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Physico-Mechanical Properties of *Prunus nepalensis* Fruit and Seed Using Image Processing and Experimental Method

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Abstract: The physico-mechanical properties of *Prunus nepalensis* fruit and seed were determined at moisture content of 88.50 and 15.62%, respectively. An image processing technique was also used to measure major dimensions and data was compared and correlated with experimental data. Strong correlation was observed between experimental and image processing technique in length and width of both fruit and seed. The true density, bulk density and porosity of fruit were measured as 1077.41, 598.08 kg/m^3 and 43.42%, respectively whereas for seed these values were 1178.84, 508.80 kg/m^3 and 57.94%. The angle of repose of fruit and seed was found to be 26.43 and 22.13°, respectively. The friction coefficient of fruit ranged from 0.421-0.477 whereas that of seed 0.369-0.435. Hardness of fruit was determined as 0.966 kg.

Key words: *Prunus nepalensis*, physical properties, mechanical properties, image processing, width

INTRODUCTION

Prunus nepalensis fruits, belong to family Rosaceae is an important indigenous and nutritionally rich underutilized fruit of North Eastern Region of India and locally known as Sohiong in Khasi (Seal, 2011; Rymbai *et al*., 2011). The pulp of this fruit is dark pink in colour due to its high anthocyanin content. The fruit is rich in β-carotene (257.1 μg) and vitamin C (608.9 mg%), antioxidant and minerals (Agrahar-Murugkar and Subbulakshmi, 2005; Seal, 2011). Tree is medium size to tall, evergreen, attaining a height of 15-20 m. Fruits are drupe, fleshy, dark purple in colour at ripening and green to pinkish colour in beginning stage, stone hard round in shape with smooth surface (Shankar and Synrem, 2012). It blooms during November to March and fruit ripens during August to early October depending on altitudinal variation. It is found in East Khasi hills, West Khasi hills and Jaintia hills (Meghalaya, India) between 1500-2000 m altitude. Fruit is eaten as fresh by local people and fruit juice and pulp are used for preparation of squash, jam, RTS (Ready to Serve) and cheery wine.

Physico-mechanical properties of *P. nepalensis* fruits and seeds are necessary for designing machines and equipments for handling, harvesting, transporting, cleaning, separating, packing, storing and processing. No design is complete without considering these properties (Razavi *et al*., 2010a). Size and shape are important in separation of undesirable materials and in the development of sizing and grading machinery (Kaleemullah and Gunasekar, 2002). For designing of drying and aeration system, bulk density and porosity are considered as these properties affect the resistance to airflow of the stored mass (Bern and Charity, 1975). Bulk density is a basic parameter to predict the structural loads for storage structures and angle of repose is important in designing the equipment for mass flow and structures for storage (Lvin, 1970). The coefficient of friction of the kernels on various surfaces helps in designing bins, silos and other storage structures (Kaleemullah and Gunasekar, 2002).

Determining seed dimensions by slide callipers is tedious and time consuming. A quick, efficient and non-destructive method for determining seed size profiles would greatly benefit processing industries. Machine vision or image analysis can be a faster, non-destructive alternative to the traditional sizing equipment currently used in the grain industry (Shahin and Symons, 2005). Digital image analysis technique has been developed and used by many researchers to determine the physical dimensions of seeds and grains like basil (Razavi *et al*., 2010a), wheat (Shouche *et al*., 2001), rice (Sakai *et al*., 1996), linseed (Keefee, 1999), lentil (Shahin and Symons, 2001), wild sage seed (Razavi *et al*., 2010b), Soybean (Shahin *et al*., 2006) and rapeseed (Tanska *et al*., 2005). Physical dimensions of corn, baby corn, soybean, pigeon pea and paddy seeds have been determined by a flatbed

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scanner and MATLAB Software (The Math Works, Inc., Natick, MA, USA) with higher accuracy (Mandal *et al*., 2012).

To prepare pulp and juice of *P. nepalensis* fruit, equipments needed to be designed and so for other purposes. There is no published literature on physical and mechanical properties of *P. nepalensis* fruits and seeds. Therefore, the objectives of this study were: to determine the physical properties of *P. nepalensis* fruits and seeds such as axial dimensions, projected area, roundness, sphericity, 1,000 grain mass, volume, true and bulk densities, angles of repose, static coefficient of friction against selected surfaces and hardness and to compare the image processing results with the ones measured experimentally.

MATERIALS AND METHODS

Sample preparation: The matured ripen *P. nepalensis* fruits were obtained from market at Shillong, India to determine the physical properties. Half of the fruits were squeezed by hands to extract the seeds and cleaned thoroughly. Seeds were then allowed to dry naturally for 2 days. Moisture content of the fruits and seeds were determined by using standard hot air oven method at 105±5°C for 24 h (Gupta and Das, 1997) which was 88.50 and 15.62% on wet basis.

Measurement of physico-mechanical properties: The length, width and thickness of the fruit were measured by a vernier calliper with an accuracy of 0.02 mm. The average diameter of fruit and seed was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter (D_a), geometric mean diameter (D_g) and sphericity (ϕ) were calculated by using the following relationships (Mohsenin, 1978):

$$D_a = \frac{L+W+T}{3} \quad (1)$$

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

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

Where:
L = The length (mm)
W = The width (mm)
T = The thickness (mm)

Surface area of *P. nepalensis* fruit and seed was found out by the following equation (Mccabe *et al*., 1986):

$$S = \pi D_g^{\ 2} \quad (4)$$

where, S is surface area (mm^2). Unit mass of fruit and seed was determined by a digital electronic balance having accuracy of 0.01 g (Mettler Toledo, Switzerland, PB3002-SDR). Balance is covered with glass walls to avoid any disturbances caused by air in reading. To calculate the mass of 1000 fruit and seed, mass of 50 randomly selected fruit and seed was averaged.

The bulk density was determined by process described by Gupta and Das (1997). A cylindrical container of 500 mL volume was filled with fruit and seed from a height of 150 mm at a constant rate and then weighing the contents by a digital electronic balance with an accuracy of 0.01 g. No manual compaction by tapping or pressing of fruits and seeds was done afterwards. The bulk density was calculated by dividing the mass by the volume of container. The pycnometric method was used to determine the volume and true density of fruits and seeds (Mohsenin, 1978). Toluene was used instead of water because toluene has the advantages of little tendency to soak into fruits and seeds and a low surface tension thus enabling it to flow smoothly over the surface of fruits and seeds (Razavi *et al*., 2010b). The fruits and seeds were used to displace toluene in a measuring cylinder after their masses had been measured (digital electronic balance having an accuracy of 0.01 g, Mettler Toledo, Switzerland, PB3002-SDR). The true volume and true density of seed were determined using the following equation (Mohsenin, 1978):

$$V = \frac{M_{td}}{\rho_t} \quad (5)$$

$$\rho_{fs} = \frac{M_{f,s}}{V} \quad (6)$$

Where:
V = The volume of fruit or seed (m^3)
M_{td} = The mass of displaced toluene by fruit or seed (kg)
ρ_t = The density of toluene (kg/m^3)
$\rho_{f,s}$ and $M_{f,s}$ = The true density (kg/m^3) and mass (kg) of fruit or seed, respectively

The porosity (ε) of *P. nepalensis* fruit and seed was calculated from bulk and true densities using the relationship given by Mohsenin (1978) as follows:

$$\varepsilon = \left(\frac{1-\rho_b}{\rho_{f,s}}\right) \quad (7)$$

where, ρ_b is the bulk density of fruit and seed (kg/m^3). The angle of repose is the property of bulk materials which indicates the cohesion among the individual grain and increases with increasing cohesion. It is the angle from the horizontal at which the material will rest in a pile. This was determined by using a topless and bottomless cylinder of 0.15 m diameter and 0.5 m height. The cylinder was placed at the centre of a circular plate having a diameter of 0.7 m and was filled with *P. nepalensis* fruit or seed. 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 1 mm precision. The angle of repose, θ was calculated using the equation (Kaleemullah and Gunasekar, 2002; Kingsly *et al*., 2006; Pradhan *et al*., 2009; Razavi *et al*., 2010b):

$$\theta = \text{arch}\tan\left(\frac{2H}{D}\right) \tag{8}$$

Where:
H = The height of the cone (m)
D = The diameter of cone (m)

The static coefficient of friction, μ of *P. nepalensis* fruit and seed was determined on three different frictional surfaces, aluminium, galvanized iron sheet and plywood. A tilting platform of 350×250 mm having arrangement of changing angle was fabricated and used for experimentation. An open-ended fibreglass cylinder having 65 mm diameter and 40 mm height was filled with the fruit/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 (α) was read (Fraser *et al*., 1978; Dutta *et al*., 1988; Nimkar *et al*., 2005; Pradhan *et al*., 2009; Razavi *et al*., 2010b). The coefficient of friction was calculated from the following relationship:

$$\mu = \tan\alpha \tag{9}$$

The texture characteristic of *P. nepalensis* fruits in terms of hardness was measured using a Stable Micro System TA-XT2 texture analyzer (Texture Technologies Corp., UK) fitted with a 75 mm flat cutting blade probe. Hardness value was considered as mean peak cutting force and expressed in kgf. The studies were conducted at a pre test speed of 1.0 mm sec^{-1}, test speed of 0.5 mm sec^{-1}, distance of 2 mm and load cell of 50.0 kg (Sirisomboon *et al*., 2000).

Image processing: Some geometrical properties of *P. nepalensis* fruit and seeds were determined using an image processing technique. It consists of a flatbed scanner connected to a computer and MATLAB Software which was described by Mandal *et al*. (2012). An HP scanjet (Hewlett-Packard Model# C7716A) document scanner was used to take images of the fruits and seeds and the images were analysed using the MATLAB 7.8.0 (The Math Works, Inc., Natick, MA, USA) Software. Fruits/seeds were spread over the scanner surface without touching to each other and scanned with highest resolution. Each image was analysed using MATLAB Software. The analysis steps involved reading image, background subtraction, contrast adjustment, thresholding, conversion to binary image, filling holes and determining physical dimensions. The scanned and analyzed images of *P. nepalensis* fruits and seeds are shown in Fig. 1.

The next step in the process was to develop a scale. For this purpose, a coin was scanned and all the dimensions were calculated using the steps discussed above. Dimensions of the coin were also measured physically using a vernier calliper and a scale was developed by dividing the original dimensions by pixel values. This scale was used to determine length, width, perimeter and projected area of the fruits and seeds by multiplying with pixel values. Sphericity and roundness were calculated according to Eq. 8 and 9, respectively (Razavi *et al*., 2010b):

$$\text{Sphericity} = \frac{4\pi A}{p^2} \tag{10}$$

$$\text{Roundness} = \frac{4A}{\pi L^2} \tag{11}$$

Where:
A = The projected area (mm^2)
p = The perimeter (mm) of *P. nepalensis* fruits/seeds

The results of the image analysis were compared to the data obtained by experimental method. Then, the

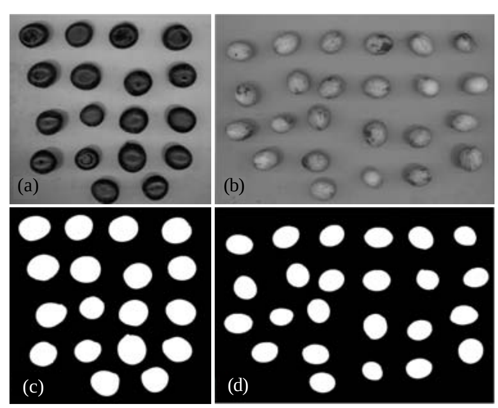

Fig. 1: Scanned images and processed binary images of *Prunus nepalensis* (a, c) fruits and (b, d) seeds

regression relationship and correlation between them (in terms of coefficient of determination, R^2) were determined using SPSS Statistical Software (IBM, Version 20.0.0).

RESULTS AND DISCUSSION

The mean and standard deviation values of all physico-mechanical properties of *P. nepalensis* fruits and seeds measured experimentally and by image processing technique are summarized in Table 1 and 2, respectively.

Table 1: Some physico-mechanical properties of *Prunus nepalensis* fruit at a moisture content of 88.50 (w.b.%)

		Methods			
		Experimental		Image analysis	
Physical properties	No. of obs.	Mean	SD	Mean	SD
Length (mm)	100	19.82	1.090	18.87	1.37
Width (mm)	100	19.53	1.140	17.03	0.88
Thickness (mm)	100	18.20	1.300		
Surface area (mm)^2	100	1156.61	127.920		
Projected area (mm)^2	100	-	-	252.33	26.47
Geometric mean diameter (mm)	100	19.16	1.050		
Arithmetic mean diameter (mm)	100	19.18	1.050		
Sphericity	100	0.97	0.020	0.850	0.03
Roundness	100	-	-	0.904	0.06
Unit mass (g)	100	5.09	0.770		
Mass of 1000 seed (g)	5	5141.14	163.965		
Volume (cc)	10	4.89	1.140		
True density (kg m^{-3})	10	1057.68	29.240		
Bulk density (kg m^{-3})	5	598.08	13.210		
Porosity (%)	5	43.42	2.020		
Angle of repose (°)	5	26.43	2.080		
Static coefficient of friction on aluminium	5	0.421	0.004		
Plywood	5	0.434	0.004		
Galvanized iron	5	0.477	0.012		
Hardness (kg)	9	0.966	0.089		

Table 2: Some physico-mechanical properties of *Prunus nepalensis* seed at a moisture content of 15.62 (w.b.%)

		Methods			
		Experimental		Image analysis	
Physical properties	No. of obs.	Mean	SD	Mean	SD
Length (mm)	50	17.090	1.230	16.570	1.03
Width (mm)	50	14.010	0.970	13.960	0.75
Thickness (mm)	50	13.960	0.810		
Surface area (mm)^2	50	701.170	53.800		
Projected area (mm)^2	50	-	-	180.790	19.97
Geometric mean diameter (mm)	50	14.930	0.570		
Arithmetic mean diameter (mm)	50	15.020	0.580		
Sphericity	50	0.877	0.055	0.601	0.16
Roundness	50	-	-	0.837	0.03
Unit mass (g)	20	1.830	0.510		
Mass of 1000 seed (g)	5	2050.400	183.240		
Volume (cc)	10	1.620	0.420		
True density (kg m^{-3})	10	1178.840	109.250		
Bulk density (kg m^{-3})	10	508.800	13.820		
Porosity (%)	10	57.940	3.410		
Angle of repose (°)	5	22.130	1.470		
Static coefficient of friction on aluminium	5	0.369	0.025		
Plywood	5	0.414	0.004		
Galvanized iron	5	0.435	0.014		

Length of fruit in experimental method ranged from 17.41-22.62 mm with a mean value of 19.82 mm whereas in image analysis it ranged from 15.83-21.20 mm with mean value of 18.87 mm. Length of *P. nepalensis* seed in experimental method was found in the range of 13.70-18.72 mm and mean length was 17.09 mm. By image analysis technique, seed length was found in the range of 14.21-18.24 mm with a mean value of 16.57 mm. Width of *P. nepalensis* fruits and seed ranged from 17.11-22.02 mm with mean value of 19.53 mm and 12.01-17.62 mm with mean of 14.01 mm, respectively in experimental method whereas in image analysis these values were 15.20-18.80 mm with mean value of 17.03 mm and 11.92-15.22 mm with mean of 13.96 mm, respectively for fruit and seed. Regression between image processing and experimental method for length and width of fruit and seed are presented in Table 3. Length of fruit and seed in image processing technique was 4.79 and 3.04% lower, respectively than experimental method. Width of seed was lower by 0.36% in image analysis method; however, width of fruit was lower by 12.80%.

In length and width of fruit, correlation between two methods was 0.943 and 0.805 whereas in seeds these values were 0.941 and 0.936 for length and width, respectively. This shows that there is strong correlation between image processing technique and experimental method for length and width of *P. nepalensis* fruits and seeds. Although, the correlation values were lower than what reported for basil seed (Razavi *et al*., 2010a) and wild sage seeds (Razavi *et al*., 2010b). This may be due to manual error while taking measurement of fruits and seeds with vernier callipers. Thickness of *P. nepalensis* fruit and seed was found in the range of 16.10-21.41 mm with mean of 18.20 and 12.02-17.52 mm with mean of 13.96 mm, respectively.

Arithmetic mean diameter, geometric mean diameter, sphericity and surface area of fruit, calculated using Eq. 1-4 were 19.18, 19.16, 0.97 and 1156.61 mm^2, respectively. In seed, these values were found to be 15.02, 14.93, 0.877 and 701.17 mm^2, respectively. Mean diameter and surface area of *P. nepalensis* fruit was lower than arecanut kernels (Kaleemullah and Gunasekar, 2002) and jatropha fruit (Pradhan *et al*., 2009). Both the fruit and seed of *P. nepalensis* were found spherical as sphericity

Table 3: The relationship between experimental (y, mm) and image processing data (x, mm) determined for length and width of *Prunus nepalensis* fruits and seeds

Dimension	Regression equation	R^2
Fruit length	Y = 1.177x-4.795	0.943
Fruit width	Y = 0.869x-0.427	0.805
Seed length	Y = 1.116x-1.365	0.941
Seed width	Y = 0.911x+1.254	0.936

values were >0.80 and 0.70 (Bal and Mishra, 1988; Dutta *et al*., 1988). Roundness and projected area were determined using image analysis technique and found 0.904 and 252.33 mm^2 of *P. nepalensis* fruit and 0.837 and 180.79 mm^2 of seed, respectively.

Unit mass and volume of *P. nepalensis* fruit ranged between 3.55-7.05 g and 3.6-6.5 cm^3 while that of seed between 0.99-2.25 g and 0.8-2.1 cm^3, respectively. Unit mass and volume of *P. nepalensis* fruit and seed were higher than Faba bean grain (Altuntas and Yildiz, 2007). Average of thousand fruit mass of *P. nepalensis* fruit and seed was found to be 5141.14 and 2050.40 g, respectively. Thousand fruit mass was lower than thousand kernel weight of arecanut (Kaleemullah and Gunasekar, 2002) but higher than jatropha fruit with moisture content of 23.33% dry basis (Pradhan *et al*., 2009), jatropha seed (Garnayak *et al*., 2008), *Moringa oliefera* seed and kernel (Aviara *et al*., 2013) and Faba bean grain (Altuntas and Yildiz, 2007).

Bulk density, true density and porosity of *P. nepalensis* fruit was 598.08, 1057.68 kg/m^3 and 43.42%, respectively. Both bulk density and true density values were lower than arecanut kernels (Kaleemullah and Gunasekar, 2002) with its highest moisture content but higher than pistachio nut and kernels (Galedar *et al*., 2010), jatropha fruit (Pradhan *et al*., 2009) and seed (Garnayak *et al*., 2008). Porosity was found higher than jatropha fruit (Pradhan *et al*., 2009), seed (Garnayak *et al*., 2008), karanja kernel (Pradhan *et al*., 2008) but lower than arecanut kernels (Kaleemullah and Gunasekar, 2002), *Moringa oliefera* seed and kernel (Aviara *et al*., 2013) and Faba bean grain (Altuntas and Yildiz, 2007). Average bulk density of *P. nepalensis* seed (508.80 kg/m^3) was lower than fruit but true density (1178.84 kg/m^3) and porosity (57.94%) were higher which justify its less sphericity than fruit. Bulk density of seed was higher than basil seed (Razavi *et al*., 2010a) but lower than karanja kernels (Pradhan *et al*., 2008) whereas, true density was found higher than basil seed and wild sage seed (Razavi *et al*., 2010b). Porosity of seed was higher than wild sage seed (Razavi *et al*., 2010b) and lower than basil seed (Razavi *et al*., 2010a).

The angle of repose is an indicator of the product's ability to flow. The angle of repose of *P. nepalensis* fruit varied between 23.44-28.68° with mean value of 26.43° which was higher than arecanut kernels (Kaleemullah and Gunasekar, 2002), wild sage seeds (Razavi *et al*., 2010b), basil seeds (Razavi *et al*., 2010a) and Faba bean grain (Altuntas and Yildiz, 2007) but lower than jatropha fruits (Pradhan *et al*., 2009), seeds (Garnayak *et al*., 2008) and karanja kernels (Pradhan *et al*., 2008). Angle of repose of seed was found to vary between 20.15-23.76° with a mean value of 22.13°.

The static coefficient of friction of *P. nepalensis* fruit and seed was obtained experimentally on three surfaces, namely aluminium, plywood and Galvanized Iron (GI) sheet. GI sheet surface had the highest coefficient of friction and it was found that the static coefficient of friction was lowest against aluminium with both fruit and seed. This was due to the smoother and polished surface of aluminium sheet compared to other sheets used. Fruit had higher friction than seed due to higher moisture content. Friction coefficient of *P. nepalensis* fruit and seed was lesser than arecanut kernels (Kaleemullah and Gunasekar, 2002), jatropha seeds (Garnayak *et al*., 2008), hemp seed (Sacilik *et al*., 2003), karanja kernels (Pradhan *et al*., 2008), fenugreek seed (Altuntas *et al*., 2005) and jatropha fruit (Pradhan *et al*., 2009) but higher than kidney bean (Esref and Halil, 2007). The hardness of *P. nepalensis* fruit was found to vary between 0.879-1.184 kg with a mean value of 0.966 kg which was lower than basil seed (Razavi *et al*., 2010a), wild sage seed (Razavi *et al*., 2010b) and pomegranate seed (Kingsly *et al*., 2006).

CONCLUSION

There was strong correlation between image processing technique and experimental method for length and width of *P. nepalensis* fruits and seeds. The length of fruit and seed in image processing technique was lower by 4.79 and 3.04% whereas width was lower by 12.80 and 0.36%, respectively than experimental method.

The average thickness, geometric mean diameter, arithmetic mean diameter and surface area of fruit and seed determined experimentally were 18.20, 19.16, 19.18 mm, 1156.61 mm^2 and 13.96, 14.93, 15.02 mm, 701.17 mm^2, respectively. The seed was less spherical than the fruit. The average unit mass, 1,000 grain mass, volume, true density, bulk density and porosity were measured as 5.09 and 5141.14 g, 4.89 cm^3; 1057.68, 598.08 kg/m^3 and 43.42%, respectively whereas for seed these values were 1.83 and 2050.40 g, 1.62 cm^3, 1178.84, 508.80 kg/m^3 and 57.94%.

The angle of repose of fruit and seed was found to be 26.43 and 22.13°, respectively. GI sheet surface had the highest coefficient of friction and it was found that the static coefficient of friction was lowest against aluminium with both fruit and seed. Fruit had higher friction than seed due to higher moisture content. Hardness of fruit was found as 0.966 kg.

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