Physical properties of bottle gourd seeds

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Abstract: The present study was aimed to evaluate physical properties of bottle gourd seeds viz., size, shape, surface area, unit mass, densities, angle of repose and coefficient of friction at the moisture content of 10.04 % (wet basis). The results revealed that the average length, width and thickness of seeds were 14.84, 7.44 and 3.34 mm, respectively. The aspect ratio, sphericity, surface area and 1,000 seed mass of bottle gourd seeds were found to be 50.45 %, 0.48, 161.78 mm^2 and 143.77 g, respectively. The average values of true and bulk densities were 721.30 and 453.80 kg m^{-3}, respectively and the corresponding porosity was 37.07%. The terminal velocity was 6.14 m s^{-1}. The coefficient of friction on plywood and plastic surfaces were observed to be the highest and lowest, respectively. As the bottle gourd seed oil contains omega-3 and 'Lagenina', the information obtained through the experiments is key parameters not only for food processors but also to the engineers for designing process and machines as well.

Keywords: Bulk density, coefficient of friction, dimensions, porosity, terminal velocity, true density

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1 Introduction

The bottle gourd (*Lagenaria siceraria),* belongs to family *cucurbitaceae,* is used in appliance of pharmaceuticals and dietary formulations (Decker-Walter et al., 2004). The bottle gourd is climbing plant having various synonyms viz., calabash gourd, lauki, dudhi or ghiya. It produces fruits of bottle shape and hard texture. It is grown throughout the tropical regions of the world mainly in Africa, Central America, China, Ethiopia, India, Japan, Sri Lanka, and Thailand (Salunkhe and Kadam, 1998; Nicola et al., 1999).

The spongy flesh tissues along with white pulp and embedded seeds exist inside the bottle gourd fruit. The bottle gourd seeds are present in large numbers and all are covered around with protectant layer, testa. The seed kernel has moisture (2.47%), protein (30.72%), oil (52.54%), carbohydrates (8.3%), fiber (1.58%) and ash (4.43%). Bottle gourd seed kernels yield 52.54% of oil with the characteristics like iodine value (126.5), free fatty acids (0.54%), saponification value (301.6) and unsaponified matter (0.67%). The components of free fatty acids are linoleic acids (64%), oleic (18.2%) and saturated fatty acids (17.8%) (Kubde et al., 2010). The oil obtained from seed is clear and pale yellow and is used as cooking oil as well as hair oil.

The bottle gourd seed oil is considered as the most dietetic oil since it contains omega-3 which is known to promote energy levels, brain function and overall human vitality. The 'Lagenina' is available in the lyophilized water extract of seeds. It is a novel ribosome inactivating protein hence possess properties like immunosuppressive, antitumour, antiviral, antiproliferative and anti-HIV activities (Wang and Ng, 2000; Kubde et al., 2010). The ethanolic extract obtained from the seeds has a potent anthelmintic activity against tapeworms which is comparable to the effect of piperazine citrate.

The bottle gourd seeds process through a series of unit operations to yield oil and its derivatives i.e. protein cake. Scientific evaluation showed that basic physical properties of biological materials have prominent role in designing

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processing machines and their control as wells as deciding final product characteristics (Amin et al., 2004). Advanced research activities in basic science provide improved techniques of handling and processing of bio-materials through mechanical, thermal, electrical, optical and other techniques, but use of these techniques in applied science lacking scientific information about basic physical properties of biological materials. The information related to properties of biological materials is essential not only to the engineers but also to the food scientists, processors, plant breeders and scientists of various fields who may find innovative uses of it (Mohsenin, 1986). The equipment performing operations like cleaning, grading, separation, oil extraction are designed by considering the physical properties of seeds. The size (such as major, minor and intermediate dimensions) and shape are important in designing of machines related with separating, sizing and grinding. The shape can be viewed in terms of its sphericity and aspect ratio which influence the flow ability characteristics of the products. The moisture content of material provides precious information for the development of the drying process. The knowledge about gravimetric properties like bulk density; true density and 1000-seed mass are useful for the design of equipment related to aeration, drying, storage and transport (Kachru et al., 1994; Dash et al., 2008). Bulk density and porosity are major constraints in the design of drying, aeration and storage systems, as these properties affect the resistance to air flow of the mass (Amin et al., 2004). The terminal velocity is very important in the design of pneumatic conveyor (Dursun and Dursun, 2005; Vilche et al, 2003). Frictional properties viz., angle of repose, coefficient of friction, etc., are playing vital role while designing conveying systems, grain bins and other storage structures (Kachru et al., 1994).

In recent years, many researchers have been reported on properties of various plant materials such as ackee apple seed (Omobuwajo et al., 2000), African star apple seed (Oyelade et al., 2005), chick pea seed (Konak et al., 2002), cumin seed (Singh and Goswami, 1996), faba bean (Haciseferogullari et al., 2003), groundnut kernel (Olajide and Igbeka, 2003), hemp seed (Sacilik et al., 2003), jatropha seed (Garnayak et al., 2008), karanja kernel (Pradhan et al., 2008), oil bean seed (Oje and Ugbor, 1991), pigeon pea (Baryeh and Mangope, 2002; Shepherd and Bhardwaj, 1986), sunflower seed (Gupta and Das, 1997; Gupta and Das, 2000), tung seed (Sharma et al., 2011) and watermelon seed (Koocheki et al., 2007). However, no study concerning physical properties of bottle gourd seed has been reported hitherto.

There is considerable interest in bottle gourd seeds because of their high nutritional quality, mainly in terms of protein and oil content. The present work reports various physical properties of bottle gourd seeds viz., the principal dimensions, geometrical mean diameter, sphericity, 1,000 seed mass, densities (true and bulk density), porosity, angle of repose and co-efficient of friction against different surfaces. This information is important to optimize the use of equipment that could improve the quality of the seed and its oil, and/or leading to lower operation/processing costs.

2 Materials and Methods

2.1 Sample

Bottle gourd seeds used in this study were procured from Varanasi (Maurya seeds company, Varanasi, Uttar Pradesh, India). The samples were then cleaned manually to remove all foreign materials such as dust, stones, dirt, immature seed, etc., and pooled together to obtain approximately 5 kg of seed materials. The seeds were kept in an airtight plastic vessel and stored at 5℃ before use. Before starting a test, the seeds were allowed to warm up under ambient room conditions (22–25℃, 30%–40% RH) to the equilibrium moisture.

2.2 Moisture content and oil content of the seeds

The moisture content of bottle gourd seeds was determined using American Society of Agricultural Engineers (ASAE) standard method (ASAE, 1983). Weighed amount of bottle gourd seed samples were dried in a hot-air oven at 105±2℃ and weighed every time after cooling the samples in a desiccator till constant weight was obtained. Weight loss on drying to a final constant weight is recorded as moisture content of the material. The moisture content (wet basis) of bottle gourd seeds was calculated using Equation (1):

$$Moisture\ content\ (\%) = \frac{(Initial\ weight\ of\ seeds - Final\ weight\ of\ seeds)}{Initial\ weight\ of\ seeds} \quad (1)$$

The oil content was determined using AOAC method (1984). The sample was extracted in a Soxhlet extraction unit with n-hexane (boiling point 40-50℃). The extract was dried for 30 min at 90℃, in a rotary evaporator, cooled and the residual oil weighed. Reported values are means of five determinations.

2.3 Physical dimensions of the seeds

To determine the size, the seeds were randomly selected from the lots. The seeds, in terms of the three principal axial dimensions, that is its length (*L*), width (*B*) and thickness (*T*), were measured using a vernier caliper (Model CD-6BS-Mitutoyo Corporation, Japan) with an accuracy of ±0.01 mm. Since seed size was considered an important parameter in processing bulk samples, they were classified into three categories namely small, medium and large based on their length.

The basis on which dimensional classification is to be based was set up by calculating the average dimension ($\bar{X}$) and the associated standard deviation (σ_x). Then, small, medium, and large size seeds were so defined that their specific X dimension satisfies the following three inequalities:

Small size group $X < \bar{X} - \sigma_x$

Medium size group $\bar{X} - \sigma_x < X < \bar{X} + \sigma_x$

Large size group $X > \bar{X} + \sigma_x$

The arithmetic mean diameter, D_a and geometric mean diameter, D_g of the seeds were calculated by using the following Equation (2) and Equation (3) (Mohsenin, 1986):

$$D_a = (L + B + T) / 3 \quad (2)$$

$$D_g = (LBT)^{1/3} \quad (3)$$

Sphericity (ϕ) of the seed was calculated as Equation (4) (Mohsenin, 1986):

$$\phi = \frac{(LBT)^{1/3}}{L} \quad (4)$$

The aspect ratio, R_a was calculated as Equation (5):

$$R_a = B/L \times 100 \quad (5)$$

To evaluate the 1000 seeds mass, mass individual of 50 randomly selected seed samples were measured separately using an electronic balance (Sartorius, Model No. BSA224S-CW, Made in Germany) with an accuracy of 0.001g and multiplied by 20. The reported value is mean of 10 replications. The surface area (S, mm^2) of seed sample was calculated from the following Equation (6):

$$S = \pi D_g^{\ 2} \quad (6)$$

2.4 The densities of the seeds

The bulk material (seeds) was put into a container with known weight and volume (1,000 cm^3) and was weighed by means of an electronic balance having an accuracy of 0.001 g. No separate manual compaction of seed was done. The bulk density was calculated from the mass of the seeds and the volume of the container (Gupta and Das, 1997).

The true density was determined using the toluene (C_7H_8) displacement method in order to avoid absorption of water during the experiment (Jha, 1999; Coskuner and Karababa, 2007). Toluene was used instead of water because of its low absorption by the seeds, its surface tension is low, so that it fills even shallow dips in seed, and its dissolution number is low (Mohsenin, 1986). The true density was found as an average of the ratio of their masses to the volume of toluene displaced by the seeds. The volume of toluene displaced was found by immersing a weighted quantity of bottle gourd seed in the toluene.

The porosity (%) is the parameter indicating the amount of pores in the bulk materials. It was calculated from the bulk and true density using Equation (7) given as follows (Mohsenin, 1986).

$$Porosity\ (\%) = \frac{(True\ density - Bulk\ density)}{True\ density} \times 100 \quad (7)$$

2.5 The angle of repose of the seeds

The angle of repose indicates the cohesion among the individual units of a material. The angles of repose of bottle gourd seeds were measured by the emptying method (Bart-Plange and Baryeh, 2003). The angle of repose was determined by using an open ended cylinder of 15 cm diameter and 50 cm height. The cylinder was placed at the centre of a circular plate having a diameter of 70 cm and was filled with bottle gourd seeds. The cylinder was raised slowly until it formed a cone on the circular plate.

The height of the cone was recorded by using a moveable pointer fixed on a stand having a scale of 0-1 cm precision. The angle of repose (θ) was calculated using Equation (8):

$$\theta = tan^{-1}(2H/D) \quad (8)$$

where, θ is angle of repose (degree); H is the height of the cone (cm) and D is the diameter of cone (cm).

2.6 The terminal velocity of seeds

The terminal velocity was measured by using an air column. For each test, the 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 fruit suspension was measured by an electronic anemometer (EUROLAB, AM4205 Anemometer, Made in Germany, Range: 0.4-30.0 m s^{-1} and Accuracy ± 2%).

2.7 The coefficient of friction for different materials

The coefficients of friction between the seeds and the materials that are used commonly in the bottle gourd seed post-harvest processing such as galvanized iron sheet, plywood, plastic sheet and glass were determined. A tilting platform of 350 mm×120 mm was fabricated and used for experimentation. An open-ended plastic cylinder having 65 mm diameter and 40 mm height was filled with the seed and placed on the adjustable tilting surface. 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 (screw pitch 1.4 mm), until the cylinder just started to slide down and the angle of tilt was read from a graduated scale (Fraser et al., 1978; Shepherd and Bhardwaj, 1986; Dutta et al., 1988; Nimkar et al., 2005). The coefficient of friction was calculated using the following Equation (9):

$$\mu_s = \tan\alpha \quad (9)$$

where, μ_s is coefficient of friction; and α is angle of inclination of material surface.

2.8 The statistical tool

The data analysis was carried out by using the SAS software. The results obtained were analyzed using ANOVA at 95% levels of significance ($P = 0.05$).

3 Result and Discussion

The average seed moisture at the time of experiment was 10.04±0.08% wet basis. This moisture content of the seed increases the storage stability, and also helps in post harvest processing operations. The yield of oil was found to be 43.5%. Table 1 shows the size distribution of the bottle gourd seed. These seeds presented three unequal semi-axes, and they may, therefore, be described as being flat in shape. A summary of the descriptive statistics of the various physical dimensions is shown in Table 1. The frequency distribution curves (Figure 1) for the dimensions at moisture content of 10.04% (wet basis) show a trend towards a normal distribution. The average length, width and thickness for bottle gourd seed were 14.84 (±0.13), 7.44 (±0.06) and 3.34 (±0.04) mm, respectively. Longitudinal dimension i.e. length (L) for the seed ranged from 11.20 to 17.40 mm. About 69% of the seeds were of medium size with length varying between 13.52 to 16.15 mm, while about 15 and 16% were large size (L > 16.15 mm) and small size (L< 13.52 mm) seeds respectively (Figure 1).

Table 1 Some physical properties of bottle gourd seeds at moisture content of 10.04 % (wet basis)

Physical properties	N	Mean	Minimum	Maximum	SD
Moisture content (wet basis)/%	5	10.04±0.08	9.83	10.30	0.19
Oil Content/%	5	43.5±0.25	42.89	44.35	0.61
Length (L)/mm	100	14.84±0.13	11.20	17.40	1.32
Width (B)/ mm	100	7.44±0.06	6.30	9.00	0.57
Thickness (T)/ mm	100	3.34±0.04	2.30	4.30	0.41
Arithmetic mean diameter (D_a)/ mm	100	8.54±0.06	6.87	9.53	0.61
Geometric mean diameter (D_g)/ mm	100	7.16±0.05	5.83	8.23	0.53
Sphericity	100	0.48±0.003	0.42	0.58	0.03
Aspect ratio/%	100	50.45±0.47	41.95	60.71	4.73
Unit mass/g	100	0.141±0.001	0.126	0.157	0.009
1,000 seed weight/g	10	143.77±2.83	128.76	155.76	8.96
Surface area/mm^2	100	161.78±2.35	106.77	213.02	23.47

Physical properties	N	Mean	Minimum	Maximum	SD
Bulk density/kg m^{-3}	10	453.80±2.27	446.00	465.00	7.19
True density/kg m^{-3}	10	721.30±4.00	699.00	736.00	12.66
Porosity/%	10	37.07±0.42	35.34	39.40	1.33
Terminal velocity/m s^{-1}	10	6.14±0.03	5.97	6.26	0.10
Angle of repose/degree	10	44.61±1.97	32.32	51.04	6.24

Note: *N* is the number of samples.

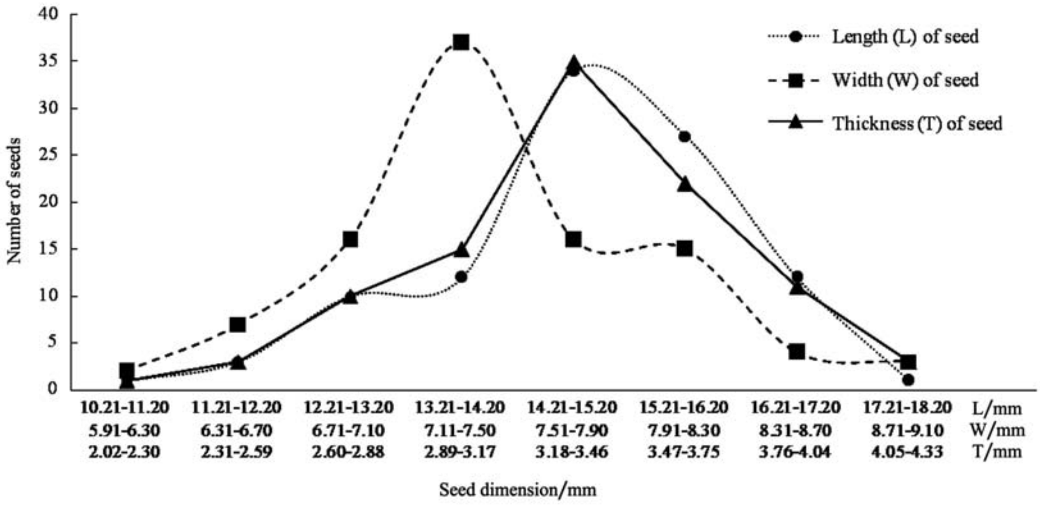

Figure 1 Frequency distribution curves of bottle gourd seed length, width and thickness at a moisture content of 10.04% (wet basis).

The geometric mean diameter was found to be 7.16 ± 0.05 mm and this value is lower than the length and width, and higher than thickness (Table 1). *L/T* ratio exhibited the highest value, while the L/D_g and *L/W* ratio presented close values (Table 2). The following general expression can be used to describe the relationship among the average dimensions of bottle gourd seeds:

$L = 2W = 4.5T = 2.07D_g = 0.09S = 0.31Ø = 105.37M$;

$W = 2.26T = 1.04D_g$; and $T = 0.47D_g$.

Table 2 Correlation coefficient of bottle gourd seed dimensions at moisture content of 10.04% (wet basis) (N=100)

Particulars	Ratio	Degree of freedom	Minimum	Maximum	Standard deviation	Correlation
L/W	2.00	99	1.65	2.38	0.18	0.390**
L/T	4.50	99	3.06	7.01	0.60	0.340**
L/M	105.37	99	76.60	129.69	11.67	-0.078^{NS}
L/D_g	2.07	99	1.73	2.41	0.13	0.728**
L/S	0.09	99	0.07	0.12	0.01	0.722**
L/Ø	30.88	99	20.20	40.33	4.10	-0.594**
W/T	2.26	99	1.68	3.52	0.29	0.373**
W/D_g	1.04	99	0.92	1.21	0.06	0.708**
T/Dg	0.47	99	0.34	0.57	0.04	0.825**

Note: ** Significant at 1% level, ^{NS} Non significant.

The coefficient of correlation (Table 2) showed that the *L*/*W*, *L*/*T*, L/D_g, *L*/S and *L*/Ø ratios were highly significant. This fact indicated that width, thickness, geometric mean diameter and surface area were positively related to length of the bottle gourd seeds while sphericity was negatively correlated and *L*/M have not been found to be statistically significant.

The seed shape was determined in terms of its sphericity and aspect ratio (Pradhan et al., 2008). It was seen from the Table 1 that the sphericity and aspect ratio of the bottle seed was found to be 0.48 and 50.45%, respectively. The experimental values of sphericity and aspect ratio for bottle gourd seed resulted to be lower than that of pumpkin and watermelon (Altuntas, 2008), kola nut

(Kareem et al., 2012) and Bambara groundnut from Botswana (Mpotokwane et al., 2008). As per the investigations by Garnayak et al., 2008 and Bal and Mishra (1988), the grain/seed is spherical when the sphericity value is more than 0.70. Hence, bottle gourd seed is treated as an equivalent to flat. Considering the modest aspect ratio (which relates the seeds width to length) and sphericity, it may be deduced that bottle gourd seeds would slide slowly on flat surfaces. This tendency to either roll or slide is very important in the design of hoppers and dehulling equipment for the seed. Furthermore, the shape indices indicated that the bottle gourd seed may be treated as a flat for an analytical prediction of its drying behavior. However, the surface area was found to be 161.78 ± 2.35 mm^2. The surface area is a relevant tool in determining the shape of the seeds. This will actually be an indication of the way the seeds will behave on oscillating surfaces during processing (Alonge and Adigun, 1999).

The mean of 1,000 seed mass of bottle gourd seeds was found to be 143.77 ± 2.83 g. The bulk density and true density of bottle gourd seeds were ranging from 446 to 465 kg m^{-3} and 699 to 736 kg m^{-3}, respectively. The averages of both true density and bulk density were 453.80±2.27 kg m^{-3} and 721.30 ± 4.00 kg m^{-3}, respectively (Table 1). The bulk density as well as true density values was thus, higher than that of sunflower seed (Gupta and Das, 1997), and lower than that of guar seed (Vishwakarma et al., 2012) and kola nut (Kareem et al., 2012). This parameter is important because it determines the capacity of storage and transport systems. The porosity of bottle gourd seeds was found to be 37.07 ± 0.42%. This characteristic can be used to separate the seeds from other heavier foreign materials. It must be noted that porosity of the mass of seeds determines the resistance to airflow during aeration and drying process.

The terminal velocity of the bottle gourd seed were ranging from 5.97 to 6.26 m s^{-1} with average of about 6.14 ± 0.03 m s^{-1}. This value is higher than those reported for pigeon pea (Baryeh and Mangope, 2002) and lower than those reported for guar seed (Vishwakarma et al., 2012). The data on terminal velocity can be used in designing the aspiration unit which will be useful in the cleaning of the bottle gourd seeds to remove impurities like dust and lighter impurities, which are lighter than the seed, as well as in the separation of the seeds from heavier impurities, such as stones and pebbles. Seed cleaning unit operation is an important pre-requisite for the seed industry.

The average value of angle of repose of the bottle gourd was found between 32.32° and 51.04° with average of 44.61° ± 1.97°. It was observed that the mean angle of repose of bottle gourd seed is considerably higher than that reported for sesame seed as 32° by Tunde-Akintunde and Akintunde, 2004), and mean angle of repose of pumpkin and watermelon (Altuntas, 2008). This showed that a result of the flat shape of the seeds, which facilitates sliding. The smoother outer surface and the shape of the seeds are apparently responsible for the values of repose angle, and thus the easiness of the seeds to slide on each other.

The results of the coefficient of friction, which may directly and indirectly affecting the design of the processing machine, was determined on four different material surfaces (galvanized iron sheet, plywood, plastic sheet and glass), have been tabulated in Table 3. It was observed that the coefficient of friction was highest (0.93 ± 0.01) for plywood and lowest (0.61 ± 0.008) for plastic sheet among all the other materials. The least coefficient of friction may be owing to the smoother and more polished surface of the plastic sheet than the other materials used. This data on the coefficient of friction will be important for designing of storage bins, hoppers, pneumatic conveying system, screw conveyors, forage harvesters, threshers, etc.

Table 3 Frictional properties of bottle gourd seeds at moisture content 10.04% (wet basis)

Coefficient of friction	Plywood	Galvanized iron sheet	Plastic	Glass
N	10	10	10	10
Mean	0.93	0.69	0.61	0.63
Minimum	0.88	0.63	0.56	0.60
Maximum	0.98	0.76	0.64	0.69
SD	0.03	0.04	0.03	0.03

Note: N is the number of samples.

4 Conclusions

The following conclusions were drawn from the investigation about the physical properties of bottle gourd seeds at an average moisture content of 10.04% (wet basis) and oil content of 43.5%. The average characteristic dimensions; length, width and thickness were 14.84, 7.44 and 3.34 mm, respectively. The frequency distribution curves of the axial dimensions tend a normal distribution. The arithmetic mean diameter and geometric mean diameter were 8.54 and 7.16 mm, respectively. This parameter can be used for the theoretical determination of seed volume and sphericity. The average value of sphericity and aspect ratio for bottle gourd seeds were 0.48 and 50.45%, respectively. The average of one thousand seed mass and surface area for seeds was 143.77 g and 161.78 mm^2, respectively. For bottle gourd seed the bulk density and true density were 453.80 and 721.30 kg m^{-3}, respectively while the porosity was 37.07%. Terminal velocity of bottle gourd seed was found to be 6.14 m s^{-1}. The coefficient of friction was lowest on plastic (0.61) and highest on plywood (0.93). In summary, this paper deals with the physical properties of bottle gourd seeds, enlarging the knowledge about this species and providing useful data for its post-harvest handling, to design sorters and grading machines, and further industrial processing.

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