Characterisation of *Madhuca longifolia* seed in relation to processing and design of equipment

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RESEARCH ARTICLE

Abstract

Madhuca longifolia, commonly known as mahua, is an important crop due to its industrial uses and applications of its flower, fruit and seed. The characterisation of mahua seeds is essential for its further processing as well as for the design of post-harvest equipment. Therefore, the aim of the study was to characterise the mahua seed in terms of its physical, mechanical and chemical properties. The physical properties, namely principal dimensions, aspect ratio, sphericity, angle of repose, surface area, densities and frictional properties were determined. Various mechanical properties, which include hardness, deformation at rupture, percentage deformation at rupture, fracturability, 1st fracture at deformation and energy for fracture of the seed were also investigated. The chemical composition such as moisture, protein, oil, carbohydrates and ash content were determined. In this study, it was found that the mean major, intermediate and minor dimensions were 3.04, 1.6 and 1.3 cm at 9.4% (w.b.) moisture content, respectively. The bulk density and true density of the seeds were found to be 381 and 1,481.54 kg/m^3, respectively, and the corresponding porosity was 73.96%. Other physical properties were also determined, and their importance is highlighted in the paper. Results show that the average hardness was 40.55 N/mm. The average energy requirement for fracture of the mahua seed was 177.57 N-mm. It was also found that mahua seed contains 40.37%, (w/w) oil and 33.63% protein. These results are very important for designing of post-harvest processing equipment especially in mahua seed decorticator/dehuller and also required for further processing and value addition of these seeds.

Keywords: mahua seed, moisture content, density, hardness

1. Introduction

Madhuca longifolia (mahua) belongs to the family *Sapotaceae*. It is widely available in central and north Indian plains. It is also found in Sri Lanka and Myanmar (Sunita and Sarojini, 2013; Yadav *et al.*, 2012). It is a large sized deciduous tree and grows about 20 m in height and possesses evergreen or semi-evergreen foliage. The tree is found throughout the green forest of India. The tree has spiritual and artistic importance in the tribal culture. It is an important crop due to its industrial uses of its flower, fruit and seed. Leaves are 10 to 30 cm in length and contain glucoside, glycoside, organic compound and sapogenin. Mahua flowers are pale yellow in colour and are a rich source of sugar and free fatty acids. Mahua flower produce mahua seed with a production rate of 181 thousand metric tonnes in India (Jha and Vaibhav, 2013). The seed contain around 33-43% of oil (Ghadge and Raheman, 2005). Mahua oil esters used as a potential substitute for diesel fuel (Puhan *et al.*, 2005). Mahua contains many pharmacological benefits and potential to supply several benefits to the people. These seeds and flowers are used as antidiabetic, internal organ protecting, anti-pyretic, antiulcer, anti-fertility, analgesic, anti-oxidant, emetic, swelling, piles, inflammation, wound healing and anti-headache (Patel *et al.*, 2011, 2012).

Many researchers studied the basic physical, mechanical and chemical composition of agricultural materials and mentioned the potential applications in equipment and process design. Many scientific developments have already occurred to improvise the processing conditions of agricultural material through various mechanical, thermal, electrical and optical techniques, but the basic physical and mechanical characteristics of any agricultural materials play a significant role for its initial processing, machine designing, etc. This characterisation knowledge is essential for the food scientists, processor, plant breeders and engineers (Patel *et al.*, 2011; Pradhan *et al.*, 2009). The physical, mechanical and chemical properties are reported by many researchers/scientists for various type of seeds i.e. mahua flower (Patel *et al.*, 2011), simarouba (Dash *et al.*, 2008), jatropha (Karaj and Müller, 2010), flax seed (Pradhan *et al.*, 2010) and pine nut (Özgüven and Vursavuş, 2005). However, there is no information available on characterisation of mahua seed in relation to its processing and machine designing.

The knowledge of engineering properties of mahua seed is necessary for design and development of the processing technology Figure 1 and post-harvest process equipment for cleaning, grading, sorting and decortication/deshelling (Sahoo *et al.*, 2009). Hence, the research was focused on characterisation of mahua seed in terms of its physical, mechanical and chemical composition for development of process technology.

2. Materials and methods

Mahua seeds were collected from Rourkela (22.26° N, 84.85° E), Odisha, India. These seeds were cleaned and separated from the dust, stone, immature and infected seeds. The cleaned samples were stored in aluminium containers at room temperature until use.

For determination of the physical properties, 100 samples were selected randomly to conduct various experiments. The principal dimensions such as major, intermediate and minor dimensions were determined with the help of a digital vernier calliper (Mitutoyo, Kawasaki, Japan) with an accuracy of ±0.01 mm (Figure 1).

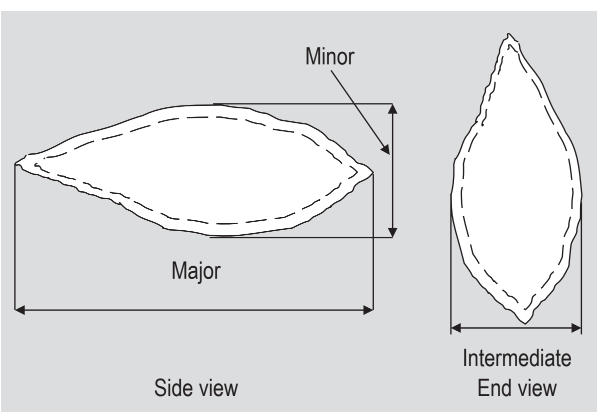

Figure 1. Schematic representation of three major principal dimensions of mahua seed (the dotted lines represent the kernel inside the seed).

The seed dimension was taken to be an essential parameter for some unit operation. Hence, each seed sample was grouped into three categories i.e. large, medium and small dimensional based on their major dimensions (Kaleemullah and Gunasekar, 2002). The seeds were divided on the basis of size for determination of the mean dimension ($\bar{L}$) and the related standard deviation (σ_L). Then, as per the Equation 1-3, size distributions such as small, medium and large seeds were categorised (Pradhan *et al.*, 2010).

Small size group: $L < \bar{L} - \sigma_L$ (1)

Medium size group: $\bar{L} - \sigma_L < L > \bar{L} + \sigma_L$ (2)

Large size group: $L > \bar{L} + \sigma_L$ (3)

Using Equation 4 and Equation 5, the arithmetic mean diameter (A_m) and geometric mean diameter (G_m) of the mahua seeds were determined (Sirisomboon *et al.*, 2007):

$$A_m = (a + b + c) / 3 \quad (4)$$

$$G_m = (abc)^{(0.333)} \quad (5)$$

The values of sphericity, (ϕ) and aspect ratio (R_a) of mahua seeds were determined by the Equations 6 and 7 (Kaptso *et al.*, 2008; Owolarafe and Shotonde, 2004):

$$\phi = ((abc)^{(0.333)}) / a \quad (6)$$

$$R_a = (b/a) \times 100 \quad (7)$$

Where, a is the major, b is the intermediate and c is the minor dimension.

The test weight in term of one thousand seed mass was evaluated by using a digital electronic balance reading to an accuracy of 0.001 g (Wensar analytical balance; Wensar Weighing Scales Limited, Chennai, India). The surface area of mahua seed was evaluated by following equation (Sirisomboon *et al.*, 2007):

$$S = \pi G_m^2 \quad (8)$$

Where, S is the surface area, cm^2 and G_m is the geometric mean diameter.

The bulk density (kg/m^3) for mahua seed samples were determined by the method described by Özgüven and Vursavuş (2005). Similarly, the true density, i.e. the ratio between the mass and the true volume of the bulk material, was recorded as per the method described by Dash *et al.*(2008) and Sirisomboon *et al.* (2007). Porosity (%) was evaluated from values of bulk and true densities of bulk samples. It was calculated by following equation (Davies, 2009):

$$\epsilon = (1 - (\rho_b / \rho_t)) \times 100 \quad (9)$$

Where, ε is the porosity (%), p_b is the bulk density (kg/m^3) and p_t is the true density (kg/m^3). The results of bulk density, true density and porosity are average of 10 replications.

An angle measurement apparatus was fabricated to measure the angle of repose of the seeds. The seeds were free fall from a height of 15 cm to a circular plate of 22 cm diameter, which form a natural heap of seeds sample. The angle of repose was then recorded from the diameter and height of the heap using the following relationship (Mwithiga and Sifuna, 2006):

$$\theta = \tan^{-1}(2H/D) \quad (10)$$

Where, H is the heap height of seeds (cm), and D is the circular plate diameter of the apparatus (cm). The average angle of repose value is reported from 10 replications.

For the post-harvest processing of the seeds, various structural surfaces such as plastic, glass, plywood and galvanised iron sheet are used throughout the industries. Hence, these materials were taken to determine the coefficient of friction of mahua seed. The surfaces were joined to a tilting table. This table had a dimensions of 50 cm long, 30 cm wide and 60 cm height. It was loaded with seeds and levelled. With the help of a manual handle, tilting of the surface was done. With the help of an angle metre (attached to the tilting surface), the angle at which sample began to slide down the surface was noted. It was determined as tangent (α) angle. The coefficient of friction was calculated as follows (Altuntaş and Yıldız, 2007; Shirkole *et al.*, 2011):

$$\mu = \tan \alpha \quad (11)$$

Where, μ is the coefficient of friction, and α is the angle of tilt (degree).

For the design of any post-harvest equipment, mechanical properties of those agricultural materials are essential parameters for development of the machine. Mechanical properties namely hardness, deformation at rupture, percentage deformation at rupture, fracturability and first fracture at deformation were evaluated by puncture test using a texture analyser (Brookfield CT3; AMETEK Brookfield, Middleboro, MA, USA). For each experiment single seed was used and 10 replications were conducted for each test. The puncture test was carried out using texture analyser. Each sample was aligned horizontally from stem end to the apex on the platform. A square flat aluminium plate (88 mm by 100 mm by 12.5 mm) was used to puncture the sample at the deformation speed of 0.5 mm/s. TA44 cylinder probe (4 mm diameter) was used for all the experiment. The load cell was 10 kg. The hardness, deformation at hardness, percentage deformation at rupture, fracturability, 1st fracture at deformation were evaluated by texture analyser software (TexturePro CT; AMETEK Brookfield). Hardness is the ratio of rupture force to deformation at rupture point. Deformation at rupture is the deformation when the seed is completely broken down. Deformation at rupture percentage is the percentage deformation at rupture. Fracturability is the minimum force required to break the sample. 1st fracture at deformation is the first deformation at fracture of the sample. Energy for fracture is the energy needed to fracture the sample, which could be determined from the area under the curve between the initial point and the fracture point (Karaj and Müller, 2010; Manuwa and Muhammad, 2011; Ghosh *et al.*, 2017; Sirisomboon *et al.*, 2007; Swain and Gupta, 2013; Vursavuş and Özgüven, 2005).

The proximate composition such as moisture, oil, protein, carbohydrates and ash were determined by standard methods as recommended by AOAC International (William and George, 2000).

The sample was grounded to a fine powder by using home mixer for conducting the experiments. To determine the moisture content, 10 g of sample was taken and kept in hot air oven (hot air oven; Universal, New Delhi, India) at 103±2° C for 24 h (Sacilik *et al.*, 2003). The nitrogen content was measured by Kjeldahl method (Kjeldahl unit; Pelican Equipment, Chennai, India) using 1 g of sample. The amount of protein in the sample was evaluated by multiplying total nitrogen and a factor of 6.25 (Akinhanmi *et al.*, 2008).

Moisture free sample was taken to extract the oil. 10 g of sample was taken into cellulose thimble (26×60 mm) and transfer into Socs plus equipment (Pelican Equipment). The oil content was determined by using n-hexane at 60 °C (Abdulkarim *et al.*, 2005; Shashi Kumar *et al.*, 2016). Ash content was determined by incineration of 3 g of sample in muffle furnace method maintained at 550° C for 5 h (William and George, 2000). The total carbohydrates were determined by difference (Gharibzahedi *et al.*, 2013).

All the experiments were done in triplicates and the mean and standard deviations were calculated. All the statistical analysis was carried out to determine the level of significance by Microsoft Excel 2013 (Microsoft, Redmond, WA, USA).

Results and discussion

Mahua seeds are presented into three unequal semi-axes and dimensions are reported. Table 1 shows the major dimension of the mahua seed (ungraded), varied from 2.5 to 3.8 cm with the average value of 3.04±0.24 cm. From Table 1, it was observed that around 85% of the seeds were of medium size with length ranging from 2.07 to 1.72 cm, while about 7% and 18% of the seeds were large size (a > 2.07 cm) and small size (a < 1.77 cm), respectively.

The frequency distribution curve of mahua seeds are shown in Figure 2. It was observed that maximum numbers of seeds are under medium size group (2.8-3.2 cm major dimension). The average intermediate and minor dimensions were found be 1.6 and 1.3 cm, respectively (Table 1). Similar results for longitudinal dimensions of other seeds such as caper seed (Dursun and Dursun, 2005), chickpea (Ghadge *et al.*, 2008) and jatropha fruit (Pradhan *et al.*, 2009) were reported. The usefulness of these principal dimensions is highlighted by various scientists for the design of different types sieves, components of the machine and other processing conditions.

Table 1. Categorisation on size (± standard deviation) of mahua seeds at moisture content of 9.40% (w.b.).

Particulars	Size category: Ungraded	Large	Medium	Small
Major dimension of the seeds (cm)	2.5-3.8	>2.07	2.07-1.72	<1.77
% of seeds	100	7	85	18
Average dimensions				
Major (a) (cm)	3.04±0.24	3.07±0.27	3.01±0.24	3.04±0.24
Intermediate (b) (cm)	1.60±0.12	1.64±0.12	1.60±0.12	1.54±0.12
Minor (c) (cm)	1.30±0.17	1.44±0.17	1.38±0.17	1.38±0.16
Arithmetic mean diameter (cm)	2.01±0.12	2.05±0.14	2.01±0.12	1.91±0.12
Geometric mean diameter (cm)	1.81±0.03	1.93±0.13	1.89±0.12	1.88±0.12

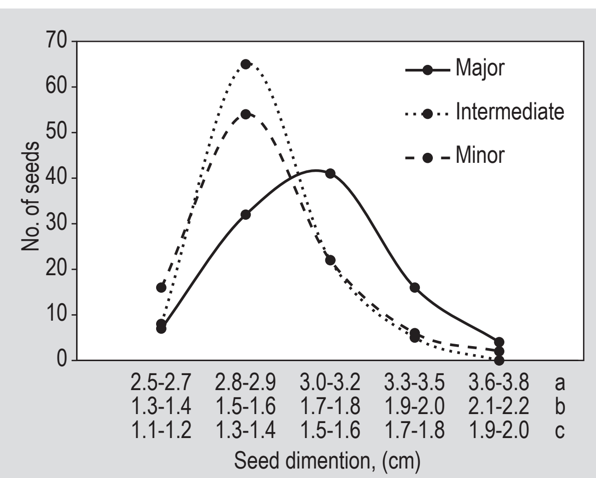

Figure 2. Frequency distribution curve of mahua seed dimension at 9.4% moisture content (w.b.).

Table 2 shows that a/b ratio exhibited the highest value followed by a/G_m and a/c ratio. It is also observed that all correlations between the ratios of measured dimensions were found significant based on the coefficients of correlation (r) values. This is due to the fact that the major dimension of the seed is positively related to its minor, intermediate dimensions and geometric mean diameter. These ratios are helps to check the relationship among the dimension of seeds. The importance of these ratios will be helpful in designing various sieves, separating and grading devices. From the results, one can conclude that the length of the seed is positively related to its width, thickness and geometric mean diameter. The relationship between major, intermediate and minor dimensions of mahua seed can be described by the following general expression:

$$a = 1.9b = 2.33c \quad (12)$$

Some other physical properties of mahua seeds are reported in Table 3. Result shows that the sphericity value of the seed found is to be 0.60 and aspect ratio was 53.11%. These values are lower than the jatropha seed (Karaj and Müller, 2010), simarouba (Dash *et al.*, 2008) and *Thevetia peruviana* (Sahoo *et al.*, 2009). Researcher reported that seeds are spherical in shape when the sphericity value is >0.70. In this research mahua seed were treated as flat ellipsoid shaped seed. It helps in prediction of drying behaviour (Garnayak *et al.*, 2008; Sirisomboon *et al.*, 2007). Surface area and 1000 seed mass found to be 10.40±0.42 cm^2 and 1,697.5±145.38 g, respectively (Table 3). These values are higher than the ground nut (Davies, 2009) and tung seeds

Table 2. Correlation between dimensions of mahua seed at 9.40% (w.b.) moisture content.[1]

Particulars	Ratio	Degree of freedom	Correlation of coefficient	*P*-value
a/b	1.90	99	0.670	<0.001
a/c	2.33	99	0.393	<0.001
a/G_m	1.67	99	0.614	<0.001
b/c	1.23	99	-0.153	<0.001
b/G_m	0.88	99	-0.475	<0.001
c/G_m	0.71	99	-0.096	<0.001

[1] G_m = geometric mean diameter; a = major dimension; b = intermediate dimension; c = minor dimension.

Table 3. Physical properties of mahua seeds at 9.40% (w.b.) moisture content.

Properties	N[1]	Mean	Maximum	Minimum	Standard deviation
Sphericity	100	0.60	0.71	0.49	0.03
Aspect ratio (%)	100	53.11	74.07	40.62	5.85
Surface area (cm^2)	100	10.40	11.81	9.66	0.42
1000 seed mass (g)	10	1,697.5	1,850	1,464	145.38
Bulk density (kg/m^3)	10	381	420	340	23.78
True density (kg/m^3)	10	1,481.54	1,833.33	1,250	169.06
Porosity (%)	10	73.96	80.36	69.9	3.37
Angle of repose (°)	10	38.70	45	30	2.14
Coefficient of friction					
Galvanised iron sheet	10	0.47	0.53	0.42	0.03
Ply wood	10	0.44	0.46	0.40	0.01
Glass sheet	10	0.40	0.44	0.34	0.03
Plastic sheet	10	0.52	0.57	0.48	0.02

[1] N = number of samples.

(Sharma *et al.*, 2011). These results are used in grading and separation process to separate the foreign and unwanted materials from sample. Also used in design of storage structure, bins and silos (Shirkole *et al.*, 2011; Vursavuş and Özgüven, 2005).

The bulk density and the true density are calculated as 381±23.78 and 1,481.54±169.09 kg/m^3. These values are lower than the groundnut kernel (Olajide and Igbeka, 2003) and pine nuts (Özgüven and Vursavuş, 2005). The lower value of bulk density for mahua seed may be due to its larger in size. The corresponding porosity was 73.96±3.37%. It was higher than the *Thevetia peruviana* seed (Sahoo *et al.*, 2009) and sorghum seeds (Mwithiga and Sifuna, 2006). These properties are helps to determine the resistance to airflow during aeration and drying process.

The average angle of repose was 38.7±2.14°. It was higher than lentil seed (Amin *et al.*, 2004) and caster seed (Taghi Gharibzahedi *et al.*, 2011). Due to the flat shape of the mahua seed, the angle was bigger as compared to other seeds. The coefficient of friction for mahua seed was determined with four different surfaces (plywood, glass, plastic and galvanised iron sheet) as shown in Table 3. It was observed that the coefficient of friction was highest (0.52) for plastic sheet and lowest (0.44) for glass sheet among all other contacting materials. Researcher reported that coefficient friction was high in plastic sheet in different studies (Sahoo *et al.*, 2009; Sharma *et al.*, 2011). For design of storage bins, hoppers, pneumatic conveying system, screw conveyors, forage harvesters, decorticator, sheller, dehuller and threshers, the values these properties are essential (Pradhan *et al.*, 2010; Sahay and Singh, 2004).

Table 4 shows the mechanical properties of mahua seed at 9.4% (w.b.) moisture content. Results show that the hardness of the seed was 40.55±1.73 N/mm. It was higher than the jatropha seed (Karaj and Müller, 2010) and lesser than apricot pit (Vursavuş and Özgüven, 2004). The mean value of deformation at hardness and percentage deformation at rupture was 3.97 mm and 32.92%. It was lower than the barberry seed and higher than sal seed (Fathollahzadeh and Rajabipour, 2008; Shashi Kumar *et al.*, 2016). The fracturability of mahua seed was 27.94 N at 2.04 mm distance. It was lesser than the cashew nut (Swain and Gupta, 2013) and hazelnut (Güner *et al.*, 2003). The energy required for fracture was 177.57±1.99 mm. It was lower than the pistachio nut (Galedar *et al.*, 2009) and higher than

Table 4. Mechanical properties of mahua seed at 9.40% (w.b.) moisture content.[1]

Properties	Mean	Max	Min	Standard deviation
Hardness (N/mm)	40.55	42.12	38.69	1.73
Deformation at rupture (mm)	3.97	4.41	3.35	0.55
Percentage deformation at rupture (%)	32.92	33.7	31.85	0.96
Fracturability (N)	27.94	28.4	27.46	0.47
1^{st} fracture at deformation (mm)	2.04	2.69	1.41	0.64
Energy required for fracture (N-mm)	177.57	179.3	175.4	1.99

[1] Each value was average of ten samples.

the jatropha seeds (Karaj and Müller, 2010) and sal seed (Shashi Kumar *et al.*, 2016). The hardness, fracturability and energy required for fracture for mahua seed is less than other seeds such as apricot pit, pistachio nut. It indicates that mahua seed is easy to decorticate/dehulling. Maximum and minimum values of mechanical properties were also reported. These properties play an important role in design the various seed decorticator/dehuller.

Chemical properties of mahua seeds were analysed and results were reported in Table 5. The mean moisture content of mahua seed was 9.40±1.19% (w.b.). The mean protein content was 33.63±0.11%. The mean oil content of mahua seeds was 40.37±2.7%. The mean carbohydrates and ash content was 14.17±0.89 and 2.43±0.42%, respectively. The oil content of mahua seed is comparable to other seeds such as jatropha, *Moringa oleifera* seed and sal seed (Abdulkarim *et al.*, 2005; Garnayak *et al.*, 2008; Shashi Kumar *et al.*, 2016). This value of oil is an indication that mahua seed oil is a good source of oil. It can be used for food and non-food industries for the production of various products. Researcher reported that an ash content of 1.5 to 2.5% for nut has been recommended for suitable for animal feeds (Akintade and Bratte, 2015). The values of protein, carbohydrate and ash content was lesser than the *M. oleifera* seed and sal seed (Abdulkarim *et al.*, 2005; Shashi Kumar *et al.*, 2016). According to chemical analysis mahua seed is a good source of oil and protein. It can be used for alternative source of edible oil and protein. These chemical properties of mahua seed are very important in the development of new food and non-food products.

Conclusions

Mahua seed is one of the important tree born oil seed. It is mainly processed for extraction of its oil. In this research, characterisation of the seed in term of physical, mechanical and chemical properties were done. The result obtained from this study showed that the average principal dimensions such as major, intermediate and minor are 3.04, 1.6 and 1.3 cm, respectively. The mean value of aspect ratio is 53.11% and sphericity is 0.60 for mahua seed. From the result, it is concluded that the shape of the mahua seed is flat ellipsoid. Other physical properties such as 1000 seed mass, bulk density, true density, porosity, angle of repose and coefficient of friction on different surface were determined. The results show that the hardness of the seed was 40.55 N/mm at 3.97 mm distance. It helps in dehulling/decortication of seeds and other mechanical properties of mahua seed were determined. The average seed moisture was 9.4% (w.b.). It helps in the storage stability and dehulling processes. It was observed that mahua seed contains 40.37% oil (w/w). The high percentage of oil makes this mahua seed a distinct potential for the oil industry and other non-food industries. The knowledge about this species and these scientific data on properties can be useful for its processing operations, equipment development, handling of mahua seeds and further industrial processing.

Table 5. Composition of mahua seed at 9.4% (w.b.) moisture content.[1]

Properties	Mean ± standard deviation (%)
Moisture	9.40±1.19
Protein	33.63±0.11
Oil	40.37±2.70
Carbohydrates	14.17±0.89
Ash	2.43±0.42

[1] Each value was average of three samples.

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