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Moisture dependent engineering properties of onion (*Allium cepa* var *aggregatum*) umbels

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ABSTRACT

Physical properties of onion (*Allium cepa* var *aggregatum* L.) umbels namely size, shape, bulk density, particle density, angle of repose, frictional properties etc., were determined as a function of moisture content in the moisture range of 10.26 to 50.15% (db). These important physical properties of onion umbels are necessary for the design and development of machines for threshing, cleaning and handling operations of onion umbels. The average length, width and thickness of onion umbels varied from 49.66 to 50.24, 47.20 to 50.20 and 34.89 to 37.69 mm respectively. Average geometric mean diameter of the umbels varied from 43.01 to 46.03 mm while sphericity and mass of hundred umbels (M100) increased from 0.855 to 0.885 and 267.36 to 487.42 g as the moisture content increased in the above range. Bulk density and true density of onion umbels increased from 61.26 to 156.12 and 141.05 to 297.02 kg/m^3 respectively for the above said increase in moisture content. Porosity and angle of repose of umbel increased linearly from 45.95 to 56.55% and 30.83 to 38.13° respectively with increase in moisture content from 10.26 to 50.15%. The coefficient of friction of onion umbels also increased linearly with increase in moisture content of umbels on different surfaces. From the investigation on the physical properties of onion umbels, viz. bulk density, true density, porosity, angle of repose, static coefficient of friction on various surfaces, viz. mild steel, rubber sheet, galvanised-iron sheets, aluminium sheets, cardboard sheets and stainless steel sheets increased linearly with increase in the moisture range between 10.26 to 50.15% (db).

Key words: Angle of repose, Bulk density, Coefficient of friction, Onion umbels, Porosity and True density

Onion (*Allium cepa* var *aggregatum* L.) is an herbaceous plant belongs to Liliaceae family. It is an important commercial horticultural crop used as vegetable and spice all over the world and is rich in sulfur-containing compounds that are responsible for their pungent odours and for many of their health-promoting effects. A wide variety of allyl sulfides and sulfoxides are present in the onion. It is an outstanding source for polyphenols, including the flavonoid quercetin.

In India, onion is the highest foreign exchange earner among fruits and vegetables. It occupies an area of 1.09 Mha, with an annual production of 17.51 Mt. India is the second largest producer (16.10 tonnes/ha) of onion, in the world next to China but the productivity of onion in India is lower than China and other countries like, Egypt, Netherlands and Iran, etc. (Indian Horticulture Database 2011). Today, world per capita onion consumption is estimated as 6.10 kg. It ranks sixth among the world's leading vegetable crops and third in the US (National Onion Association 2011).

Onion is a biennial crop and grows four month to produce seeds. It is a long-day plant. The day length influences bulb of onion, but has little effect on seed setting. It appears to be day-neutral for seed production. It requires cool conditions during early development of the bulb crop and again prior to and during early growth of seed. In the early stages of growth, a good supply of moisture is required and temperatures should be fairly cool. During bulbing development, harvesting and curing of seeds, fairly high temperatures and low humidity is desirable. Seed production is widely adapted to temperate and subtropical regions.

There are two methods of seed production. Seed to seed and bulbs to seed methods and both the methods are in practice for onion seed production. However, bulb to seed method is the most widely followed method for seed production. In the seed to seed method, onion crop is raised using seed and the bulb produced from this crop is continued in the field to bloom and form seed. In the bulb to seed method, the bulbs produced in the previous season are harvested, selected, stored and replanted to produce seeds in the second year. Mostly the bulb to seed method is followed for seed production because it permits selections

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of 'true-to-type' and healthy bulbs for seed production and seed yields are comparatively very high. The seed to seed method, however, can be practiced for varieties having poor keeping quality (Agarwal 2008).

In the case of onion crop, all ear-heads (umbels) do not mature simultaneously. Therefore, matured umbels are harvested, selectively. When seeds inside the capsules become black and 20 to 25% black seeds are exposed, the umbels are cut with 3-5 cm length stalk (stems attached). The umbels are spread on cement concrete floor to avoid attack of mould growth and for uniform drying. This method prevents loss of seeds and mixing of seeds with small stones and soil particles. Umbels are threshed manually by beating with sticks or treading under tractor tyres when the capsules are ready to brittle and break.

Physical properties are essentially required for the design of processing machines for various unit operations such as threshing, cleaning, sorting, handling and packaging. To design equipment for aeration during storage, there is a need to know various physical properties of onion umbels as a function of moisture content (Srivastava *et al.* 1990). The size and shape are important in design of separation and sizing machines. Bulk density, particle density and porosity affect the structural loads and thoroughput, the angle of repose is important in designing of storage and conveying structures. The coefficient of friction of the umbel against various surfaces is also necessary in the design of conveying equipment, power requirements and storage structures. Some of such studies reported include determination of 1000 kernal weight, bulk density, particle density, porosity for makhana (Jha 1999), bulk density, true density, angle of repose, coefficient of friction on metal surfaces, specific heat, thermal diffusivity and conductivity of gorgon nut were determined by Jha and Prasad (1993), mean bean mass, sphericity, bulk density, particle density and porosity of category B cocoa beans as a function of bean moisture content (Bart-Plange and Baryeh 2003), size, 1000 seed weight, true density, bulk density, porosity of locust bean seed (Ogunjimi *et al.* 2002), 1000 seed mass, grain surface area, volume, sphericity, true density, bulk density and porosity of pigeon pea as a function of grain moisture content (Baryeh and Mangope 2003), length, width, height, sphericity, surface area, geometric and arithmetic mean diameters of Iranian pistachio varieties as a function of moisture content (Razavi *et al.* 2007). Size, shape, Bulk density, true density, porosity, angle of repose, specific heat, thermal diffusivity and conductivity of coleus tubers (Chandrasekar *et al.* 2013) are reported for the benefit of researchers and processors.

The objective of this study was to investigate some important moisture-dependent physical properties of onion umbels (otherwise known as small-onion in Tamil Nadu, Kerala, Karnataka and Andhra Pradesh) namely, size, sphericity, mass of 100-umbels, bulk density, true density, porosity, angle of repose, static co- efficient of friction on various surfaces in the moisture content range from 10.26 to 50.15% (db). The data collected in the present investigation will be highly useful for the design of feed hopper and its sloping side, feeding chute size and inclination etc.

MATERIALS AND METHODS

Fully matured, fresh onion umbels were harvested at different dates to have different moisture contents from farmer's fields at J Krishnapuram near Palladam, Thirupur district and Athicombai near Oddanchithram, Dindigul areas of Tamil Nadu, India. The umbels were cleaned manually to remove foreign materials before conducting actual studies. All the physical properties were determined using fresh onion umbels harvested at different dates having moisture contents of 10.26, 13.30, 23.20, 36.41, 46.55 and 50.15% (db), respectively. The initial moisture content of the samples was determined by oven drying at 105°C for 24h (Suthar and Das 1996). After harvest, cleaned onion umbels were dried on cement concrete floor under direct sunlight. All the experiments were replicated thrice at each moisture level and the average values were reported.

At each moisture content, length, width, thickness (major, medium and minor diameters) and mass of randomly selected 200 onion umbels were measured as reported by Mohsenin (1980), Kaleemullah (1992), Deshpande *et al.* (1993), Chandrasekar and Visvanathan (1999). Dimensions were measured using a digital vernier calliper having a least count of 0.10 mm. The geometric mean diameter (Dg) and sphericity (ϕ) of onion umbels were calculated using the following relationships (Mohsenin 1970),

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

$$\phi = \{(LWT)^{1/3}/L\} \quad (2)$$

where, L - length of the onion umbels (mm), W - width of the onion umbels (mm), T - thickness of the onion umbels (mm), and Φ - sphericity (decimal).

The sphericity, ϕ of onion umbels was calculated as reported by Mohsenin (1986) and Gupta and Das (1997) using the following formula,

$$\phi = D_g/L \quad (3)$$

where, Φ - sphericity, decimal. D_g - geometric mean diameter, mm, and L - length of umbels (mm).

Mass of 100-umbels was determined using an electronic balance having a least count of ± 0.001 g and mean values of mass of 100-umbels was determined and reported.

The mean bulk density of the onion umbels was determined by piling known mass of the onion umbels over a flat surface from a height of 100 cm at constant rate. The volume of the cone formed was calculated by measuring the circumference and mean slant height of the cone. The bulk density was calculated from the mass of the onion umbels piled and volume of the cone formed.

$$BD = M/V \quad (4)$$

where, BD = bulk density (kg/m^3), M – mass (kg), and V – volume (m^3).

Porosity of onion umbels is the volume of air space in bulk of the umbels, which is not occupied by the umbels.

Porosity of the onion umbels was determined (Thompson and Isaacs 1967) using multivolume air comparison pycnometer (Micrometrics Instrument Corporation, Model 1305) using the following relationship.

$$\in = \frac{P_2 - P_z}{P_z} \times 100 \quad (5)$$

where, P_1 - Peak pressure after filling air into the sample, (kg/cm^2), P_2 - Pressure after expansion of air in to the sample (kg/cm^2).

True density of onion umbels was determined from the values of bulk density and porosity using the following relationship.

$$\rho_t = \left(\frac{\rho_b}{1-\in}\right) \quad (6)$$

where, ρ_t -True density (kg/m^3), ρ_b - Bulk density (kg/m^3), and $\in$ - Porosity (decimal).

The angle of repose is the angle formed by a heap of onion umbels over a horizontal surface. The cone height was recorded using a movable pointer fixed on a stand having a least count of 1 mm. The diameter D was determined by measuring the circumference of the heap formed. The experiment was replicated thrice for each moisture content and the mean value was recorded. The angle of repose was calculated using the following formula

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad (7)$$

where, θ - angle of repose (degree), H - height of cone (mm), and D - diameter of cone (mm).

Coefficient of friction may be defined as the frictional forces acting between surfaces of contact and sample at rest on it with respect to each other. The apparatus used for the determination of coefficient of friction in the present study consisted of a frictionless pulley fitted on a frame, a bottomless rectangular container, a loading pan and test surfaces. The bottomless container placed on the test surface was filled with onion umbels of known weight and weights were added on the loading pan until the container began to slide. The weight of the onion umbels and the weights added on the pan represent the normal force (N) and lateral force (F), respectively. The coefficient of static friction was calculated as given below.

$$\text{Coefficient of friction } (\mu) = \frac{\text{Lateral force } F(g)}{\text{Normal force } N(g)} \quad (8)$$

The experiment was performed on different test surfaces like card board, galvanised iron, mild steel, stainless steel, rubber sheet and aluminium. Each time, the experiment was conducted with fresh umbels three times and the average value was determined and recorded as the average coefficient of friction.

RESULTS AND DISCUSSION

Dimensions of onion umbels

Average length, width and thickness of the onion umbels varied from 49.66 – 50.24, 47.20-50.20 and 34.89-37.69 mm respectively as the moisture content increased from 10.26 to 50.15 per cent (db). The mean values of length (major diameter), width (medium diameter) and thickness (minor diameter) of onion umbels recorded at different moisture contents were plotted against moisture content and shown in Fig 1 (Table 1). From Fig 1, it is observed that there was no significant difference in the length, whereas width and thickness of onion umbels increased with increasing moisture content. The plots of umbel dimension vs moisture content fit well to linear regression equation. It is observed that a linear relationship exist between moisture contents and umbel dimensions.

Table 1 Umbel dimension

Moisture content (%) (db)	Length (L) (mm)	Breadth (B) (mm)	Thick-ness (T) (mm)	Geometric mean diameter (Dg) (mm)	Spher-icity (ϕ)	Mass of 100-umbels (kg)
10.26	49.66	47.20	34.89	43.38	0.874	264
13.3	49.74	47.70	35.19	43.51	0.875	292
23.2	50.24	48.20	35.69	44.02	0.876	324
36.41	50.99	48.95	36.44	44.77	0.878	374
46.55	51.49	49.45	36.94	45.28	0.879	434
50.15	52.24	50.20	37.69	46.03	0.881	487

A higher value of coefficient of determination indicates the best fit of regression equations to the experimental values as given below. A similar increasing trend was observed for need nut (Visvanathan *et al.* 1996) and hemp seed (Sacilik *et al.* 2003).

$L = 0.0599x + 48.951,\ R^2 = 0.9685$
$B = 0.0656x + 46.672,\ R^2 = 0.9726$
$T = 0.0656x + 34.161,\ R^2 = 0.9726$

where, L - length of onion umbel (mm), B - width of onion umbel (mm), T - thickness of onion umbel (mm), and x - moisture content of onion umbels (%db).

Geometric mean diameter: The mean diameter of the umbels varied from 43.38 to 46.03 mm (Table 1) with increase in moisture content from 10.26 to 50.15 % (db). The plot of geometric mean diameter vs moisture content (db), clearly indicates the presence of linear relationship between moisture content and geometric mean diameter. From Table 1, it is seen that a unit change in the moisture content caused 0.0757 unit change in the geometric mean diameter value. Higher R^2 value of 0.9732 indicates the best fit of regression equation to the experimental values.

$$D_g = 0.0599x+42.475,\ R^2 = 0.9732$$

where, D_g - geometric mean diameter of onion umbel (mm), x - moisture content of onion umbels (%db).

Sphericity: Average sphericity value of onion umbels (Table.1) increased from 0.874 to 0.881 as the moisture content increased from 10.26 to 50.15% (db). This clearly indicates that the onion umbels are nearer to sphere at the time of harvest (fresh), i.e. at 50.15% moisture content (db) and becomes somewhat sphere with flat at both ends after drying to 10.26% moisture content (db). The plot of average sphericity value at the corresponding moisture content showed increased sphericity value with increase in moisture content. The effect of moisture content on sphericity is much less as compared to other dimensions of onion umbels (Fig 1). Similar trends have been reported by Aydin *et al.* (2002) for Turkish mahaleb, Sacilik *et al.* (2003) for hemp seed and Ozarslan (2002) for cotton seed. The relationship between moisture content and sphericity can be represented by the following linear regression equation

$$\phi = 0.0002x + 0.8722, R^2 = 0.9792$$

where, Φ = sphericity of onion umbel (decimal), x = moisture content of onion umbels (%db).

Mass of 100-umbels: The values of mass of hundred umbels (M100) at different moisture levels increased from 264 to 487 g. Similar trend of increase in mass with increased moisture content was reported by Sacilik *et al.* (2003) for hemp, Altuntas *et al.* (2005) for fenugreek, Singh and Goswami (1996) for cumin. Mass of 100-umbels was found to establish a linear relationship of following form with the moisture contentbear the following relationship with the moisture content.

$$M_{100} = 4.966x + 214.28, R^2 = 0.9669$$

where, M_{100} = average mass of 100-umbels, and x = moisture content of onion umbels (%db).

Bulk density and True density: The bulk density (BD) and true density (TD) of onion umbels are listed in the Table 2. From table it is observed that the bulk density and true density increased from 61.26 to 156.12 and 141.05 to 297.02 kg/m^3 respectively, as the moisture content increased from 10.26 to 50.15%, (db) respectively. Bulk density increased by 60% and true density increased around 52% from their initial values. The relationship between bulk density and true density with moisture content is shown in Fig 1. Similar trend in bulk density with moisture content was reported for sheanut kernel (Aviara *et al.* 2000). Similar increasing trend for true density was reported by Yalcýn and Ozarslan (2004) for vetch seed and Aviara *et al.* (2005) for Balanites aegyptiaca nuts. From Fig 1, it is seen that both bulk density and true density, established linear relationship with moisture content of the following form

$$BD = 2.0301x + 49.324, R^2 = 0.9632$$

$$TD = 3.333x + 126.01, R^2 = 0.9522$$

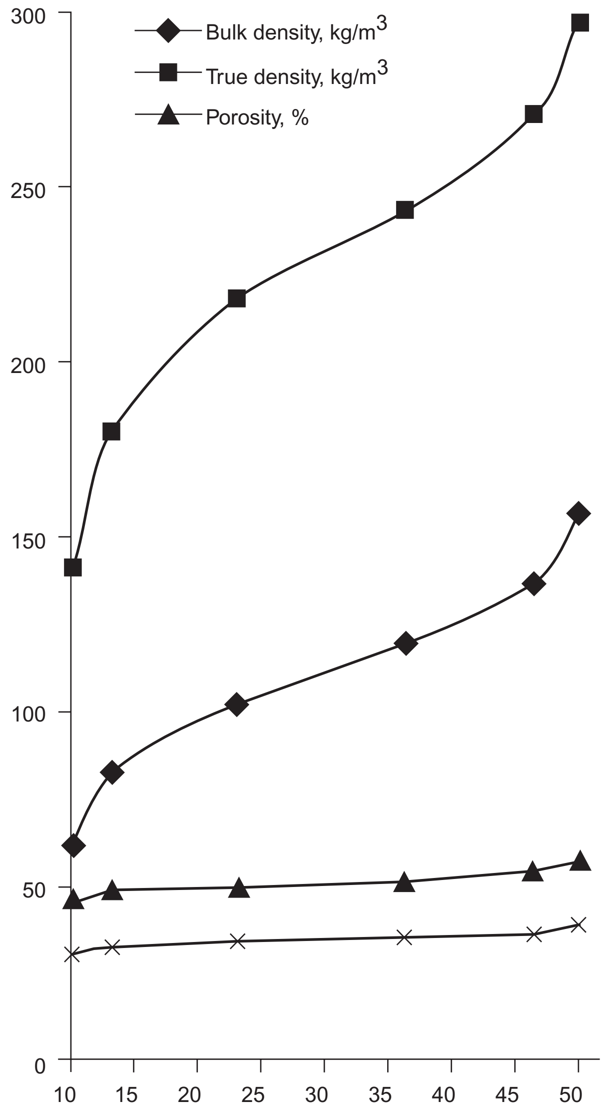

Fig 1 Effect of moisture content on the umbel dimensions

where, BD = bulk density onion umbels (kg/m^3), TD = true density onion umbels (kg/m^3), and x = moisture content of onion umbels (%db).

Porosity of onion umbels: The change in porosity with moisture content of onion umbels is shown in Fig.1. The figure shows that the porosity of the onion umbels increased from 45.95 to 56.55% as the moisture content increased from 10.26 to 50.15% (db). The change in porosity with

Table 2 Mechanical property

Moisture content (%) (db)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	Angle of repose (°)
10.26	61.26	141.05	45.95	30.83
13.30	82.59	180.01	48.40	32.09
23.20	101.69	218.08	49.11	33.81
36.41	118.90	242.95	51.06	35.09
46.55	136.74	270.24	54.37	36.01
50.15	156.12	297.02	56.55	38.12

Table 3 Frictional property

Moisture	Static coefficient of friction on various surfaces					
content% (db)	AL	MS	SS	GI	CB	RS
10.26	0.50	0.31	0.28	0.48	0.50	0.54
13.30	0.54	0.42	0.34	0.52	0.56	0.55
23.20	0.60	0.46	0.43	0.59	0.61	0.60
36.41	0.63	0.58	0.53	0.66	0.67	0.65
46.55	0.65	0.61	0.59	0.72	0.71	0.71
50.15	0.68	0.62	0.65	0.75	0.72	0.76

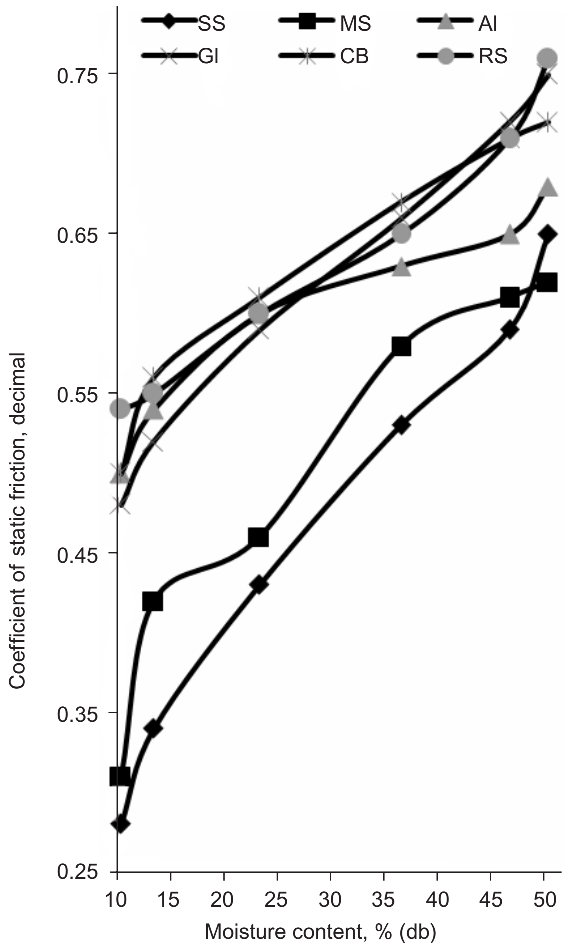

Fig. 2 Coeffiencient of static friction on test surfaces

moisture content is linear and followed a relationship of the form given below. High R^2 value indicates that the regression equation fits well to the experimental results and similar trend was observed in white lupin (Gupta and Das, 1997) and chick pea seeds (Konak *et al*. 2002).

$$\in = 0.0023x + 0.4419, R^2 = 0.9395$$

where, $\in$ = porosity of onion umbels (%), and x = moisture content of onion umbels (%db).

Angle repose of onion umbels: From the experimental data (Table 2), it is observed that the angle of repose of onion umbels increased linearly (from 30.83 to 38.13°) with increase in moisture content from 10.26 to 50.15%. The experimental results of angle of repose with moisture content are shown in Fig 1. The relationship is linear and positive. These results were in accordance with the results of Joshi *et al.* (1993), Gupta and Das (1997) and Sacilik *et al*. (2003) for pumpkin seed, sunflower and hemp seed, respectively. The following equation represents the relationship between angle of repose and moisture content.

$$\Theta = 0.1532x + 29.781, R^2 = 0.9501$$

where, Θ = angle of repose of onion umbels (^{O}), and x = moisture content of onion umbels (%db)

Coefficient of friction: Static coefficient of friction obtained on six different surfaces at different moisture contents in the range of 10.26 to 50.15% (db) is shown in Table 3. When the experimental data were plotted against moisture content (Fig 2), it is observed that the coefficient of friction on different surfaces increased linearly with the increase in the moisture content.

The relation between moisture content and coefficient of friction on various test surfaces is linear. It followed the regression equation of the following forms

$$\mu_{ss} = 0.0085x + 0.2155, \quad R^2 = 0.9858$$
$$\mu_{MS} = 0.007x + 0.2889, \quad R^2 = 0.9245$$
$$\mu_{Al} = 0.0039x + 0.4829, \quad R^2 = 0.936$$
$$\mu_{GI} = 0.0064x + 0.4286, \quad R^2 = 0.9923$$
$$\mu_{CB} = 0.0051x + 0.4766, \quad R^2 = 0.9602$$
$$\mu_{RS} = 0.0051x + 0.4807, \quad R^2 = 0.9763$$

where, $\mu_{ss,}$ $\mu_{MS,}$ μ_{Al}, μ_{GI}, μ_{CB}, μ_{RS} = coefficient of static friction on stainless steel surface, mild steel surface, aluminium surface, galvanized iron surface, cardboard surface, rubber surface respectively, and x = moisture content of onion umbels (%db).

From the results, it is seen that the lowest coefficient of friction (0.28) was observed on stainless steel surface followed by mild steel (0.31). The highest coefficient of friction was recorded on rubber sheet (0.54) at minimum moisture content of 10.26% (db). All regression equations fit well to the experimental values with high R^2 values.

(a) From the investigation on the physical properties of onion umbels (viz.) bulk density, true density, porosity, angle of repose, static coefficient of friction on various surfaces (viz.) mild steel, rubber sheet, galvanised-iron sheets, aluminium sheets, cardboard sheets and stainless steel sheets increased linearly with increase in the moisture range between 10.26 to 50.15% (db).

(b) The coefficient of friction of onion umbels also increased linearly with increase in moisture content of umbels on different surfaces.

REFERENCES

Agarwal R L. 2008. *Seed Technology*. Oxford and IBH Publishing Co (P) Ltd, New Delhi.

Altuntas E, Ozgoz E and Taser O F. 2005. Some physical properties of fenugreek (*Trigonella foenum-graceum L.*) seeds. *Journal of Food Engineering* **71**(1): 37–43.

Aviara N A, Haque M A and Izge I A. 2000. Physical and frictional properties of sheanut. *Agro Science* **1**: 19–34.

Aviara N A, Mamman E and Umar B. 2005. Some physical properties of Balanites aegyptiaca nuts. *Biosystems Engineering* **92**(3): 325–34.

Aydin C, Ogut H and Konak M. 2002. Some physical properties of Turkish Mahaleb. *Biosystems Engineering* **82**(2): 231–4.

Bart- plange A and Baryeh E A. 2003. The physical properties of category B cocoa beans. *Journal of Food Engineering* **60**: 219–27.

Baryeh E A and Mangope B K. 2003. Some physical properties of Qp – 38 variety of pigeonpea. *Journal of Food Engineering* **56**(1): 59–65.

Chandrasekar V and Visvanathan R. 1999. Physical and thermal properties of coffee. *Journal of Agricultural Engineering*

Research **73**: 227–34.

Chandrasekar V. 2013. Moisture dependent physical and thermal properties of coleus tubers. *Journal of Agricultural Engineering* **50**(1): 19–26

Deshpande S D, Bal S and Ojha T P. 1993. Physical properties of soybean. *Journal of Agricultural Engineering Research,* **56**: 89-98.

Gupta R K and Das S K. 1997. Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research* **61**: 1–8.

Indian Horticulture Database, 2011. Government of India. (http://nhb.gov.in)

Jha S N and Prasad S. 1993. Physical and thermal properties of gorgon nut. *Journal of Food Process Engineering* **16**(3): 237–45.

Jha S N. 1999. Physical and hygroscopic properties of makhana. *Journal of Agricultural Engineering Research* **72**(2): 145–50.

Joshi D C, Das S K and Mukherjee R K. 1993. Physical properties of pumpkin seeds. *Journal of Agricultural Engineering Research* **54**: 219–29.

Kaleemulah S. 1992. The effect of moisture content on the physical properties of grount nut kernels. *Tropical Science* **32**: 129–36.

Konak M, Carman K and Aydin C. 2002. Physical properties of chickpea seeds. *Biosystems Engineering* **82**: 73–78.

Mohsenin N N. 1970. *Physical Properties of Plant and Animal Materials*. Gordon and Breach Science Publishers, New York.

Mohsenin N N. 1980. *Physical Properties of Plant and Animal Materials*. Gordon and Breach Science Publishers, New York.

Mohsenin N N. 1986. *Physical Properties of Plant and Animal Materials*. Gordon and Breach Science Publishers, New York.

Ogunjimi L A O, Aviara N A and Aregbesola O A. 2002. Some engineering properties of locust bean seed. *Journal of Food Engineering* **55**: 95–9.

Ozarslan, C. 2002. Physical properties of cotton seed. *Biosystems Engineering* **83**(2): 169–74.

Razavi M A, Emadzadeh B, Rafe A and Mohammed A A. 2007. The physical properties of pistachio nut and its kernel as a function of moisture content and variety, Part I Geometric properties. *Journal of Food Engineering* **81**(1): 209–17.

Sacilik K, Ozturk R and Keskin R. 2003. Some physical properties of hemp seed. *Biosystems Engineering* **86**: 191–8.

Singh K K and Goswami T K. 1996. Physical properties of cumin seed. *Journal of Agricultural Engineering Research* **64**(2): 93–8.

Srivastava A K, Mahoney W T and West N L. 1990. The effect of crop properties on combine performance. ASAE Paper 63–67.

Suthar S H and Das S K. 1996. Some physical properties of karingda (*Citrullus lanatus* Mansf) seeds. *Journal of Agricultural Engineering Research* **65**: 15–22.

Thompson R A and Isaacs G W.1967. Porosity determination of grains and seeds with air comparison pycnometer. *Transactions of ASAE*: 10: 693–6.

Visvanathan R, Palanisamy P T, Gothandapani L and Sreenarayanan V V. 1996. Physical properties of neem nut. *Journal of Agricultural Engineering Research* **63**: 19–26.

Yalcýn I and Ozarslan C. 2004. Physical properties of vetch seed. *Biosystems Engineering* **88**(4): 507–12.

http//www.onions-usa.org (2011).