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Some Physical Properties of Caper Seed

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Some physical properties of caper seed were evaluated as a function of moisture content. In the moisture range from 6·03 to 16·35% d.b., the dimensions of the major, medium and minor axes varied from 3·09 to 3·67 mm, 2·40 to 2·90 mm and 1·52 to 1·87 mm, respectively. In the above moisture range, the arithmetic and geometric mean diameters increased from 2·34 to 2·81 mm and from 2·24 to 2·71 mm, respectively. The sphericity, surface area, projected area and thousand seed mass increased from 0·725 to 0·738, from 15·81 to 23·07 mm^2, from 7·37 to 9·25 mm^2, and from 6·60 to 7·75 g, respectively, while the bulk density, true density and porosity decreased from 438 to 399 kg m^{-3}, 806 to 678 kg m^{-3} and 45·7 to 41·1%, respectively. The terminal velocity and angle of repose increased from 6·1 to 7·7 m s^{-1} and 21 to 32°, respectively, and the static coefficient of friction on four structural surfaces increased from 0·547 to 0·698 for rubber, 0·523 to 0·656 for plywood (with wood grains parallel to the direction of movement), 0·402 to 0·469 for galvanised metal sheet and 0·356 to 0·456 for aluminium sheet.
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1. Introduction

Capers (*Capparis* L.) are in the family of Capparaceae and known by different names in Turkish such as gebere, kapari, kebere, keditırnağı (Özcan *et al.*, 2004). Caper plants are small shrubs and may reach about 1 m upright. The perennial shrub plant has thick and deep roots and is generally thorny and hairy (Francis, 2004).

Capers are cultivated for several purposes in the world since ancient times. Various parts of caper plant can be used as drugs, foods and cosmetics (Özcan, 1998; Baytop, 1999). The commercially valuable parts of caper are the immature flower buds, which are pickled in vinegar or preserved in granular salt. Semi-mature fruits and young shoots with small leaves may also be pickled for use as a condiment (Alkire, 2003). Seeds are rich in protein, oil and fibre. Seed oil has a high content of oleic and linoleic acids. So, seeds can be used in several forms for food and feed (Akgül & Özcan, 1999). Caper plants are also used for landscaping, control of erosion and animal feeding (Özcan, 1998; Baytop, 1999).

Certain species and varieties of capers have been cultivated in Mediterranean regions and have become an important economic plant in Italy and Spain for the last three decades (Özcan & Akgül, 1998). Two capers species are most commonly found in Turkey, namely, *C. Spinosa* L. and *C. Ovata* Desf. (Davis, 1965). In the recent years, capers are grown as a commercial crop in Turkey. Because, there are international demands for its valuable parts.

Caper plants are grown from seed and by vegetative cuttings (Alkire, 2003). Caper seeds are kidney shaped and grey-brown in colour (Stephens, 1994). The caper seeds are shown in *Fig. 1*. Seeds are obtained from caper fruits. The dehisced caper fruits are collected and the seeds are separated from the fruits. After this process, the seeds are rinsed in tap water, dried in shade and kept at room temperature (Olmez *et al.*, 2004).

Studies have been carried out to determine physical, medicinal, aromatic and chemical properties of different parts of caper plants (Rodrigo *et al.*, 1992; Inocencio *et al.*, 2000; Çala *et al.*, 2002; Özcan *et al.*, 2004). However, no published literature was found on the detailed physical properties of caper seed and their relationship with moisture content. The physical properties of caper seeds, like those of other seeds, are essential

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Notation

A, B	regression coefficient
A_p	projected area, mm^2
a	major axial dimension, mm
b	medium axial dimension, mm
c	minor axial dimension, mm
D	diameter of heap at its base, mm
D_a	arithmetic mean diameter, mm
D_g	geometric mean diameter, mm
H	height of heap above the floor, mm
M	moisture content of sample, % d.b.
M_f	final moisture content of sample, % w.b.
M_i	initial moisture content of sample, % w.b.
m_{1000}	thousand seed mass, g
Q	mass of water to added, kg
R^2	coefficient of determination
S	surface area, mm^2
V_t	terminal velocity, m s^{-1}
W_i	initial mass of sample, kg
α	angle of tilt, deg
ε	porosity, %
θ	angle of repose, deg
μ	static coefficient of friction
μ_{ru}	static coefficient of friction on rubber
μ_{pl}	static coefficient of friction on plywood
μ_{ga}	static coefficient of friction on galvanised metal sheet
μ_{al}	static coefficient of friction on aluminium
ρ_b	bulk density, kg m^{-3}
ρ_t	true density, kg m^{-3}
ϕ	sphericity, decimal



Fig. 1. Caper seeds

for the design of equipment for handling, harvesting, transporting, cleaning, separating, packing, storing and processing. These physical properties affect the conveying characteristics of solid materials by air or water. Size, shape, and physical dimensions of caper seeds are important in sizing, sorting and other separation process. Bulk and true densities of caper seeds are necessary to design the equipment for processing and storing such as dryers and bins. The porosity of the seeds is the most important for packing. The porosity also effects the resistance to airflow through bulk seeds. Terminal velocity is very important in the design of pneumatic conveyor. The angle of repose is essential in determination of packaging or storage structure for the material. The coefficient of static friction plays an important role in transport and storage of seeds. The designs lead to inadequate applications if the systems are designed without taking these physical properties into consideration. The object of this study was to investigate some moisture-dependent physical properties of caper seed namely, size, sphericity, surface area, projected area, thousand seed mass, bulk density, true density, porosity, terminal velocity, angle of repose and static coefficient of friction in the moisture range from 6·03 to 16·35% d.b.

2. Materials and methods

The caper seeds (*Capparis ovata* Desf.) used in this study were obtained from a local market for study. The seeds were cleaned manually to remove all foreign matter, broken and immature seeds. The initial moisture content of the seeds was determined by using the standard hot air oven method at least 15 g samples at 105 ± 1 °C for 24 h (Gupta & Das, 2000). The initial moisture content of the seeds was found to be 6·03% d.b.

The seed samples of the desired moisture levels were prepared by adding the amount of distilled water as calculated from the following relationship (Balasubramanian, 2001):

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

where: Q is the mass of water to added in kg; W_i is the initial mass of the sample in kg; M_i is the initial moisture content of the sample in % w.b. and M_f is the final

moisture content of the sample in % w.b. Finally, the moisture content of seed samples was expressed as a % d.b. The moisture content of seeds was determined by the standard method at the time of each experiment.

The samples were sealed well in separate polyethylene bags and kept in a refrigerator at 5 °C for 15 days for the moisture to distribute uniformly throughout the sample. Before each test, the required quantity of seed was taken out of the refrigerator and allowed to warm up to the room temperature for about 2 h (Deshpande *et al.*, 1993; Nimkar & Chattopadhyay, 2001).

All the physical properties of the seeds were investigated at six moisture levels of 6·03, 7·90, 10·00, 12·15, 14·23 and 16·35% d.b.

To determine the average size of the seed, a sample of 100 seeds was randomly picked and their three principal dimensions namely, major, medium and minor axes were measured using a micrometer with an accuracy of 0·01 mm.

The average diameter of seed was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter D_a and geometric mean diameter D_g of the seed were calculated by using the following relationships (Mohsenin, 1970):

$$D_a = (a + b + c)/3 \tag{2}$$

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

where: a is the major axis, b is the medium axis and c is the minor axis in mm. The sphericity ϕ of seeds was calculated by using the following relationship (Mohsenin, 1970):

$$\phi = \frac{(abc)^{1/3}}{a} \tag{4}$$

The surface area S in mm^2 of caper seed was found by analogy with a sphere of same geometric mean diameter, using the following relationship (Olajide & Ade-Omowaye, 1999):

$$S = \pi D_g^2 \tag{5}$$

The projected area of the seed was measured by image analysis method (Sahoo & Srivastava, 2002). The thousand seed mass was determined by means of a digital electronic balance reading to 0·001 g.

The bulk density of the caper seed at six different moisture levels was determined by filling a circular container of 500 ml volume with seed from a height of 150 mm at a constant rate and then weighing the contents. No separate manual compaction of seeds was done (Singh & Goswami, 1996). The bulk density was calculated from the mass of the seeds and the volume of the container.

The true density, as a function of moisture content, was determined using the toluene displacement method. Toluene (C_7H_8) was used in place of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced was found by immersing a weighed quantity of caper seed in the toluene (Singh & Goswami, 1996; Öğüt, 1998; Konak *et al.*, 2002).

The porosity of caper seed at six different moisture contents was calculated from the following relationship (Mohsenin, 1970):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) 100 \tag{6}$$

where: ε is the porosity in %; ρ_b is the bulk density in $kg\,m^{-3}$ and ρ_t is the true density in $kg\,m^{-3}$.

The terminal velocities of seeds at different moisture contents were measured using an air column device (Joshi *et al.*, 1993; Gupta & Das, 1997; Sacilik *et al.*, 2003). For each experiment, a sample was dropped into an air stream from the top of the air column. Then airflow rate was gradually increased until the seed became suspended in the air stream. The air velocity near the location of the seed suspension was measured using a vane anemometer having at least $0{\cdot}01\,m\,s^{-1}$ accuracy. Each sample consisted of 20 seeds selected randomly at the same moisture content of the seed.

To determine the angle of repose of caper seeds, a tube (inner diameter 104 mm and height 210 mm) was kept vertically on a horizontal galvanised metal floor and filled with the sample. Tapping during filling was done to obtain uniform packing and to minimise the wall effect, if any. The tube was slowly raised above the floor so that whole material could slide and form a heap. The height of heap above the floor and the diameter of the heap at its base were measured and the angle of repose was calculated using the following relationship (Jha, 1999).

$$\theta = \tan^{-1}(2H/D) \tag{7}$$

where: θ is the angle of repose in degree; H is the height of heap above the floor in mm and D is the diameter of the heap at its base in mm.

The static coefficient of friction at different moisture contents was measured for four structural materials, namely, rubber, plywood (with wood grains parallel to the direction of movement), galvanised metal sheet and aluminium sheet. A plastic cylinder of 100 mm diameter and 50 mm height was placed on an adjustable tilting plate, faced with the test surface and filled with the sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was inclined gradually with a screw device until the box just started to slide down. The angle of tilt was read from a graduated scale (Joshi *et al.*,

1993; Gupta & Das, 1997; Nimkar & Chattopadhyay, 2001). The coefficient of friction was calculated from the following relationship:

$$\mu = \tan \alpha \quad (8)$$

where: μ is the coefficient of friction and α is the angle of tilt in degree.

All the experiments were replicated five times, unless stated otherwise, and the average values were reported. The data were statistically analysed for various parameters of study at different moisture contents.

3. Results and discussion

3.1. *Seed dimensions*

The mean values and standard errors of the axial dimensions of the caper seeds at different moisture contents are presented in Table 1. As can be seen in Table 1, the three axial dimensions increased with increase in moisture content from 6·03 to 16·35% d.b. The dimensional increases in major axis, medium axis and minor axis were 18·8%, 20·8% and 23·0%, respectively.

The average diameters calculated by the arithmetic mean and geometric mean are also presented in Table 1. The average diameters increased with the increase in moisture content as axial dimensions. The arithmetic and geometric mean diameter ranged from 2·34 to 2·81 mm and 2·24 to 2·71 mm as the moisture content increased from 6·03 to 16·35% d.b., respectively.

3.2. *Sphericity*

The values of sphericity were calculated individually with Eqn (4) by using the data on geometric mean diameter and the major axis of the caper seed and the results obtained are presented in *Fig. 2*. The sphericity of the caper seed increased from 0·725 to 0·738 when the moisture content increased from 6·03 to 16·35% d.b. Similar trends have been reported by Aydin *et al.* (2002) for mahaleb, Özarslan (2002) for cotton and Sacilik *et al.* (2003) for hemp seed. The relationship between sphericity and moisture content can be represented by the following equation:

$$\phi = 0{\cdot}718 + 0{\cdot}0013\ M \quad (9)$$

with a value for the coefficient of determination R^2 of 0·959. The relationship between sphericity and moisture content was found to be significant at a significance level of 0·01.

3.3. *Surface area*

The variation of the surface area with the seed moisture content is plotted in *Fig. 3*. This figure indicates that the surface area increases linearly with increase in seed moisture content. The surface area of caper seed increased from 15·81 to 23·07 mm^2 when the moisture content increased from 6·03 to 16·35% d.b. Similar trends have been reported by Aviara *et al.* (1999) for guna seed and Sacilik *et al.* (2003) for hemp seed.

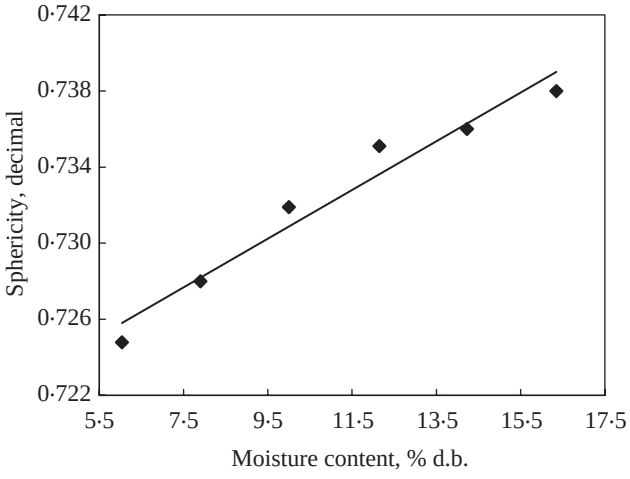

Fig. 2. Effect of moisture content on sphericity of caper seeds

Table 1
Means and standard errors of the axial dimensions of caper seeds

Moisture content, % d.b.	*Axial dimension, mm*			*Average diameter, mm*	
	Major axis (a)	*Medium axis (b)*	*Minor axis (c)*	*Arithmetic mean (a+b+c)/3*	*Geometric mean $(abc)^{1/3}$*
6·03	3·09±0·024	2·40±0·025	1·52±0·006	2·34	2·24
7·90	3·22±0·020	2·50±0·026	1·60±0·003	2·44	2·34
10·00	3·37±0·016	2·62±0·026	1·70±0·031	2·56	2·47
12·15	3·51±0·026	2·75±0·028	1·78±0·020	2·68	2·58
14·23	3·60±0·020	2·83±0·027	1·83±0·016	2·75	2·65
16·35	3·67±0·018	2·90±0·022	1·87±0·028	2·81	2·71

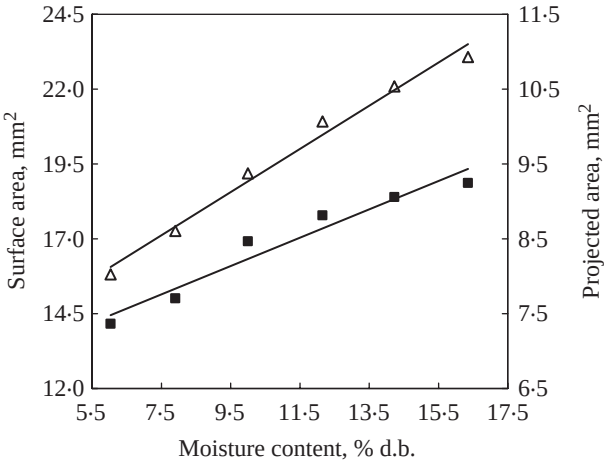

Fig. 3. Effect of moisture content on surface area and projected area of caper seeds: △, surface area; ■, projected area

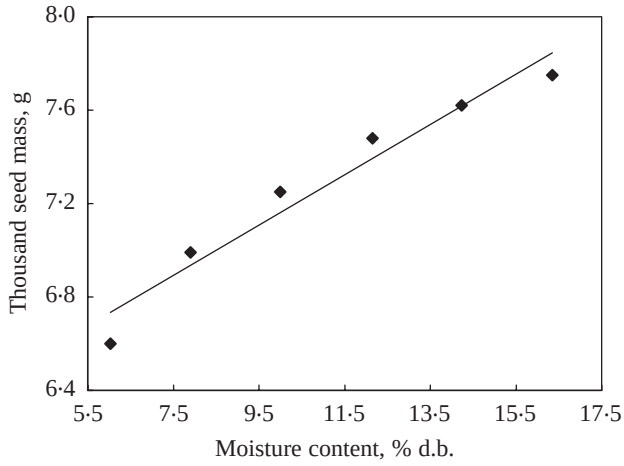

Fig. 4. Effect of moisture content on thousand seed mass of caper seeds

The relationship existing between moisture content and surface area can be expressed as follows:

$$S = 11{\cdot}7 + 0{\cdot}722\ M \tag{10}$$

with a value for the coefficient of determination R^2 of 0·986. The variation in surface area with moisture content was significant at a significance level of 0·01.

3.4. *Projected area of seed*

The projected area of caper seed increased from 7·37 to 9·25 mm^2, while the moisture content of seed increased from 6·03 to 16·35% d.b. (*Fig. 3*). Similar trends have been reported for many other seeds (Deshpande *et al.*, 1993; Tang & Sokhansanj, 1993; Çarman, 1996; Öğüt, 1998; Konak *et al.*, 2002). The relationship between projected area and moisture content was significant (probability $<0{\cdot}01$) and can be represented by the following equation:

$$A_p = 6{\cdot}34 + 0{\cdot}189\ M \tag{11}$$

with value of R^2 of 0·947.

3.5. *Thousand seed mass*

It can be seen from *Fig. 4* that thousand seed mass of caper seed m_{1000} increased linearly from 6·60 to 7·75 g when the moisture content was increased from 6·03 to 16·35% d.b. A linear increase in thousand seed mass with increase in seed moisture content has been reported by Deshpande *et al.* (1993) for soybean, Öğüt (1998) for white lupin, Jha (1999) for makhana and Nimkar and Chatopadhyay (2001) for green gram. The relationship between thousand seed mass and moisture content can

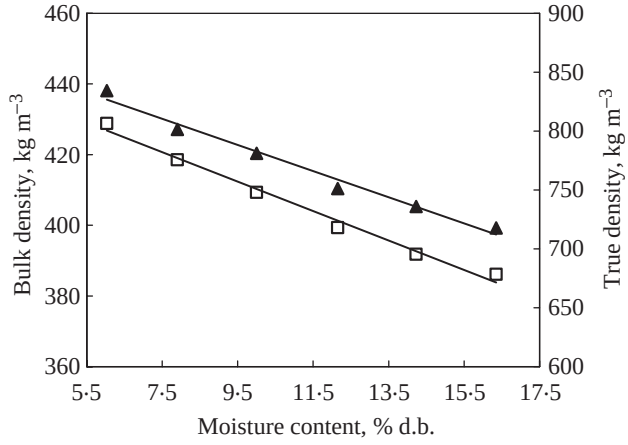

Fig. 5. Effect of moisture content on bulk density and true density of caper seeds: ▲, bulk density; □, true density

be represented by the following regression equation:

$$m_{1000} = 6{\cdot}08 + 0{\cdot}108\ M \tag{12}$$

with a value of R^2 of 0·951. This relationship was significant at a level of 0·01.

3.6. *Bulk density*

The experimental results of the bulk density for caper seed at different moisture levels are presented in *Fig. 5*. The bulk density decreased from 438 to 399 kg m^{-3} as the moisture content increased from 6·03 to 16·35% d.b. The negative linear relationship of bulk density with moisture content was also observed by various research workers (Deshpande *et al.*, 1993; Gupta & Das, 1997; Nimkar & Chattopadhyay, 2001; Konak *et al.*, 2002; Bart-Plange & Baryeh, 2003). The decrease in bulk

density with increase in moisture content shows that the increase in mass resulting from the moisture gain of the sample is lower than the accompanying volumetric expansion of the bulk. The relationship between bulk density and moisture content can be represented by the following regression equation:

$$\rho_b = 457{\cdot}9 - 3{\cdot}70\ M \tag{13}$$

with a value for the coefficient of determination R^2 of 0·982.

3.7. *True density*

The experimental results of the true density for caper seed at different moisture contents are also presented in *Fig. 5*. The true density of the seed decreased from 806 to 678 kg m^{-3} as the moisture content increased from 6·03 to 16·35% d.b. The decrease in true density values with increase in moisture content may be due to lower weight increase of seed in comparison with its volume expansion on moisture gain. A similar decreasing trend in true density have been observed by Deshpande *et al.* (1993) for soybean, Nimkar and Chattopadhyay (2001) for green gram and Kaleemullah and Gunasekar (2002) for arecanut kernel. The relationship between true density and moisture content of the caper seed can be expressed as follows:

$$\rho_t = 876 - 12{\cdot}5\ M \tag{14}$$

with a value for the coefficient of determination R^2 of 0·989. The variation in true density with moisture content was significant at a significance level of 0·01.

3.8. *Porosity*

The porosity of caper seed was found to decrease linearly with the increase in moisture content (*Fig. 6*). As the moisture content increased from 6·03 to 16·35% d.b., the porosity decreased from 45·7 to 41·1%. The variation in porosity with moisture content was significant at a significance level of 0·01. Deshpande *et al.* (1993), Joshi *et al.* (1993), Tang and Sokhansanj (1993), Suthar and Das (1996) and Konak *et al.* (2002) reported a similar decrease in porosity when the moisture content was increased for soybean seed, pumpkin seed, lentil seed, karingda seed and chick pea seed, respectively. Since the porosity depends on the bulk and true densities, the magnitude of variation in porosity depends on these densities only. The relationship between porosity and the moisture content of the caper seed can be represented by the following equation:

$$\varepsilon = 48{\cdot}43 - 0{\cdot}458\ M \tag{15}$$

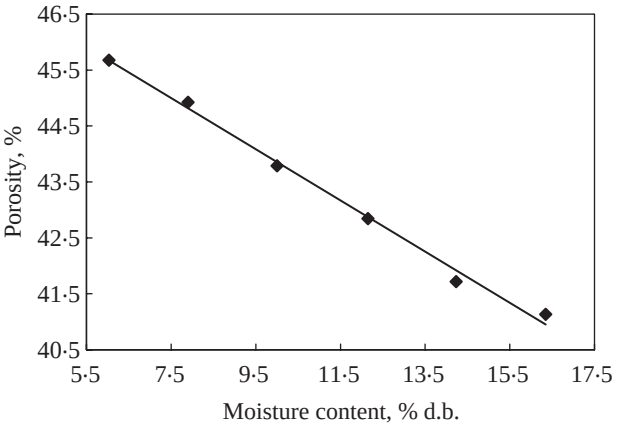

Fig. 6. Effect of moisture content on porosity of caper seeds

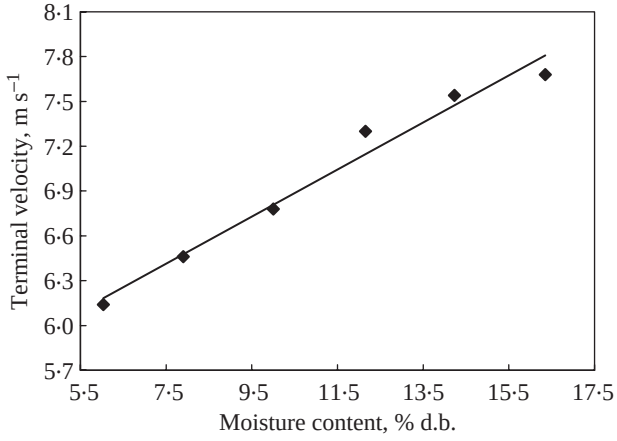

Fig. 7. Effect of moisture content on terminal velocity of caper seeds

with a value for the coefficient of determination R^2 of 0·994.

3.9. *Terminal velocity*

The experimental results for the terminal velocity of caper seed at various moisture content are plotted in *Fig. 7*. The terminal velocity increased linearly from 6·1 to 7·7 m s^{-1} as the moisture content increased from 6·03 to 16·35% d.b. Singh and Goswami (1996), Suthar and Das (1996), Nimkar and Chattopadhyay (2001), Konak *et al.* (2002) and Sacilik *et al.* (2003) have reported a linear increase in terminal velocity with increase in the moisture content for cumin seed, karingda seed, green gram, chick pea seed and hemp seed, respectively. The increase in terminal velocity with increase in moisture content can be attributed to the increase in mass of an individual seed per unit frontal area presented to the air

stream. The relationship between moisture content and terminal velocity can be expressed by the following equation:

$$V_t = 5{\cdot}234 + 0{\cdot}158\ M \tag{16}$$

with a value for the coefficient of determination R^2 of 0·975. The variation in terminal velocity with moisture content was significant at a significance level of 0·05.

3.10. *Angle of repose*

The experimental results for the angle of repose for caper seed at various moisture levels are shown in *Fig. 8*. It is observed that the angle of repose increased with increase in moisture content. It increased from 21 to 32° in the moisture range of 6·03–16·35%. The results were similar to those reported by Baryeh (2002) for millet, Aydin *et al.* (2002) for mahaleb, Sahoo and Srivastava (2002) for okra seed. The increase in the angle of repose with increase in moisture content of the seed could be due to the higher projected area which may increase the internal friction of the seeds. An increased moisture content of the seed may also result in increase in internal friction. The relationship existing between moisture content and angle of repose appears linear and can be formulated as follows:

$$\theta = 15{\cdot}10 + 1{\cdot}071\ M \tag{17}$$

with a value for the coefficient of determination R^2 of 0·963.

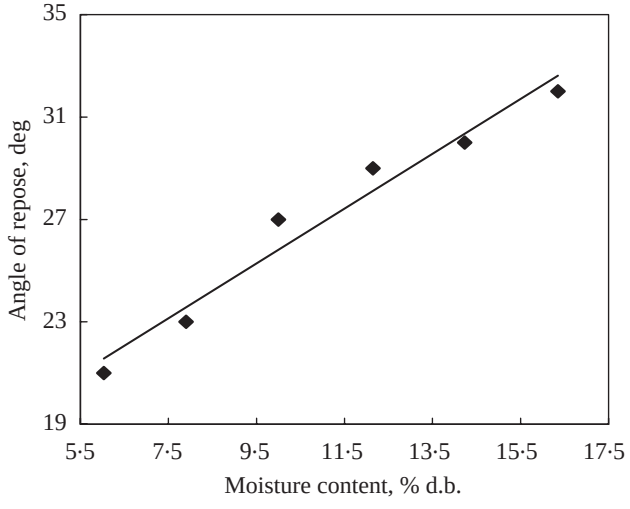

Fig. 8. Effect of moisture content on angle of repose of caper seeds

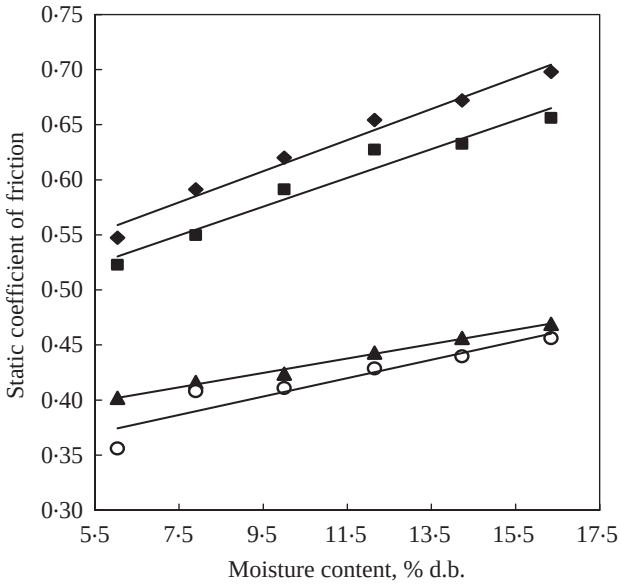

Fig. 9. Effect of moisture content on coefficient of static friction of caper seeds: ♦, rubber; ■, plywood; ▲, galvanised metal; ○, aluminium

3.11. *Static coefficient of friction*

The static coefficient of friction for caper seed, determined with respect to four different structural surfaces, are given in *Fig. 9*. It is observed that the static coefficient of friction increased with increase in moisture content on all surfaces. This could be due to increased adhesion between the seed and the surface at higher moisture values. Similar results were found by other researchers (Çarman, 1996; Suthar & Das, 1996; Nimkar & Chattopadhyay, 2001; Konak *et al.*, 2002). At all moisture contents, the static coefficient of friction was greatest against rubber (0·547–0·698), followed by plywood (0·523–0·656), galvanised metal sheet (0·402–0·469) and the least for aluminium sheet (0·356–0·456). This may be owing to smoother and more polished surface of aluminium than other test surface.

The relationships between moisture content and static coefficients of friction on all test surfaces can be represented by the following equations:

$$\mu_{ru} = 0{\cdot}4738 + 0{\cdot}0141\ M \tag{18}$$

$$\mu_{pl} = 0{\cdot}4515 + 0{\cdot}0131\ M \tag{19}$$

$$\mu_{ga} = 0{\cdot}3625 + 0{\cdot}0065\ M \tag{20}$$

$$\mu_{al} = 0{\cdot}3237 + 0{\cdot}0084\ M \tag{21}$$

where μ_{ru}, μ_{pl}, μ_{ga} and μ_{al} are the coefficients of friction on rubber, plywood, galvanised metal sheet and aluminium sheet, respectively. The values of the

coefficient of determination R^2 for μ_{ru}, μ_{pl}, μ_{ga} and μ_{al} are 0·979, 0·958, 0·994 and 0·881, respectively.

4. Conclusions

The investigation of the physical properties of caper seed as a function of moisture content revealed the following:

(1) The major axis, medium axis and minor axis of seed increased from 3·09 to 3·67 mm, 2·40 to 2·90 mm and 1·52 to 1·87 mm as the moisture content increased from 6·03 to 16·35% d.b.
(2) The arithmetic and geometric mean diameters increased from 2·34 to 2·81 mm and 2·24 to 2·71 mm, respectively, in the moisture range from 6·03 to 16·35% d.b.
(3) As the moisture content increased from 6·03 to 16·35% d.b., the sphericity, surface area, projected area and thousand seed mass varied from 0·725 to 0·738, 15·81 to 23·07 mm^2, 7·37 to 9·25 mm^2 and 6·60 to 7·75 g, respectively.
(4) The bulk density, true density and porosity decreased from 438 to 399 $kg\,m^{-3}$, 806 to 678 $kg\,m^{-3}$ and 45·7 to 41·1%, respectively, as the moisture content increased from 6·03 to 16·35% d.b.
(5) The terminal velocity and angle of repose increased linearly from 6·1 to 7·7 $m\,s^{-1}$ and 21 to 32°, respectively, as the moisture content increased from 6·03 to 16·35% d.b.
(6) The static coefficient of friction increased linearly with increasing moisture content from 6·03 to 16·35% d.b. for all surfaces. The static coefficient of friction varied from 0·547 to 0·698, 0·523 to 0·656, 0·402 to 0·469 and 0·356 to 0·456 for rubber, plywood, galvanised metal sheet and aluminium sheet, respectively.

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