The Pharma Innovation Journal 2022; 11(11): 624-630

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(11): 624-630

www.thepharmajournal.com
Received: 21-08-2022
Accepted: 27-09-2022

Sahu FM
Centre of Excellence on Post Harvest Technology, Navsari Agricultural University, Navsari, Gujarat, India

Suthar SH
Department of Processing and Food Engineering, CAET, Navsari Agricultural University, Dediapada, Gujarat, India

Sharma VK
Department of Agricultural Engineering, College of Agriculture, Navsari Agricultural University, Waghai, Gujarat, India

Shrivastava A
Department of Statistics, NM College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India

Corresponding Author:
Sahu FM
Centre of Excellence on Post Harvest Technology, Navsari Agricultural University, Navsari, Gujarat, India

Moisture dependent physical properties of Mahua seed (*Madhuca longifolia*)

Sahu FM, Suthar SH, Sharma VK and Shrivastava A

Abstract
The study was conducted to investigate some moisture-dependent physical properties of mahua seed namely, seed dimensions, thousand seed mass, sphericity, bulk density, true density, porosity, angle of repose and static coefficient of friction against different materials. The physical properties of mahua seed were evaluated as a function of moisture content in the range of 9 –18% (d.b.). The average length, width, thickness and 1000 seed mass were 29.80mm, 16.65mm, 1.34mm and 1954 g, respectively at moisture content of 9% d.b. The geometric mean diameter and sphericity increased from 18.77 to 19.17 mm and 0.63 to 0.64 as moisture content increased from 9 to 18% d.b., respectively. In the same moisture range, bulk densities of the rewetted mahua seed increased from 443.4 to 646.8 kg/m^3, true density increased from 635.6 to 973.2 kg/m^3, and the corresponding porosity increased from 30.24 to 33.54%. As the moisture content increased from 9 to 18% d.b., the angle of repose and the statics coefficient of friction against mild steel and plywood were increased from 35° to 41° and 0.413 to 0.457 and 0.365 to 0.392 respectively.

Keywords: Mahua, moisture content, physical properties, porosity, sphericity

1. Introduction

Mahua (*Madhuca longifolia*) a tree of Indian origin, belonging to family *Sapotaceae* is also known as the Indian butter tree. Mahua seed is an important tree- borne oilseed (TBO) and Non-timber forest produce (NTFP) valued for its high content (33-61%) of pale yellow semi -solid natural hard fat commercially known as mahua butter (Singh, 1998; Ghadge and Raheman, 2005) [23, 7]. The seeds are collected/harvested with the beginning of rainy season in month of June to July with an annual production of 1.81 Million metric tonnes of fruit in India covering the states of Jharkhand, Chhattisgarh, Odisha and further west towards Madhya Pradesh, Maharashtra, and Gujarat. Kernel is about 70% by weight of the mahua seeds. This makes it one of the most important tree seed oil source in tribal area of India (Jha and Vaibhav, 2013) [9]. The physical properties of mahua seed, like those of other seeds and grains are essential for design of equipment used for their handling, storing and processing. Knowledge of physical properties of agricultural materials and their dependence on the moisture content constitute important in the design of machines, structures, processes and controls in analyzing and determining the efficiency of a machine or an operation in developing new consumer products and in evaluating and retaining the quality of the final product. Such basic information should be of value not only to engineers but also to food scientists and processors who may exploit these properties and find new uses (Mohsenin 1986) [13]. To design a machine for handling, cleaning, conveying, decorticating, storing and milling, the physical properties of mahua seed at different moisture contents must be known. Size and shape are most often used when describing seeds, grains, fruits and vegetables. Quality differences in fruits, vegetables, grains and seeds can often be detected by differences in density. When seed are transported hydraulically, the design fluid velocities are related to both density and shape. Porosity, which is the percentage of air space in particulate solids, affects the resistance to air flow through bulk solids. Knowledge of frictional properties is needed for design of handling equipment.

Many researchers have conducted experiments to find the physical properties of various fruits and nuts. Kashaninejad and Tabil (2006) [12] determined some physical and aerodynamic properties of pistachio nut and its kernel as a function of moisture content in order to design processing equipment and facilities. Reddy et al. (2004) [17] obtained some physical properties of sapota. The knowledge of physical properties properties of mahua seed is necessary for design and development of the processing technology and post-harvest process equipment for cleaning, grading, sorting and decortication/deshelling (Sahoo et al., 2009) [19].

Though the information on physical properties for many food grains is available, the information of these properties for mahua seed at various moisture levels is lacking and hence this study was undertaken for determination of moisture dependent physical properties of mahua seed.

2. Material and Methods

Mahua seeds were procured from dediapada region of Gujarat, India for the study. The sample was cleaned manually to remove all foreign materials such as dust, dirt, small branches and immature seeds. The cleaned and graded mahua seeds were sun dried and the initial moisture content of seed was determined by using the standard hot air oven method at 105 ± 1 °C for 24 h (Brusewitz, 1975; Gupta and Das, 1997; Ozarslan, 2002; Altuntases *et al.* 2005; Coskun *et al.* 2005) [3, 8, 15, 2, 4]. The initial moisture content of the fresh seed and dried seed were 138% and 8% d.b., respectively. Seeds became non-viable when desiccated below 9.4% moisture content in natural drying conditions (Varghese *et al.* 2002) [26]. Physical properties for mahua seed were investigated in the simulated moisture content range of 9–18% (db), since harvesting, transportation, storage and dehulling operations of mahua seed are performed in this range.

Samples were moistened with a calculated quantity of water by using the following equation (1) (AACC 2000; Coskun *et al.* 2005) [1, 4] and conditioned to raise their moisture content to the desired four different levels of 9, 12, 15 and 18% (d.b.).

$$Q = W_i\left(\frac{m_f - m_i}{100 - m_f}\right) \quad \text{…(1)}$$

Where, Q is the weight of water to be added (g); W is the initial weight of mahua seed sample (g); m_i is the initial moisture content of grain sample (% db) and f_i is the final moisture content of mahua seed sample (% db).

A pre-determined quantity of tap water was added to the seed sub-lot of 5 kg and was thoroughly mixed. These rewetted samples were then poured in high density polyethylene bags of 100 micron thickness and the bags were sealed tightly. As mahua seeds are also chilling sensitive, damage may occur even at 15°C (Varghese *et al.* 2002) [26] so seed samples were kept at 16°C inside a cold storage for a week to enable the moisture to distribute uniformly throughout the sample. Before starting the tests, the required quantities of the samples were taken out of the cold storage and allowed to warm to room temperature for about 2 h and the moisture was checked using the standard oven-dry method. All the physical properties of the seed were assessed at moisture levels of 9, 12, 15, and 18% (d.b.). The rewetting technique to attain the desired moisture content in seed and grain has frequently been used (Nimkar and Chattopadhyay, 2001; Sacilik *et al.* 2003; Coskun *et al.* 2005) [14, 18, 4]. All tests were conducted in the laboratory at an ambient temperature of about 30±2 °C and relative humidity of 55 – 65%.

2.1 Seed dimensions

For each moisture content, the length, width and thickness of mahua seed were measured by a vernier caliper (Mitutoyo, Japan) with an accuracy of ±0.01 mm. The average diameter of seed was calculated by using the geometric mean of the three axial dimensions. The geometric mean diameter (D_g) in mm of the seed were calculated by using the following relationships (Mohsenin, 1986) [13]:

$$D_g = (LBT)^{\frac{1}{3}} \quad \text{…(2)}$$

The sphericity (φ) of mahua seed was determined using the following equation (Mohsenin, 1986) [13]:

$$\phi = \frac{(LBT)^{\frac{1}{3}}}{L} \quad \text{…(3)}$$

Where,

L is the Length, mm; B is the Width, mm and T is the Thickness, mm

2.2 Thousand seed mass

A seed mass of approximately 5 kg was roughly divided in to 10 equal portions and then 100 numbers of mahua seeds were randomly picked from each portion, and weighed on a digital electronic balance (Model CSW-6SL, SCALETECH, India) with an accuracy of ±0.5 g. The measurement was repeated for 5 times and the mean value was taken.

2.3 Bulk density, true density and porosity

The bulk density(ρ_b) is based on the volume occupied by the bulk sample. The hectolitre apparatus was used in the determination of bulk density of mahua seed. The mahua seeds, having a moisture content of 9% (d.b.), were poured into a calibrated container up to its top from a height of about 15 cm. Excess seeds were removed by strike-off plate of hectolitre apparatus indicating that volume of remaining of mahua seed was 1000 cm^3. The mahua seed were then weighed on an electronic balance (SCALETECH, 6000 ± 0.5g); and bulk density was calculated from the mass of the seeds and the volume of the container. Five repetitions were made and average value was reported and expressed as kg/m^3. The bulk density for mahua seeds was determined at other levels of moisture contents in similar way. No separate manual compaction of seeds was done. The true density defined as the ratio between the mass of mahua seed and the true volume of the seed, was determined using the toluene (C_7H_8) displacement method. Toluene was used in place of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of mahua seed in the toluene (Sacilik *et al.* 2003) [18]. The porosity of bulk mahua seed, at different levels of moisture content was calculated from the values of true density and bulk density using the relationship gives by Mohsenin (1986) [13] as follows

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad \text{…(4)}$$

Where,

ε is the porosity, %; ρ_b is the bulk density, kg/m^3 and ρ_t is the true density, kg/m^3

2.4 Angle of repose
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 21 cm and was filled with the seeds. The cylinder was raised slowly until the samples 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 the formula

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad \ldots(5)$$

Where,
H is the height of the cone, cm and D is the diameter of cone, cm

2.5 Coefficient of static friction
The coefficient of static friction of mahua seeds was determined on two different surfaces, namely mild steel and plywood. A tilting platform 950 × 250 mm was fabricated and used for experimentation. The surfaces are joined to a tilting table. The table has a manual working handle, which permitted the surfaces to tilt so that the sample began to slide. An angle meter attached to the tilting table measured the angle at which the seed began to slide down the surface. The coefficient of friction was calculated as the tangent of the angle measured. It is useful to determine the angle at which chutes must be positioned in order to achieve consistent flow of material through the outlet chute. The observations were repeated five times. The coefficient of friction was determined by following equation

$$\mu = \tan\alpha \quad \ldots(6)$$

Where, μ is the coefficient of static friction and α is the angle of inclination of the material For the average size of the seed, 100 seeds were randomly chosen and the other physical properties of the seeds were determined at four moisture (from 9 to 18% d.b.) content with 5 repetitions at each level of moisture content. All the statistical analysis was carried out to determine the level of significance and coefficient of determination R^2 by Microsoft Excel 2013.

3. Results and Discussion
3.1 Seed dimensions
Average values of the three principal dimensions of mahua seed, *viz*., length, width and thickness determined in this study at different moisture contents are presented in Table 1 and depicted in Fig. 1. Each principal dimension appeared to be linearly dependent on the moisture content as shown in Fig. 1. Very low correlation was observed between the three principal dimensions and moisture content indicating that upon moisture absorption, the mahua seed expands very little in length, width and thickness within the moisture range of 9 to 18% (d.b.). The mean dimensions of 100 seeds measured at moisture content of 9% (d.b.) are: length 29.80 ± 3.75 mm, width 16.65 ±1.91 mm and thickness 13.34 ±1.80 mm. As seen from Fig. 1, the axial dimensions of mahua seed slightly increases linearly (statistically non-significant at $P < 0.05$) when the moisture content increased from 9 to 18% (d.b.). The geometric mean diameter is also presented in Table 1 and depicted in Fig.1. The geometric mean diameter slightly increased with the increase in moisture content as axial dimensions. The geometric mean diameter ranged from 18.77 to 19.17 mm as the moisture content increased from 9 to 18% (d.b.) ($p < 0.05$).
The variation of moisture content and principal dimensions and geometric mean diameter (D_g) can be expressed mathematically as follows and the best fit equations are presented in Table 3.

$$\text{Length (L)} = 0.041\,X + 29.42 \quad (R^2 = 0.998) \quad \ldots(7)$$

$$\text{Width (W)} = 0.039\,X + 16.31 \quad (R^2 = 0.993) \quad \ldots(8)$$

$$\text{Thickness (T)} = 0.045\,X + 12.92 \quad (R^2 = 0.998) \quad \ldots(9)$$

$$D_g = 0.044\,X + 18.36 \quad (R^2 = 0.999) \quad \ldots(10)$$

Table 1: Axial dimensions, geometric mean and sphericity of mahua seed at different moisture content

Moisture content (% d.b.)	Axial dimensions (mm)			Geometric mean diameter (D_g), mm	Sphericity
	Length (L)	Width (W)	Thickness (T)		
9	29.80a	16.65a	13.34a	18.77a	0.63a
12	29.91a	16.80a	13.46a	18.91a	0.63a
15	30.04a	16.90a	13.61a	19.04a	0.63a
18	30.16a	17.01a	13.75a	19.17a	0.64a

Values in the same columns followed by different letters (a-d) are significant (p<0.05)

Table 2: Physical properties of mahua seed at different moisture content

Moisture content (% d.b.)	Thousand seed mass (g)	Bulk density (kg/m³)	True density (kg/m³)	Porosity (%)	Angle of repose (°)	Coefficient of static friction (decimal)	
						Mild steel	Plywood
9	1954 a	443 a	615 a	30.24 a	35 a	0.413 a	0.365 a
12	2003 b	492 a	742 b	31.39 b	37 b	0.430 b	0.374 b
15	2051 c	562 b	836 b	32.86 c	39 c	0.442 c	0.384 c
18	2104 d	647 c	981 c	33.54 d	41 d	0.457 d	0.392 d

Values in the same columns followed by different letters (a-d) are significant (p<0.05)

Table 3: Best fit equation for physical properties of mahua seed at different moisture content

Properties		mX + C	R^2
Length (L), mm		0.041 X + 29.42	0.998
Width (W), mm		0.039 X + 16.31	0.993
Thickness (T), mm		0.045 X + 12.92	0.998
Geometric mean diameter (D_g), mm		0.044 X + 18.36	0.999
Sphericity (φ)		0.0006 X + 0.624	0.995
Thousand seed mass (M_{1000}), g		16.58 X + 1804	0.999
Bulk density (ρ_b), kg/m^3		22.65 X + 230.1	0.985
True density (ρ_t), kg/m^3		37.72 X + 281.3	0.988
Porosity (ε), %		0.378 X + 26.89	0.982
Angle of repose (θ), degree		0.646 X + 29.32	0.999
Coefficient of static friction (μ) (decimal)	Mild steel	0.004 X + 0.369	0.996
	Ply wood	0.003 X + 0.337	0.998

3.2 Sphericity
The values of sphericity (φ) were calculated individually with Eq. (3) by using the data on geometric mean diameter and the major axis of the seed and the results obtained are presented in Table 1 and depicted in Figure 2. It is seen that the mahua seed has mean values of sphericity ranging from 0.63 to 0.64. These values are similar to jatropha seed Karaj and Müller, (2010) [11] and simarouba (Dash *et al.* 2008) [5]. Researcher reported that seeds are spherical in shape when the sphericity value is >0.70. The variation of moisture content and sphericity can be expressed mathematically as follows

$$\varphi = 0.0006\,X + 0.624 \quad (R^2 = 0.995) \qquad \ldots (11)$$

In this study mahua seed were treated as flat ellipsoid shaped seed. It helps in prediction of drying behaviour (Sirisomboon *et al.* 2007; Garnayak *et al.* 2008) [24, 6].

3.3 Seed mass
The thousand seed mass of mahua seed, M_{1000} (g) increased from 1954 to 2104 g ($p < 0.05$) as the moisture content increased from 9 to 18% (d.b.). (Table 2). The linear equation for thousand seed mass can be formulated to be

$$M_{1000} = 16.58\,X + 1804 \quad (R^2 = 0.999) \qquad \ldots (12)$$

A similar increasing trend has been reported by Visvanathan *et al.* (1996) [27] for neem nut and Sacilik *et al.* (2003) [18] for hemp seed.

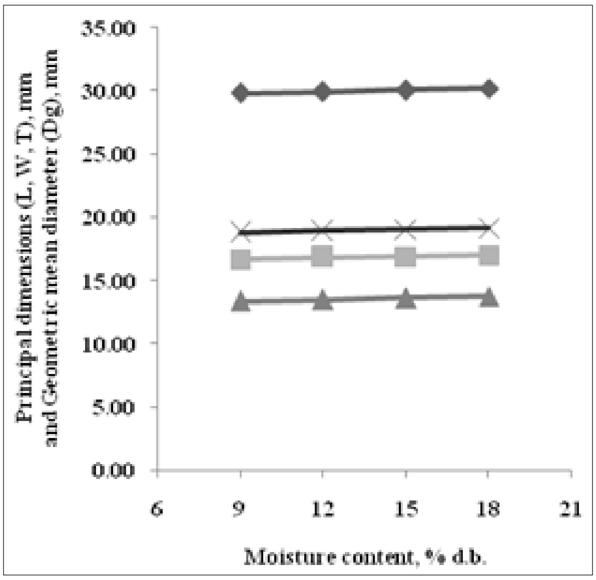

Fig 1: Effect of moisture content on axial dimensions and geometric mean diameter of mahua seed. (♦) Length; (■) width; (▲) thickness; (×) geometric mean diameter

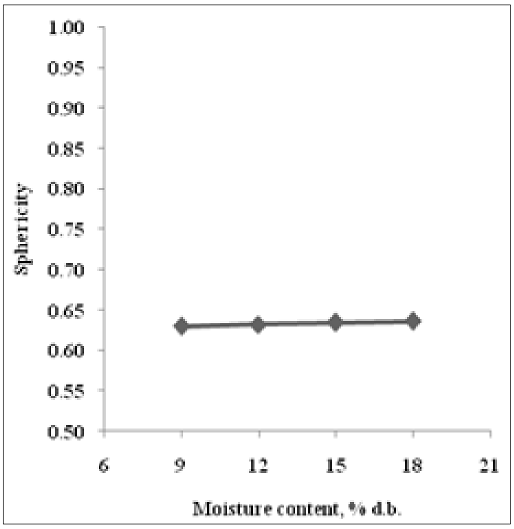

Fig 2: Effect of moisture content on sphericity of mahua seed

3.4 Bulk density and True density
The bulk density of mahua seed at different moisture levels varied from 443.4 to 646.8 kg/m^3 ($P < 0.05$) (Table 2) and indicated an increased in bulk density with an increased in moisture content from 9 to 18% (d.b.) (Fig. 4). This was due to the fact that an increase in mass owing to moisture gain in the grain sample was higher than accompanying volumetric expansion of the bulk. These results agreed with that reported by (Suthar and Das, 1996) [25] for karingda seed. An equation to explain the relationships between the bulk densities (ρ_b) and moisture content (X) of mahua seed were obtained and derived as follows:

$$\rho_b = 22.65\,X + 230.1 \quad (R^2 = 0.985) \qquad \ldots (13)$$

A plot of experimentally obtained values of true density (ρ_t) against moisture content (Fig. 4) indicated an increase ($P < 0.05$) in true density with an increase in moisture content in the specific moisture range. The increase in true density varies with increase in moisture content might be attributed to the relatively lower true volume as compared to the corresponding mass of the seed attained due to adsorption of water. The moisture dependence of the true density was described by a linear equation as follows

$\rho_t = 37.72\ X + 281.3\ (R^2 = 0.988)$ … (14)

These properties are helpful to determine the resistance to airflow during aeration and drying process. Similar results were reported by (Joshi *et al.* 1993) [10].

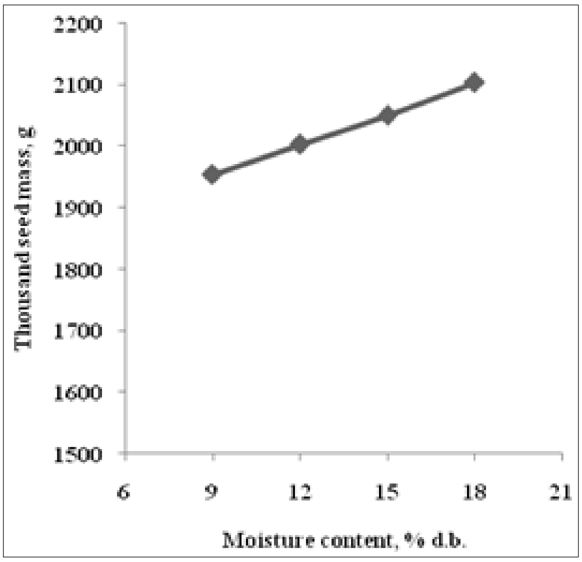

Fig 3: Effect of moisture content on thousand seed mass of mahua seed

3.5 Porosity

Porosity (ε) was evaluated using mean values of bulk density and true density in Eq. (4). The variation of porosity depending upon moisture content is shown in Fig. 5 and presented in Table 2. The porosity was found to increase linearly from 30.24 to 33.54% ($P < 0.05$) in the specified moisture levels.

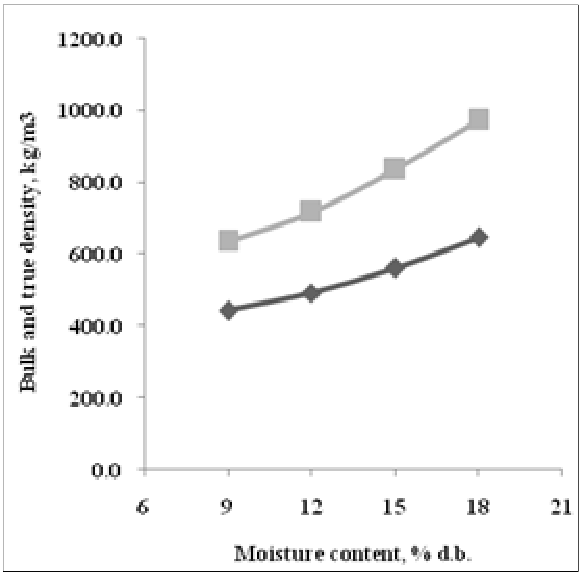

Fig 4: Effect of moisture content on bulk density and true density of mahua seed

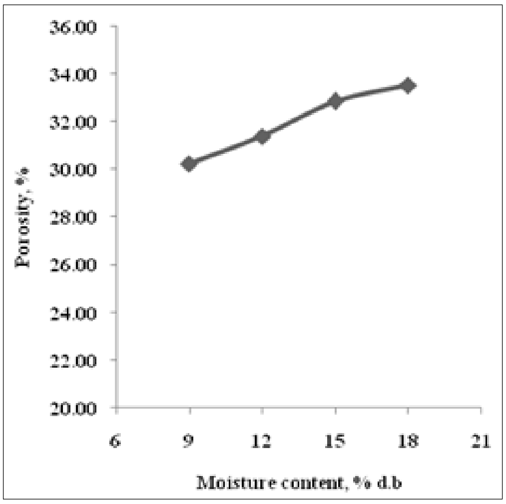

Fig 5: Effect of moisture content on porosity of mahua seed

Similar results were reported by Selvi *et al.* (2006) for linseed and Singh and Goswami (1996) for cumin seed.The relationship between porosity value and the moisture content of the seed was obtained as

$\varepsilon = 0.378\ X + 26.89\ (R^2 = 0.982)$ … (15)

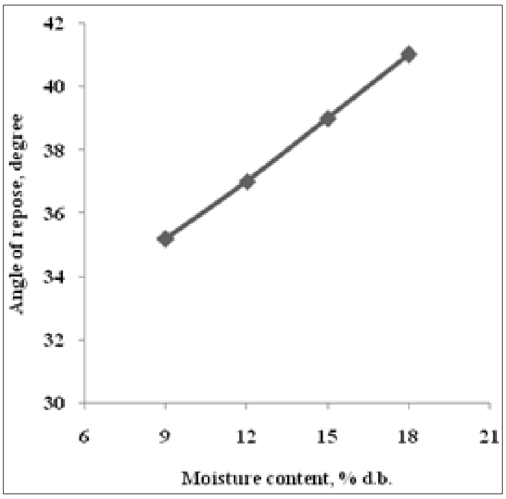

Fig 6: Effect of moisture content on angle of repose of mahua seed

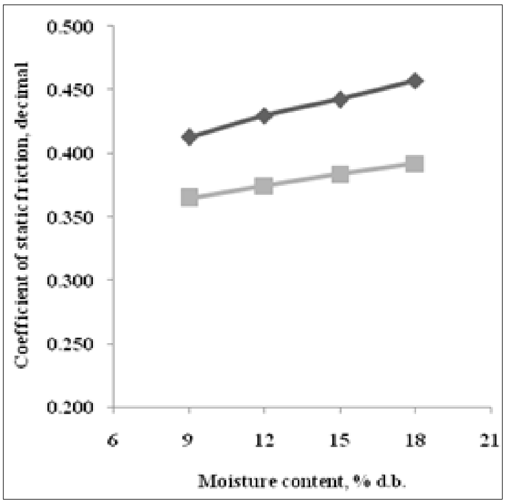

Fig 7: Effect of moisture content on coefficient of static friction of mahua seed. (♦) Mild steel; (■) Plywood

3.6 Angle of repose

The experimental results for the angle of repose (θ) with respect to moisture content are shown in Fig. 6 and presented in Table 2. The values were found to increase from 35° to 41° ($P < 0.05$) in the moisture range of 9 to 18% (d.b.). The values of the angle of repose for mahua seed bear the following relationship with its moisture content:

$$\theta = 0.646\,X + 29.32 \qquad (R^2 = 0.999) \qquad \ldots (16)$$

These results were similar to those reported by Visvanathan *et al.* (1996) [27] and Sacilik *et al.* (2003) [18] for neem nut and hemp seed, respectively. Due to the flat shape of the mahua seed, the angle was bigger as compared to other seeds. 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) [16, 20].

3.7 Static coefficient of friction

The static coefficient of friction of mahua seed against two surfaces (mild steel sheet and plywood) in the moisture range of 9 to 18% (d.b.) were presented Table 2 and depicted in Fig. 7. It was observed that the static coefficient of friction increased linearly with increase in moisture content for both contact surfaces. At all moisture contents, the static coefficient of friction against mild steel (ms) was (0.413 – 0.457) higher than for plywood (wd) (0.365 – 0.392). The reason for the increased friction coefficient at higher moisture content may be owing to the water present in the seed offering a cohesive force on the surface of contact. Increases of 10.65% and 7.34% were recorded in the case of mild steel and plywood respectively, as the moisture content increased from 9 to 18% (d.b.). The relationship between static coefficient of friction and the moisture content of the mahua seed was mathematically related as

$$\mu_{ms} = 0.004\,X + 0.369 \qquad (R^2 = 0.996) \ldots (17)$$
$$\mu_{wd} = 0.003\,X + 0.337 \qquad (R^2 = 0.998) \ldots (18)$$

4. Conclusions

The following conclusions are drawn from the investigation on moisture-dependent physical properties of mahua seed in the moisture content ranging from 9 to 18% (d.b.). The average length, width, thickness of mahua seed ranged from 29.08 to 30.16, 16.65 to 17.01 and 13.34 to 13.75 mm, respectively, as moisture content increased from 9 to 18% (d.b.). One thousand seed mass of mahua seed increased from 1954 to 2104 g and 476.78 with increase in moisture content. The geometric mean diameter and sphericity were found to increase from 18.77 to 19.17 mm and 0.63 to 0.64, respectively, in the moisture range of 9 to 18% (d.b.). Axial dimensions, geometric mean diameter and sphericity of mahua seed were not affected significantly at the various moisture levels. The bulk density, true density and porosity of mahua seed increased from 443.3 to 646.8 kg/m^3, 635.6 to 973.2 kg/m^3 and 30.24 to 33.54, respectively, as moisture content increased from 9 to 18% (d.b.). The angle of repose increased from 35° to 41° as the moisture content increased from 9 to 18% (d.b.). The static coefficient of friction increased for both the surfaces, namely, mild steel (0.413 – 0.457, 10.65%) and plywood (0.365 – 0.392, 7.34%) as the moisture content increased from of 9 to 18% (d.b.). Differences between all values are statistically significant at $P < 0.05$.

5. Acknowledgments

The author is most grateful to Navsari Agricultural University, Navsari, Gujarat, India for funding the experiment and appreciates staffs of CAET, Dediapada for providing the samples.

6. References

1. AACC. Approved methods, American Association of Cereal Chemists. 10th edn, Moisture determination, Minnasota, St Paul; c2000. p. 44-15A.
2. Altuntases EO, Zgo ZE, Tas-er OF. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. J Food Eng. 2005;71:37-43.
3. Brusewitz GH. Density of rewetted high moisture grains. Trans. ASAE 18. 1975;(5):935-938.
4. Coskun MB, Yalc I, Ozarslan C. Physical properties of sweet corn seed (*Zea mays saccharata* Sturt.). J Food Eng. 2005;74(4):523-528.
5. Dash A, Pradhan R, Das L, Naik S. Some physical properties of simarouba fruit and kernel. International Agrophysics. 2008;22:111-116.
6. Garnayak D, Pradhan R, Naik S, Bhatnagar N. Moisture-dependent physical properties of jatropha seed (*Jatropha curcas* L.). Industrial Crops and Products. 2008;27:123-129.
7. Ghadge SV, Raheman H. Biodiesel production from mahua (*Madhuca indica*) oil having high free fatty acids. Biomass and Bioenergy. 2005;28:601-605.
8. Gupta RK, Das SK. Physical properties of sunflower seeds. J Agric. Eng. Res. 1997;66(1):1-8.
9. Jha S, Vaibhav V. A culinary mahua (*Madhuca indica*). flower from Bihar, India: A potential in production of jam, alcohol for pharmacological benefits with fertiliser value. Int. J Drug Development and Research. 2013;5:362-367.
10. Joshi DC, Das SK, Mukherjee RK. Physical properties of pumpkin seeds. J Agric Eng Res. 1993;54:219-229.
11. Karaj S, Müller J. Determination of physical, mechanical and chemical properties of seeds and kernels of *Jatropha curcas* L. Indus. Crops and Products. 2010;32:129-138.
12. Kashaninejad M, Tabil LG. Some physical properties of pistachio (*Pistacia vera* L.) nut and its kernel. J Food. Engg. 2006;72(1):30-38.
13. Mohsenin NN. Physical Properties of Plant and Animal Materials. Gordon and Breach Press, New York; c1986.
14. Nimkar PM, Chattopadhyay PK. Some physical properties of green gram. J Agric. Eng. Res. 2001;80(2):183-189.
15. Ozarslan C. Some physical properties of cotton seed. Biosyst. Eng. 2002;83(2):169-174.
16. Pradhan RC, Meda V, Naik SN, Tabil L. Physical properties of Canadian grown flaxseed in relation to its processing. Int. J of Food Properties. 2010;13:732-743.
17. Reddy BS, Singh KK, Varshney AC, Mangraj S. Studies on some engineering properties of sapota (*Achras zapota*). J of Agril. Engg. 2004;41(1):1-6.
18. Sacilik K, Ozturk R, Keskin R. Some physical properties of hemp seed. Biosyst Eng. 2003;86(2):191–198.
19. Sahoo N, Pradhan S, Pradhan R, Naik S. Physical properties of fruit and kernel of *Thevetia peruviana* J.: A

potential biofuel plant. Int. Agrophysics. 2009;23:199-204.
20. Sahay K, Singh K. Unit operations of agricultural processing. Vikas Publishing House, Ravindra Mansion, Ram Nagar, New Delhi; c2004.
21. Selvi KC, Pinar Y, Yes E. Some physical properties of linseed. Biosyst. Eng. 2006;95(4):607–612.
22. Singh KK, Goswami TK. Physical properties of cumin seed. J Agric Eng Res. 1996;64:93–98.
23. Singh IS. Mahua An oil bearing tree. Technical Bulletin, ND University of Agriculture and Technology, Kumarganj, Faizabad, Uttar Pradesh, India; c1998. p. 3-11.
24. Sirisomboon P, Kitchaiya P, Pholpho T, Mahuttanyavanitch W. Physical and mechanical properties of Jatropha curcas L. fruits, nuts and kernels. Biosystems Engineering. 2007;97:201-207.
25. Suthar SH, Das SK. Some physical properties of karingda (*Citrullus lanatus* (Thumb) Mansf) seeds. Journal of Agricultural Engineering Research. 1996;65(1):15-22.
26. Varghese B, Naithani R, Dulloo ME, Naithani SC. Seed storage behaviour in *Madhuca indica* J.F. Gmel. Seed Science and Technolo. 2002;30:107-117.
27. Visvanathan R, Palanisamy PT, Gothandapani L, Sreenarayanan VV. Physical properties of neem nut. J Agric Eng Res. 1996;63:19-26.