of static friction was found. Rupture force (Pr) was determined by the forces applied through two axes (i.e., horizontal and vertical). The force values were measured using a data acquisition system previously developed for such applications.[18] All physical properties for each moisture level were studied in three replications. Analysis of variance was performed for all experimental results for the three moisture levels. The differences between the means were evaluated using Duncan's test at a 1% significance level.

RESULTS AND DISCUSSION

Capsule Dimensions and Size Distributions

Capsule dimensions and size distributions of cc6 sesame capsules at different moisture content and their relationships are given in Table 1. Dimensional characteristics increase linearly with increased moisture content from 8.1 to 15.8% w.b. The reasons for this increase are probably due to fact that capsules cellulose fibers. As the moisture content increased, the bulk density decreased slightly. This property depends on structural properties of some biological materials. Some previous studies reported different results for characteristics attributed to the moisture content, i.e., bulk density increases for apricot[21] and decreases for soybean.[22] Capsule dimensions and size distributions were found to be statically significant at a 1% probability level.

Capsule dimensions and size distributions of cc7 sesame capsules at different moisture content and their relationships are given in Table 2. The dimensions and size distribution of the cc7 capsules were similar to those of the cc6 sesame capsules. However, some properties, such as length, surface area, and 1000 capsules mass of cc7, were greater than those of the cc6 capsules. All of the properties of the cc7 capsules were found to be statistically significant at a 1% level.

Terminal Velocity

Terminal velocity of sesame capsules at different moisture contents and their relationships are given in Table 3. As the moisture content of the capsule increased, the

Table 1 Capsule dimensions and the relationships, $y = a + bx$, between physical properties and moisture content of cc6 sesame capsules.

	Moisture content (% w.b.)					
	8.1	12.3	15.8	a	b	R^2
Capsule length (mm)**	21.00 ± 0.54^{b}	22.78 ± 0.48^{a}	23.80 ± 0.32^{a}	18.10	0.37	0.989
Capsule width (mm)**	6.54 ± 0.03^{b}	7.72 ± 0.02^{a}	7.99 ± 0.10^{a}	5.12	0.19	0.914
Capsule thickness (mm)**	5.12 ± 0.07^{c}	5.56 ± 0.07^{b}	6.00 ± 0.04^{a}	4.19	0.11	0.989
Capsule geometric mean diameter (mm)**	$8.8930.10^{c}$	9.93 ± 0.09^{b}	10.45 ± 0.10^{a}	7.31	0.20	0.981
Sphericity (%)**	42.36 ± 0.19^{b}	43.58 ± 0.19^{a}	43.84 ± 0.33^{a}	40.84	0.20	0.921
Bulk density (g/cm^3)**	0.20 ± 0.02^{a}	0.19 ± 0.06^{b}	0.18 ± 0.02^{c}	0.213	−0.002	0.962
Capsule surface area (mm^2)**	248.45 ± 4.43^{c}	309.65 ± 4.66^{b}	342.74 ± 5.76^{a}	151.60	12.32	0.986
Porosity (%)**	0.40 ± 0.02^{b}	0.43 ± 0.06^{a}	0.44 ± 0.06^{a}	0.367	0.004	0.887
1000 capsule mass (g)**	330.61 ± 0.25^{c}	340.22 ± 0.62^{b}	350.47 ± 0.44^{a}	309.40	2.57	0.995
Capsule angle of reponse (°)**	20.03 ± 0.07^{b}	25.06 ± 0.04^{a}	27.05 ± 0.09^{a}	12.93	0.92	0.963

[a]y = physical properties of the cc6 sesame capsule, x = moisture content (% w.b.). **Significant levels at 1%.

Table 2 Capsule dimensions and the relationships, $y = a + bx$, between physical properties and moisture content of cc7 sesame capsules.

Properties	Moisture content (% w.b.) 8.1	12.3	15.8	a	b	R^2
Capsule length (mm)**	22.17 ± 0.18^{b}	24.00 ± 0.28^{a}	24.78 ± 0.24^{a}	19.52	0.341	0.969
Capsule width (mm)**	7.12 ± 0.04^{c}	7.59 ± 0.07^{b}	7.80 ± 0.08^{a}	6.43	0.09	0.974
Capsule thickness (mm)**	5.153 ± 0.03^{c}	5.97 ± 0.04^{b}	6.30 ± 0.03^{a}	3.99	0.15	0.965
Capsule geometric mean diameter (mm)**	9.33 ± 0.06^{b}	10.13 ± 0.01^{a}	10.85 ± 0.08^{a}	7.94	0.17	0.997
Sphericity (%)**	42.11 ± 0.44^{b}	42.20 ± 0.41^{b}	43.10 ± 0.40^{a}	40.96	0.12	0.774
Bulk density (g/cm^3)**	0.35 ± 0.01^{a}	0.31 ± 0.01^{b}	0.30 ± 0.07^{c}	0.75	−0.04	0.785
Capsule surface area (mm^2)**	273.71 ± 4.93^{c}	322.06 ± 4.36^{b}	358.14 ± 4.35^{a}	185.40	10.98	0.998
Porosity (%)**	0.39 ± 0.01^{b}	0.47 ± 0.06^{a}	0.47 ± 0.11^{a}	0.32	0.01	0.829
1000 capsule mass (g)**	360.82 ± 3.84^{c}	365.59 ± 0.42^{b}	370.32 ± 0.42^{a}	350.70	1.23	0.997
Capsule angle of reponse (°)**	20.57 ± 0.23^{b}	27.12 ± 0.38^{a}	29.46 ± 0.38^{a}	11.62	1.17	0.954

[a]y = physical properties of the cc7 sesame capsule, x = moisture content (% w.b.). **Significant levels at 1%.

Table 3 The relationships, $y = a + bx$, between terminal velocity and moisture content of sesame capsules.

	Moisture content (% w.b.) 8.1	12.3	15.8	a	b	R^2
cc6 capsule**	4.88 ± 0.07^{b}	4.99 ± 0.06^{b}	5.03 ± 0.08^{a}	4.73	0.02	0.96
cc7 capsule**	4.72 ± 0.09^{c}	5.18 ± 0.05^{b}	5.26 ± 0.06^{a}	4.18	0.07	0.90

[a]y = terminal velocity of the sesame capsule, x = moisture content (% w.b.). **Significant levels at 1%.

terminal velocity values increased. The terminal velocity of cc6 capsule at the specific moisture levels of 8.1, 12.3, and 15.8% w.b. was found to be 4.88, 4.99, and 5.03 m/s, respectively. In comparison, the terminal velocity of the cc7 capsule was found to be 4.72, 5.18, and 5.26 m/s, at the specific moisture levels of 8.1, 12.3, and 15.8% w.b., respectively. The differences between the means of terminal velocity were found to be significant ($p < 0.01$). The terminal velocity of sesame capsules was lower than some fruit and seeds, such as chickpea seeds, lentil seeds, wheat, and apricot pits.[23,24]

Static Coefficients of Friction

The static coefficient of friction, which was determined with respect to galvanized steel, plywood, and rubber surfaces, are presented in Table 4. The static coefficient of friction increased with increased moisture levels. It was found that as the moisture content

Table 4 The relationships, $y = a + bx$, between static coefficients and moisture content of sesame capsules.[a]

	Moisture content (% w.b.)					
	8.1	12.3	15.8	a	b	R^2
cc6 capsule						
Galvanized sheet**	0.45 ± 0.03^{b}	0.45 ± 0.06^{b}	0.46 ± 0.07^{a}	0.43	0.001	0.915
Plywood sheet**	0.48 ± 0.07^{c}	0.49 ± 0.04^{b}	0.51 ± 0.04^{a}	0.44	0.004	0.925
Rubber sheet**	0.48 ± 0.05^{c}	0.50 ± 0.08^{b}	0.53 ± 0.05^{a}	0.43	0.006	0.922
cc7 capsule						
Galvanized sheet**	0.44 ± 0.09^{c}	0.44 ± 0.05^{b}	0.45 ± 0.07^{a}	0.42	0.002	0.931
Plywood sheet**	0.44 ± 0.09^{c}	0.45 ± 0.08^{b}	0.47 ± 0.07^{a}	0.41	0.004	0.826
Rubber sheet**	0.46 ± 0.08^{c}	0.46 ± 0.07^{b}	0.50 ± 0.06^{a}	0.41	0.005	0.830

[a]y = static coefficients of the sesame capsule, x = moisture content (% w.b.). **Significant levels at 1%.

increased the capsules showed a greater friction coefficient on the three friction surfaces tested. At all moisture levels, the friction coefficients were highest for sesame capsules on a rubber surface and lowest for capsules on a galvanized steel surface. This is due to the different properties of the three friction surfaces tested. Similar results were previously reported for Bambara groundnuts, beans, and peanuts.[25,26] The difference between the means of the friction coefficients with different friction surfaces was found to be significant ($p < 0.01$).

Rupture Force

Rupture force of the sesame capsules and the relationship between the rupture force and moisture content are given in Table 5. The rupture force of capsules along two axes decreased with increasing moisture content. However, after 12.3% w.b., rupture force increased slightly when increasing the moisture content. The mean rupture force of the cc6 capsule at different moisture levels decreased from 32.88 to 21.24 N in the vertical axis and decreased from 130.54 to 67.12 N in the horizontal axis. The means rupture force of cc7 capsule at different moisture levels decreased from 28.32 to 21.54 N in the vertical axis and decreased from 64.79 to 43.27 N in the horizontal axis. This result shows that greater force is required to rupture the sesame capsule on the horizontal side than on the

Table 5 The relationships, $y = a + b \ln(x)$, between capsule rupture force and moisture contents of sesame capsules.[a]

	Moisture content (% w.b.)					
	8.1	12.3	15.8	a	b	R^2
cc6 capsule rupture force (N)						
Vertical**	32.88 ± 2.66^{a}	20.22 ± 1.67^{b}	21.24 ± 2.99^{b}	70.73	−18.70	0.808
Horizontal**	130.54 ± 8.67^{a}	62.65 ± 3.57^{b}	67.12 ± 2.77^{b}	337.10	−102.00	0.799
cc7 capsule rupture force (N)						
Vertical**	28.32 ± 3.54	20.92 ± 2.11^{b}	21.54 ± 1.05^{b}	50.39	−10.90	0.806
Horizontal**	64.79 ± 3.43^{a}	41.21 ± 2.21^{b}	43.27 ± 2.33^{b}	134.80	−34.60	0.803

[a]y = rupture force of the sesame capsule, x = moisture content (% w.b.). **Significant levels at 1%.

vertical side. The difference between the means of forces applied on each of the axes was found to be significant ($p < 0.01$). This difference may be attributed to physical properties of the sesame capsule.

CONCLUSION

Several physical properties of sesame capsules were determined in order to facilitate the design of specific equipment for harvesting, transporting, cleaning, packing, and storing processes. Some key points for study can be summarized as follows: All of the dimensional characteristics of both sesame types increased linearly with increased moisture content, except for bulk density. Terminal velocity of the capsules increases with increased moisture content. The static coefficient of friction was highest for capsules smashed against rubber, and the least for those smashed against galvanized steel. The rupture force of the capsules, in both vertical and horizontal planes, decreased with increased moisture content. The capsules withstood greater rupture force on the horizontal side than through the vertical side.

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