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Physical Properties of Pumpkin Seeds

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Several physical properties of pumpkin seeds and kernels were evaluated as functions of moisture content. The average length, width, thickness and unit mass of the seed were 16·91 mm, 8·67 mm, 3·00 mm and 0·203 g respectively. Corresponding values for the kernel were 14·62 mm, 6·89 mm, 2·50 mm and 0·160 g respectively. In the moisture range from 4 to 40% d.b., studies on re-wetted seed showed that the bulk density increased from 404 to 472 kg/m^3, true density decreased from 1179 to 1070 kg/m^3, porosity decreased from 65·73 to 55·46% and terminal velocity increased from 4·7 to 6·5 m/s. For the kernel, the corresponding values changed from 481 to 554 kg/m^3, 1080 to 1143 kg/m^3, 55·46 to 51·53% and from 4·27 to 5·25 m/s respectively. In the moisture range of 4 to 27% d.b. the static coefficient of friction varied from 0·41 to 0·76 for seed and from 0·34 to 0·65 for kernel over different material surfaces, while angle of repose varied from 30 to 52° for seed and 34 to 42° for kernel.

1. Introduction

Pumpkin (*Cucurbita maxima*) is extensively used as vegetable, processed food and stockfeed in different parts of the world. Although very little information is available about the production statistics of pumpkin in India, the average yield of fruits is reported to be 25 000 kg/ha (Choudhary[1]). The pumpkin fruit contains significant amounts of seed which is normally discarded. The seeds, with more than 45% oil, 30% protein (Lazos;[2] Robinson[3]) and yield ranging between 450 and 1570 kg/ha (Jacks *et al.*;[4] Pirie[5]) can indeed be considered to be a potential source of edible oil and protein next to groundnut.

Since the physical properties of pumpkin seed and kernel are the pre-requisites for the design of equipment for handling, dehulling and other processes, it is essential to determine these properties. Makanjuola[6] measured the size and shape of seeds of two watermelon varieties and correlated the dimensions of the seed and kernel. Various physical properties of melon seeds including densities, carrying velocity and surface roughness were evaluated by Ramakrishna.[7] Teotia and Ramakrishna[8] have also determined different forms of density of seeds, kernels and hulls using three commercial varieties of melon seeds. Some engineering properties of pumpkin seeds, such as hull breaking load, surface roughness, transport velocity, and densities were reported by Teotia *et al.*[9] However, detailed measurements of all principal dimensions of pumpkin seed and kernel as well as their correlation and the variations in physical properties at various levels of moisture content have not been investigated.

This paper presents results on determination of various physical properties, namely size, shape, densities, terminal velocity, coefficient of static friction against different

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Notation

L	length of seed, mm	R^2	correlation coefficient
W	width of seed, mm	V_t	terminal velocity, m/s
T	thickness of seed, mm	μ	coefficient of friction
M	unit mass of seed, g	θ	angle of repose, deg.
M_c	moisture content, % d.b.		
ρ_b	bulk density, kg/m^3	*Subscripts*	
ρ_t	true density, kg/m^3	s	seed
P_f	porosity of seed, %	k	kernel
l	length of kernel, mm	h	hull
w	width of kernel, mm	m	mild steel
t	thickness of kernel, mm	g	galvanized iron
m	unit mass of kernel, g		

material surfaces and angle of repose of pumpkin seed and kernel at different moisture contents.

2. Materials and methods

For this study, five bulk samples each weighing 5 kg of seeds of pumpkin (*Cucurbita maxima*) were procured from the local market during April–June, 1990 harvest season. All the samples were mixtures of different varieties and the initial moisture content of the seeds was found to vary between 6·0 and 7·5% d.b. The seeds were cleaned manually for foreign matter, broken and immature seeds. To obtain whole kerknels, the seeds were manually dehulled. Both seeds and kernels were packed separately in double-layered low-density polyethylene bags of 90 μ thickness, sealed and stored at low temperature (277 ± 2 K) for about 15 days before starting the experiment. For each test, the required quantity of seed and kernel was taken out and allowed to warm up for about 2 h.

To determine the size and shape of the seed, three subsamples, each weighing 0·5 kg, were randomly drawn from the bulk market sample. From each of three 0·5 kg subsamples, 200 seeds were picked and the 600 seeds thus obtained were mixed thoroughly; then 100 seeds were randomly selected and were labelled for easy identification. This method of random sampling was similar to one followed by Dutta *et al.*[10] For each individual seed and its kernel, the three principal dimensions, namely length, width and thickness were measured using a vernier caliper (least count 0·01 mm). *Fig. 1* illustrates the principal dimensions of the seed and kernel. To obtain the mass, each seed and its kernel were weighed on a precision electronic balance reading to 0·001 g.

Since seed size may play a significant role in processing, the seeds were classified into three categories, namely large, medium and small, based on their length. The distribution of seeds by number as well as by mass of each size in the sample was determined. Relationships among seed and kernel dimensions were also established using regression techniques.

To determine the effect of moisture content of the sample on some of its physical properties, seeds and kernels in the required quantities were soaked separately in tap water at 300 ± 2 K for 15 and 60 min respectively to attain a moisture content of about 40% d.b. from the initial value of 6·0 to 7·5% d.b. and 4·9 to 5·8% d.b., respectively. The samples were lightly dabbed with blotting paper to remove surface water before these were allowed to equilibrate for about 24 h. The samples were then slowly dried in a

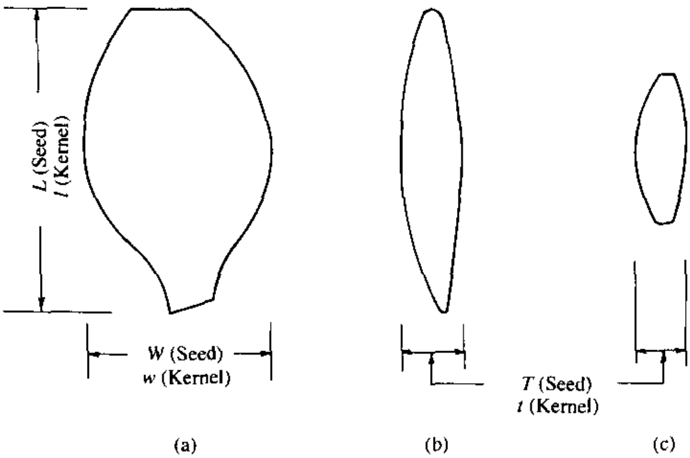

Fig. 1. Principal dimensions of seed and kernel (a) Normal to short axis, (b) Normal to medium axis and (c) Normal to major axis

thin-layer drying unit using hot air at 320 K, 40% relative humidity and 1 m/s velocity. Drying was continued for different periods to achieve different moisture contents as required. Such wetting and/or drying techniques to obtain the desired moisture content in seed and grain have been commonly used by many researchers.[6,9,11,12] Moisture content of the samples was determined by standard oven drying at 378 ± 1 K for 24 h (ISI[13]).

Bulk and true densities of seeds and kernels were determined separately at different moisture levels. The bulk density based on the volume occupied by the bulk sample was measured using a standard hectometer. True density defined as the ratio of the mass of the sample to the true volume of the particles was determined with an air comparison pycnometer (Beckman, Model 930) in which the volume of a known mass of the sample was determined by air displacement. Porosity of the bulk is the ratio of the volume of any internal pores in the particle to its bulk volume and was determined as follows.

$$\text{Porosity, \%} = (1\text{-bulk density/true density}) \times 100 \quad (1)$$

The terminal velocities of seed and its fractions at different moisture contents were measured using an air column. For each test, a small 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 near the location of the grain suspension was measured by a hot wire anemometer having a least count of 0·1 m/s. Five replications were made for each of the seed, kernel and hull samples.

The static coefficient of friction for seed and kernel was determined against two structural materials, namely mild steel and galvanized iron. A galvanized iron 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 box resting on it was inclined gradually with a screw device until the box just started to slide down and the angle of tilt was read from a graduated scale.[10,12,14]

To determine the emptying or dynamic angle of repose, a plywood box of 300 × 300 × 300 mm, having a removable front panel was used. The box was filled with the sample, then the front panel was quickly removed, allowing the seeds to flow and assume a natural slope.[10,12,14,15] The angle of repose was calculated from the measurement of the depth of free surface of the sample at the centre.

All the experiments were replicated thrice, unless stated otherwise, and the average values are reported.

3. Results and discussion

3.1. *Seed dimensions and size distribution*

Table 1 shows the size distribution of the pumpkin seeds. About 53% of the seeds were of medium size with length ranging from 14 to 18 mm, while about 38 and 9% were large size ($L > 18$ mm) and small size ($L < 14$ mm) seeds respectively. Longer seeds were broader, thicker and heavier than the medium and small seeds. It was observed that the seeds were longer, broader and thicker compared to those reported by Teotia *et al.*[9] This could be due to the difference in varieties. The following general expression can be used to describe the relationship among the dimensions of the seeds.

$$L = 1{\cdot}95W = 5{\cdot}63T = 82{\cdot}64M \tag{2}$$

The coefficients of correlation (Table 2) show that the L/W ratio is highly significant as compared to the L/T and L/M ratios. This indicates that the width of the seed is closely related to its length, while the thickness and mass show less association with the length of the seed. Similar relationships were reported for melon seeds by Makanjoula.[6] The frequency distribution curves (*Fig. 2*) for the mean values of the dimensions show a trend towards a normal distribution.

3.2. *Seed and kernel dimensional relation*

Table 1 also shows the kernel dimensions for all the three size categories of seed. The following relationship was found between the dimensions of the kernel:

$$l = 2{\cdot}12w = 5{\cdot}84t = 90{\cdot}89\,m \tag{3}$$

Table 1
Size distribution of seeds at 6·5% m.c.d.b.

Particulars	*Ungraded*	*Size category*		
		Large	*Medium*	*Small*
Length of seed, mm	11·2 to 21·0	>18	14 to 18	<14
Per cent of sample				
by number, %	100	38	53	9
by mass, %	100	42·85	51·09	6·06
Average dimensions				
Seed				
Length (L), mm	16·91 ± 2·16	19·00 ± 0·80	16·17 ± 1·04	12·43 ± 0·92
Width (W), mm	8·67 ± 1·05	9·54 ± 0·55	8·40 ± 0·66	6·57 ± 0·60
Thickness (T), mm	3·00 ± 0·33	3·25 ± 0·22	2·93 ± 0·21	2·39 ± 0·23
Mass (M), g	0·203 ± 0·032	0·229 ± 0·018	0·196 ± 0·019	0·137 ± 0·022
Kernel				
Length (l), mm	14·62 ± 1·84	16·40 ± 0·67	13·98 ± 0·95	10·90 ± 0·75
With (w), mm	6·89 ± 0·87	7·63 ± 0·51	6·64 ± 0·56	5·27 ± 0·47
Thickness (t), mm	2·50 ± 0·25	2·68 ± 0·15	2·47 ± 0·16	2·00 ± 0·21
Mass (m), g	0·160 ± 0·022	0·177 ± 0·011	0·156 ± 0·013	0·112 ± 0·019

Table 2
Correlation of seed and kernel dimensions at 6·5% m.c.d.b.

Particulars	*Ratio*	*Degree of freedom*	*Correlation coefficient*
L/W	1·95	99	0·857§
L/T	5·63	99	0·630†
L/M	82·64	99	0·649†
l/w	2·12	99	0·814§
l/t	5·84	99	0·618†
l/m	90·89	99	0·717†
L/l	1·16	99	0·993§
W/w	1·26	99	0·973§
T/t	1·20	99	0·957§
M/m	1·27	99	0·960§

§ Significant at 1% level
† Significant at 5% level

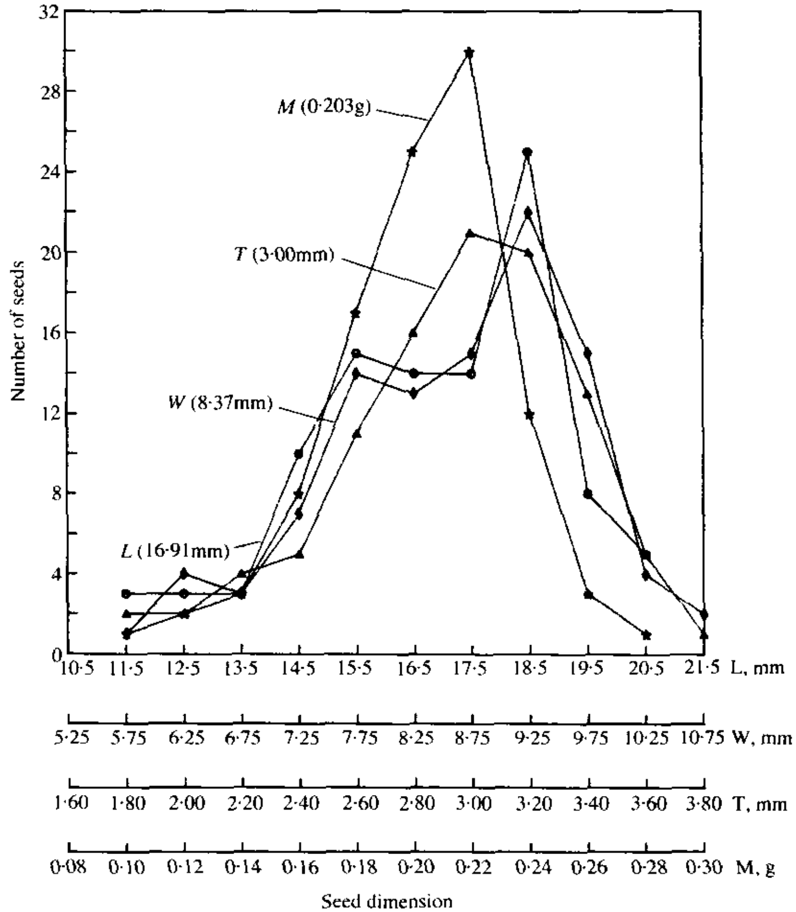

Fig. 2. Frequency distribution curves for mean values of seed dimensions (values in parentheses indicate mean dimension)

The following general expressions were found relating the dimensions of the seed and its kernel,

$$\begin{aligned} L &= 1{\cdot}16\, l, \\ W &= 1{\cdot}26\, w, \\ T &= 1{\cdot}20\, t \quad \text{and} \\ M &= 1{\cdot}27\, \text{m} \end{aligned} \tag{4}$$

with a level of significance better than 1% (Table 2). The correlations also indicate that, in general, the longer seed gives longer kernel when dehulled.

3.3. *Bulk density*

The values of the bulk density for different moisture levels varied from 404 to 472 kg/m^3 for seeds and 481 to 554 kg/m^3 for kernels. The bulk density of the seeds is less than that of the kernels at any given moisture level (Table 3). This may be attributed to the presence of hull which significantly reduces the total mass per unit volume occupied by the seed. The bulk density of the pumpkin seed and kernel was compared with that of *other seeds and grains.*[8,10,12,14,16] *It was observed that the values were close to those of* other cucurbita seeds, but were lower than those of pulses, fababean and oilbean.

The bulk density of seed and kernel was found to bear the following relationships with moisture content.

$$\rho_{bs} = 379{\cdot}3 + 5{\cdot}86M_c - 0{\cdot}09M_c^2 \quad (R^2 = 0{\cdot}979) \tag{5}$$

$$\rho_{bk} = 471{\cdot}8 + 3{\cdot}20M_c - 0{\cdot}03M_c^2 \quad (R^2 = 0{\cdot}931) \tag{6}$$

The bulk density increased with increase in moisture content for both seed and kernel. Thus, it appears that the increase in mass owing to moisture gain was greater than the corresponding volumetric expansion of the bulk seed. Similar increasing trends were

Table 3
Density of seed and its constituents in relation to moisture content

Constituent	*Moisture content,* % *d.b.*	*Bulk density,* kg/m^3	*True density,* kg/m^3	*Porosity,* %
Seed	5·8	404	1179	65·73
	8·1	427	1174	63·63
	20·0	464	1152	60·59
	32·2	468	1120	58·21
	40·7	472	1070	55·46
Kernel	4·2	481	1080	55·46
	7·0	498	1108	55·05
	15·5	514	1120	54·11
	26·3	536	1135	52·78
	38·0	554	1143	51·53
Hull	10·5	75	1533	95·11

reported for other flat-shaped seeds such as watermelon seed and kernel[8] and pistachios.[16] However, others have reported a decrease in bulk density with increase in moisture content for grains such as gram,[10] pigeon pea,[12] and fababean.[14]

The possibility of moisture lodging itself in the void space between seeds also suggests itself; but this is unlikely, since moisture equilibration of the seeds was accomplished separately before measurements were made. However, this is an interesting point that may need further study to provide definitive evidence.

3.4. *True density*

The true density of seed was found to vary from 1179 to 1070 kg/m^3, while that of kernel varied from 1080 to 1143 kg/m^3, when the moisture level for both increased from about 4·0 to 40·0% d.b. (Table 3). In comparison with other grains, the true density of pumpkin seed was found to be less than that of pulses[10,12] and cereals,[11] but only slightly less than that of melon seeds.[8] The variations in true density with moisture content of pumpkin seed and kernel can be represented by the following correlations.

$$\rho_{ts} = 1177 - 0{\cdot}43M_c - 0{\cdot}07M_c^2 \quad (R^2 = 0{\cdot}932) \tag{7}$$

$$\rho_{tk} = 1072 + 4{\cdot}00M_c - 0{\cdot}06M_c^2 \quad (R^2 = 0{\cdot}871) \tag{8}$$

Eqns (7) and (8) show that the true density of seeds decreased, while that for the kernels increased, as moisture content increased. This phenomenon may be attributed to the possible higher volume expansion of individual seed than kernel on moisture gain. Similar trends were reported for many other grains.[10–12] Up to about 25% moisture content dry basis, the seed had a true density higher than that of kernel. However, beyond this value, the kernel had a higher true density.

3.5. *Porosity*

Porosity of the bulk as defined in Eqn (1) was calculated from the relevant experimental data. It decreased from 65·73 to 55·46% and from 55·46 to 51·53% for the seed and kernel respectively, when the moisture content increased from about 4 to 40% d.b. Relationships between the porosity and moisture content for seed and kernel derived from Table 3 are shown in Eqns (9) and (10) respectively.

$$P_{fs} = 66{\cdot}48 - 0{\cdot}27M_c \quad (R^2 = 0{\cdot}988) \tag{9}$$

$$P_{fk} = 55{\cdot}90 - 0{\cdot}12M_c \quad (R^2 = 0{\cdot}998) \tag{10}$$

3.6. *Terminal velocity*

The experimental results for the terminal velocity of the pumpkin seed and its fractions at various moisture levels are plotted in *Fig. 3.* The terminal velocity was significantly lower for hull than for seed and kernel at all moisture levels. The difference in terminal velocity for seed and kernel was small. The results are similar to those reported by Ramarkrishna[7] for different melon seeds. As moisture content increased, the terminal

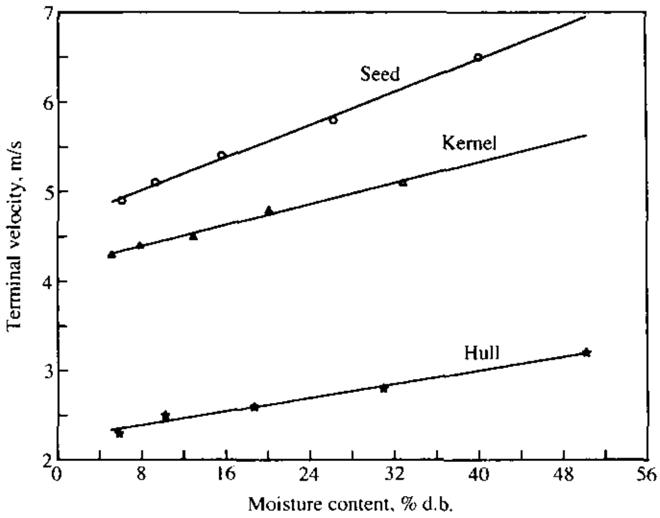

Fig. 3. Effect of moisture content on terminal velocity

velocity was found to increase linearly for seed, kernel and hull [Eqns (11) to (13)].

$$V_{ts} = 4{\cdot}59 + 0{\cdot}05M_c \quad (R^2 = 0{\cdot}992) \tag{11}$$

$$V_{tk} = 4{\cdot}25 + 0{\cdot}02M_c \quad (R^2 = 0{\cdot}946) \tag{12}$$

$$V_{th} = 2{\cdot}22 + 0{\cdot}02M_c \quad (R^2 = 0{\cdot}987) \tag{13}$$

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 across the air path, and also due to friction on the edges of the seed in motion. However, it is not possible to comment on the relative significance of these effects, except to say that the shape factor has an effect.

3.7. *Static coefficient of friction*

The static coefficients of friction for pumpkin seed and kernel, determined with respect to two metallic surfaces are presented in *Fig. 4*. It was observed that the static coefficient of friction for seed was higher than that for kernel against both mild steel and galvanized steel. This suggests that the seeds are rougher than the kernels. The coefficient of friction was slightly higher for the mild steel than for galvanized iron. This may be due to the smoother and more polished surface of the galvanized iron sheet compared to mild steel sheet used. The coefficient of friction (μ) increased with moisture content for all the cases and bears the following relationships.

$$\mu_{sm} = 0{\cdot}32 + 0{\cdot}014M_c \quad (R^2 = 0{\cdot}984) \tag{14}$$

$$\mu_{sg} = 0{\cdot}30 + 0{\cdot}013M_c \quad (R^2 = 0{\cdot}983) \tag{15}$$

$$\mu_{km} = 0{\cdot}31 + 0{\cdot}008M_c \quad (R^2 = 0{\cdot}976) \tag{16}$$

$$\mu_{kg} = 0{\cdot}30 + 0{\cdot}007M_c \quad (R^2 = 0{\cdot}967) \tag{17}$$

When compared with other grains, the coefficient of friction for pumpkin seed was higher than that of gram,[10] pigeon pea,[12] fababean[14] and oilbean seed.[15]

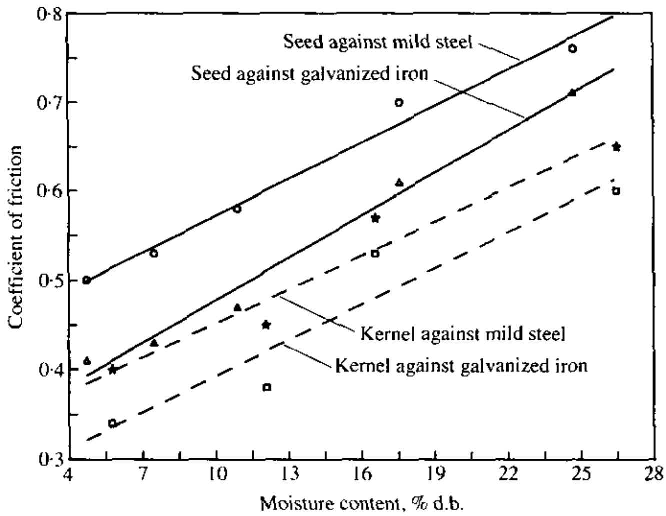

Fig. 4. Effect of moisture content on coefficient of friction

3.8. *Angle of repose*

Table 4 shows the experimental values of the angle of repose for seed and kernel at various moisture levels. The angle of repose increased from 30 to 52° for seed and from 34 to 42° for kernel, in the moisture range of 4·5 to 26·5% d.b.; these variations can be represented by the following relationships.

$$\theta_s = 26 + 0{\cdot}98M_c \quad (R^2 = 0{\cdot}933) \tag{18}$$

$$\theta_k = 32 + 0{\cdot}37M_c \quad (R^2 = 0{\cdot}987) \tag{19}$$

The value of angle of repose for pumpkin seed was considerably higher than those reported for gram,[10] pigeon pea,[12] fababean[14] and oilbean seed.[15] This is due to the rough surface of pumpkin seed imposing resistance to the seeds from sliding on each other.

Table 4
Angle of repose of seed and kernel in relation to moisture content

Seed		*Kernel*	
Moisture content, % d.b.	*Angle of respose, deg.*	*Moisture content, % d.b.*	*Angle of repose, deg.*
4·7	30·1	5·7	34·6
6·5	34·2	12·1	36·5
10·9	36·9	16·6	39·0
17·6	40·0	26·5	42·0
24·3	51·9		

3.9. *General discussion*

It is evident from the results presented here that the major physical properties of pumpkin seed and kernel are influenced by moisture content within the range from about 4 to 40% d.b. In turn, this will determine the behaviour of the seed and its components during processing. Incidentally, it should be noted that the hull has a tremendous potential for absorbing moisture. In fact, results of experiments (not presented here) carried out by the authors have shown that the moisture absorption rate was fastest during the first 15 min of soaking and about 75% of the moisture absorbed was in the hull, kernels accounting for the remaining 25% only. This suggests that the hull, apart from its normal role of protecting the kernel including its delicate embroyo from mechanical and other damage, may also protect the latter from adverse effects of moisture as well.

4. Conclusions

1. The average length, width and thickness of pumpkin seed was 16·91, 8·67 and 3·00 mm respectively, while the corresponding values for kernel were 14·62, 6·89 and 2·50 mm. More than half the seeds were of medium size. The average unit mass of seed and kernel was 0·203 g and 0·160 g respectively.
2. All the physical properties of the pumpkin seed studied in this work varied with moisture content.
3. The seeds had a lower bulk density and a higher true density than the kernels. For the seed, bulk density increased from 404 to 472 kg/m^3, while true density decreased from 1179 to 1070 kg/m^3 as the moisture increased from about 4 to 40% d.b. The corresponding densities for the kernel increased from 481 to 554 kg/m^3 and 1080 to 1143 kg/m^3.
4. The terminal velocity for the hull (2·29 to 3·03 m/s) was significantly lower than that for seed (4·70 to 6·50 m/s) and the kernel (4·27 to 5·25 m/s) at all moisture contents from 4 to 40% d.b.
5. The coefficient of friction of seed was higher than that of kernel and increased from 0·41 to 0·76 and from 0·34 to 0·65 for the seed and the kernel respectively with increase in moisture content from 4 to 27% d.b.
6. The angle of repose varied from 30 to 52° for seed and 34 to 42° for kernel, in the moisture range of 4 to 27% d.b.

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