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Note

Physical properties of fruit and kernel of *Thevetia peruviana* J.: a potential biofuel plant

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A b s t r a c t s. *Thevetia peruviana* J. is a potential biofuel crop with cosmopolitan distribution and ensuring fruit-harvest almost throughout the year. Different physical properties of fruit and kernel such as, dimensions, 1000-unit mass, surface area, sphericity, bulk density, true density, aspect ratio and angle of repose has been determined for ease in designing structures and equipments for handling, transportation, storage and processing. The shell has higher moisture content than kernel and fruit. Oil content in the kernel is as high as 62.14% (w/w) while other parts of fruits bear negligible amount of oil. The frequency distribution of size and weight for fruit and kernel has been evaluated. The sphericity of kernel is 10.14% more and the surface area is 77.12% less than that of fruit. Bulk densities of fruits and kernels are 591.70 and 657.73 kg m^{-3}; the corresponding true densities are 1106.68 and 942.05 kg m^{-3}. The porosity of fruit and kernel are 46.51% and 29.82% respectively. The angle of repose of fruit is 1.75% higher than kernel.

K e y w o r d s: *Thevetia peruviana* J., oil, physical properties, fruit, kernel, moisture content

INTRODUCTION

The search for alternative sources of fuel to supplement or replace fossil fuels so as to fetch their increasing demands, uncertain availability and to reduce the related pollution problems of their combustion has drawn our attention towards fuels of biological origin (Encinar *et al*., 1999; Marchenko and Semenov, 2001), which provides a regenerable feedstock. Of these, the most common being developed and used at present are biodiesels, which are fatty acid methyl esters (FAMEs) of seed oils and fats. A myriad of edible and non-edible oils could be used as bio-diesel feedstocks, but the appropriate technology would be to utilize the abundantly available native non-edible oil feedstocks rather than edible ones. One of these feedstocks could be *Thevetia peruviana* J. oil.

Thevetia peruviana J. belongs to the order apocynales of Apocynaceae family. It is a native of tropical America: especially Mexico, Brazil and West Indies and has naturalized in tropical regions worldwide. In the native countries it is believed to be more than 2000 years old. It is known as yellow oleander (nerium), gum bush, bush milk, exile tree in India, cabalonga in Puerto Rico, ahanaiin Guyana, olomi ojo by Yorubas in Nigeria. Inspite of high oil content (67%) of its kernel (Azam *et al*., 2005) and favourable protein content (37%) in de-oil cake (Ibiyemi *et al*., 2002) it has remained only an ornamental or fencing or wasteland plant. The plant is an evergreen perennial shrub reaching a height of 4.5 to 6 m with deep green linear sword-shaped leaves and funnel shaped (yellow, white or pinkish yellow coloured) flowers. The plant starts flowering after one and a half year and after that it blooms thrice a year (Balusamy and Manrappan, 2007). *Thevetia peruviana* J. plants produce more than 400-800 fruits yearly depending on the rainfall and plant age (Ibiyemi *et al*., 2002). Almost all parts of the plant are poisonous and bear white coloured latex. The number of kernels per fruit and the oil yield are significantly different among geographical locations. The plant has annual seed yield of 52.5 t h^{-1} and about 1750 l of oil can be obtained from a hectare of waste land (Balusamy and Manrappan, 2007). Its kernel oil has a very good thermal stability (Ibiyemi *et al*., 1995) and thus has a potential for various uses.

Thevetia fruits and kernels undergo a series of unit operations before reaching the final step of oil extraction. Developing designs, fabricating particular equipments and structures for these unit operations like handling, transport, processing, and storage and also for assessing the behavior of the product quality (Sahay and Singh, 1996) the knowledge of physical properties of oilseeds are very important. Physical

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properties of *Thevetia* fruit and kernel are essential to design equipments for decortication, drying, cleaning, grading, storage and oil extraction. The size, shape and angle of repose of fruit and kernel can be used to determine the lower size limit of the conveyors, such as belt conveyor, bucket elevator, screw conveyor and hopper. Bulk density is used in determining the size of storage bin. Moisture content is useful information in the drying process.

Most of the research on *Thevetia* has revolved around the clinical, toxicological, pharmacological *etc* aspects. Probably this is the reason for limited research on oil and protein of *Thevetia* that would have promoted its industrial and domestic potentials. Though literatures are available on *Thevetia* plant and its oil characteristics (Ibiyemi *et al*., 2002), hardly any study is available on its physical properties.

Before proceeding forward it would be necessary to understand about different parts of the fruit (Fig. 1). The fruits of *T. peruviana* are drupes and are rhomboidal in shape with a fissure on the ventral side where it can be opened up. It consists of deep green-waxy pericarp, fleshy mesocarp and a bony endocarp. After drying, the pulpy meso-pericarp (hull) shrunk and turns dark to expose the endocarp. The bony endocarp (shell) has been referred as fruit in the texts for convenience in understanding. This endocarp encapsules seed(s). The seed coat is very much fragile. With utmost care one can get intact seeds but normally the seed coat ruptures or at least the wing shaped structure gets separated. During manual/mechanical dehulling, hardly 1 to 2% seed coat remains intact. That is the reason why emphasis has been given on taking measurements of fruit (endocarp) and kernel.

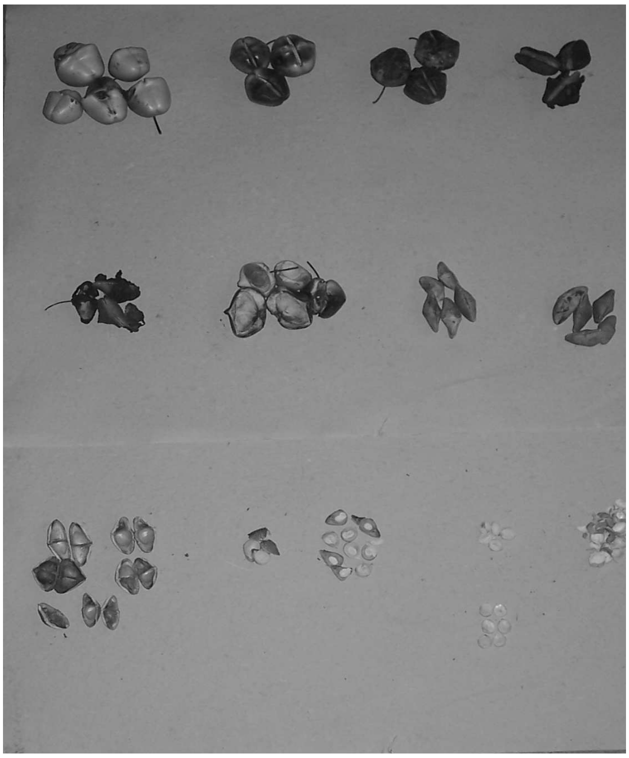

Fig. 1. Different parts of *Thevetia peruviana* J. fruit and seed. Fresh fruit on progressive stages of drying showing opening of the ventral fissure (a-d), release of bony endocarp from shrunken hull (e), position of endocarp in the fruit (f), fresh endocarp (g); dried endocarp (h), shell showing position of seed (i), whole seed with wing and seed coat (j), seed with seed coat but without wing (k), kernels (l), seed wings (m), seed coat (n).

The aim of this study was to investigate the physical properties of *Thevetia* fruit and kernel. The parameters studied include moisture content, oil content, size, 1000-unit mass, fruit part fraction, arithmetic mean diameter, geometric mean diameter, sphericity, aspect ratio, surface area, bulk density, true density, porosity and angle of repose.

MATERIALS AND METHODS

Thevetia peruviana J. fruits had been procured in winter season from IIT campus, New Delhi, India. The fruits were hand-picked from below the tree. Meso-pericarp (hull) of the fruit and other foreign materials were cleaned off the bony endocarp. Then fruits were bone-dried (weight taken after keeping inside a desiccator, every time) in hot air oven, at 80°C (Yorco Sales Pvt. Ltd., India) and stored in jute bag for further processing. The fruits were shelled (removal of bony endocarp) and decorticated (removing seed-coat from seed to get kernel) manually to obtain kernel and different observations also carried out in the same season.

Weighed amount of stored fruit and kernel were dried in a hot-air oven at 80°C and weighed every time after cooling the samples in a desiccator till constant weight. Similarly, moisture contents of kernel and shell were determined.

For oil content determination (AOAC, 1984), *T. peruviana* kernels were grinded for about 1 min, sieved through a 2 mm sieve and extracted in soxhlet apparatus using petroleum ether (boiling point 60-80°C). Heavy grinding should be avoided as it results in to formation of a pasty mass. The extract was concentrated in rotavapour, the residual oil was cooled and weighed. The oil content of fruit and shell were measured similarly. Reported values of fruit, kernel and shell are means of five determinations.

The fruit and kernel material each were divided into 5 lots and 20 samples were selected at random from each lot to obtain 100 samples for conducting the experiment. Hence, measurements of all size and shape indices were replicated one hundred times. The fruit size, in terms of the three principal axial dimensions, that is length (L), width (W) and thickness (T) were measured using vernier caliper (Mitutoyo, Japan) with an accuracy of 0.02 mm. The measurements of fruit fractions were replicated twenty times to get mean value.

The arithmetic mean diameter (D_a), geometric mean diameter (D_g), bulk density (ρ_b), true density(ρ_t), sphericity (ϕ), porosity (ε), aspect ratio (R_a), surface area (S) of bulk sample (fruit and kernel), and weight of ftuit and kernel (Wt) were calculated using standard formulas (Aviara *et al*. 2005; Burubai *et al*., 2007; Kiani *et al*., 2008; Sharifi *et al*., 2007; Tabatabaeefar, 2003).

The angle of repose (θ) was determined by using an open-ended cylinder of 15 cm diameter and 50 cm height. The cylinder was placed at the centre of a circular plate having a diameter of 70 cm and was filled with fruit or kernel. The cylinder was raised slowly until it formed a cone on the circular plate. The height of the cone was recorded by using a moveable pointer fixed on a stand having a scale of 0 – 1 cm precision (Aviara *et al*., 2005; Dash *et al*., 2008; Koocheki *et al*., 2007; Pradhan *et al*, 2008; Razavi and Farahmandfar, 2008). The reported value is mean of 20 replications.

Table 1. Moisture and oil content of *Thevetia* fruit and fruit parts (number of samples – 5)

Part of fruit	Moisture content (%, w.b.)	Oil content (%)
Fruit	4.52 ± 0.39	8.56 ± 0.58
Kernel	3.13 ± 0.04	62.14 ± 0.461
Shell	4.64 ± 0.46	0.36 ± 0.01*
Seed coat	4.04 ± 0.16	8.41 ± 0.23
Seed wing	4.77 ± 0.13	2.01 ± 0.09

Data are mean values ± standard deviation, *hexane soluble materials (solid or semi solid at 27ºC).

RESULTS

The average moisture and oil content of *T. peruviana* fruit and different parts of the fruit are given in Table 1. The shell of the fruit contains higher moisture content as compared to fruit and kernel. Seed wings bear a bit higher moisture (residual moisture) than other components. On an average, kernel constitutes only 16.14% of the fruits where as shell fraction is 83.86%. The kernel contains as high as 62.14% non-drying oil. Seed coat and seed wing contains semi-oily material around 8.41 and 2.01%, respectively. The shell contains some hexane soluble material (0.36%). So the shell should be separated before oil expulsion.

The physical parameters of fruit and kernel are given in Table 2. The 1000-unit mass, fraction of fruit parts, arithmetic mean diameter and geometric mean diameter are provided along with other physical parameters. The length, width and thickness ranges for fruit are 23.10-41.70, 12.90-18.40, and 12.10-18.70 mm and that of for kernel are 11.10-15.30, 9.20-12.20 and 3.30-6.20 mm. Average values of these parameters for fruit are found to be 31.08 ± 3.47, 15.87 ± 1.13, and 14.27± 1.17 mm and that of kernel are 13.35± 1.05, 10.75± 0.59 and 5.40± 0.46 mm, respectively. Sphericity, the other important related parameter of *Thevetia* fruit and kernel are 0.62 and 0.69, respectively. Similarly, the surface area to volume ratio (SA/Vol) values is 0.481 and 0.698 mm^{-1} for fruit and kernel of *T. peruviana*, respectively.

Table 2. Physical properties of *Thevetia* fruit and kernel

Physical properties	Number of sample	Fruit	Kernel
Length (mm)	100	31.08 ± 3.47	13.35 ± 1.05
Width (mm)	100	15.87 ± 1.13	10.75 ± 0.59
Thickness (mm)	100	14.27 ± 1.17	5.40 ± 0.46
1000 unit mass (g)	20	2586.63 ±69.65	330.92 ± 11.68
Kernel fraction (%)	20	16.14	N.A.
Shell fraction (%)	20	83.86	N.A.
Arithmetic mean diameter (mm)	100	20.41 ± 1.71	9.83 ± 0.52
Geometric mean diameter (mm)	100	19.14 ± 1.47	9.17 ± 0.48
Sphericity (decimal)	100	0.62 ± 0.03	0.69 ± 0.04
Surface area (mm^2)	100	1157.60 ± 179.53	264.86 ± 26.86
Aspect ratio (%)	100	51.44 ± 4.33	80.85 ± 6.00
Bulk density (kg m^{-3})	20	591.7 ± 8.91	657.73 ± 5.23
True density (kg m^{-3})	20	1106.68 ± 38.85	942.05 ± 79.87
Nos per m^3		222 364	1 840 515
Porosity (%)	20	46.51 ± 1.15	29.82 ± 6.48
Angle of repose (°)	20	44.05 ± 2.04	43.28 ± 0.90

N.A. – not applicable. Other explanations as in Table 1.

The frequency distribution of length, width, thickness, arithmetic mean and weight for fruit and kernel has been graphically represented in Fig. 2a,b, respectively. Length, thickness, arithmetic mean diameter and weight of fruits (*Wt*) have highest frequency in their respective second intervals where as for kernels it is 4th interval. Width has higher frequencies under 3rd interval for both fruits and kernels. Except for *W*, the frequencies of other four parameters (*L, T, Da* and *Wt*) follow similar trends. Frequencies for *L, W, T, Da* and *Wt* between 2nd to 4th intervals are 91, 86, 78, 87, and 71% for fruit. Similarly, 71, 85, 74, 88, and 77% are for kernel. The ranges of weight for fruits and kernels are 1.58-4.57 and 0.15-0.46 g, respectively. The 1000 unit mass for fruit and kernel are 2 586.63 and 330.92 g, respectively.

The surface area of fruit is 77.12% larger than the kernel. The mass or energy transfer rate through the surface of the fruit might be slower than the rate for kernel as the surface area of fruit is higher than that of kernel. The bulk density of fruit and kernel are 591.7 and 657.73 kg m^{-3}, respectively. The respective porosity of *Thevetia* fruit and kernel are found to be 46.51 and 29.82%. The porosity of the bulk of kernel is lower than that of fruits. From the bulk density, true density and 1000 unit mass values, calculation for the number of fruits and kernels per m^3 comes to 222364, 1840515, respectively.

The aspect ratio of fruit is 51.44% and that of kernel is 80.85% *ie* kernels have high aspect ratio than fruit. In contrary, angle of repose of fruit (44.05±2.04) is 1.75% higher than that of kernel. This might have been due to the

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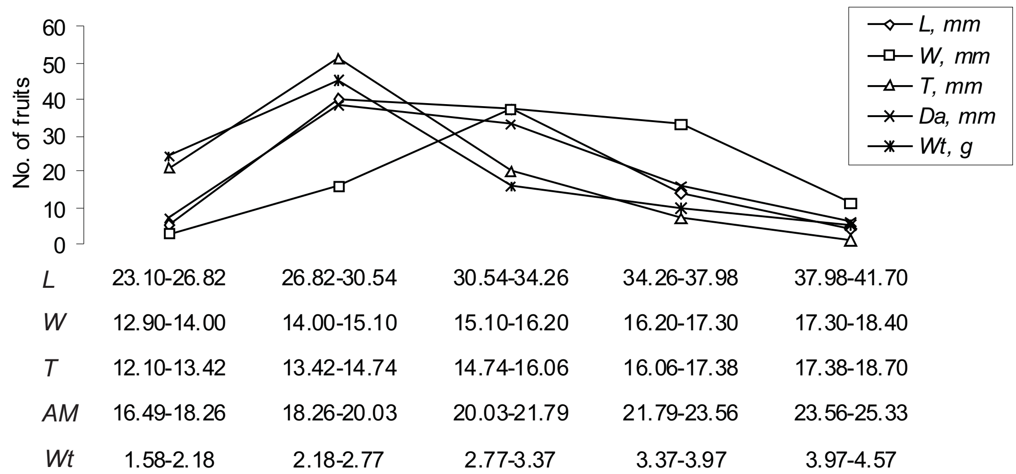

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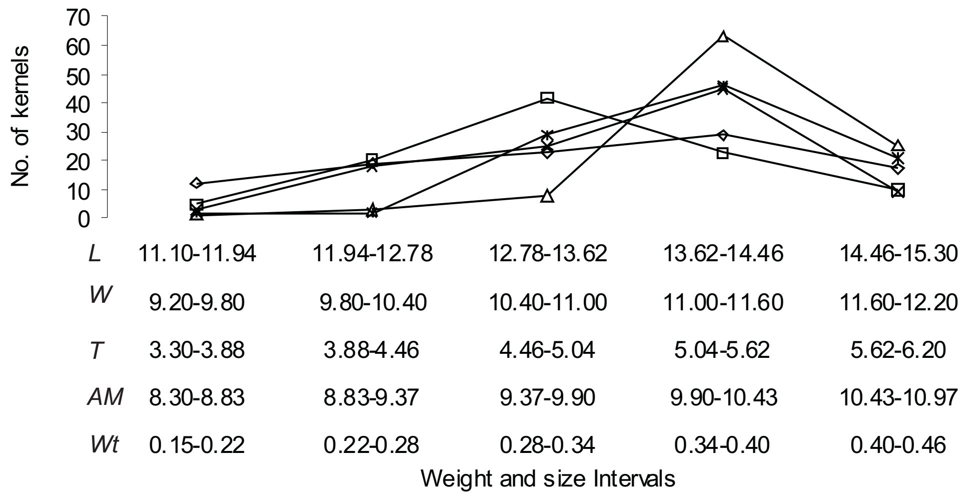

Fig. 2. Frequency distribution curves of length, width, thickness, arithmetic mean diameter and weight for *T. peruviana*: a – fruit, b – kernels.

surface characteristics of fruits leading to the higher cohesion among the individual fruits and therefore to the higher angle of repose.

DISCUSSION

As revealed from the results, the shell of the stored fruit has slightly higher moisture content as compared to whole fruit and kernel but on an average there is little variation in moisture content in different components. The lower moisture content in kernels must be pertaining to its very high oil content. As high moisture content of fruit may increase free fatty acid (FFA) level, storage of kernels than fruits may be preferred to ensure a good quality of oil. This proposition about storage is also supported by lower arithmetic and geometric mean diameter, lower surface area, higher bulk-density, higher numbers per unit volume, lower porosity and lower angle of repose of kernel than fruit. Similarly, as kernel constitutes only 16.14% of the fruits and rest is shell, the space economy of storage and transport do not support fruits. Due to these physical properties, kernel than fruits will ensure quality feedstock storage and transport in lesser space and lower expenditure.

The high non-drying oil content (62.14%) of kernel and the semi-oily material from seed coat and seed wing are valuable. The negligible quantity of hexane soluble material (0.36%) in shell is not important in terms of oil yield. These values shows that as compared to the oil content of other tree born oilseed (TBO) like karanja, *Jatropha* and neem (Bringi and Mukerjee, 1987; Gübitz *et al*., 1999; Kandpal and Madan, 1995; Srivastava and Verma, 2007; Visvanathan *et al*., 1996) oil content of *Thevetia* kernel is very high, so a potential oil seed crop for biodiesel production.

Mohsenin (1980) have discussed the significance of length, width, thickness, arithmetic mean diameter and geometric mean diameter in determining aperture sizes and other parameters in machine designing which were later highlighted by Omobuwajo *et al*. (1999). Corresponding to length, width and thickness of *T. peruviana*, values of *Jatropha* fruit, the most widely researched biodiesel feedstock, are 33.36, 31.51, and 30.05 mm, and that of kernel are 15.45, 10.25 and 7.42 mm (Sirisomboon *et al*., 2007). Similarly, the length and stem-end diameter of neem nut are 14.56 and 7.72 mm, respectively (Visvanathan *et al*., 1996). Thus, *Thevetia* fruit is smaller than *Jatropha* fruit but bigger than neem nut. The frequency distribution of length, width, thickness, arithmetic mean and weight for fruit and kernel shows that more than 70% of fruits and kernels fall under 2nd and 4th intervals which indicate that while designing machinery more emphasis should be given to these dimensions representing a higher population. The 1000 unit mass for fruit and kernel are 2586.63 and 330.92 g, respectively. The corresponding reported value of *Jatropha* fruit (2280 g) is lower and kernel (476 g) is higher than that of *Thevetia* (Naik *et al*., 2007). The weight ranges of 1.58-4.57 and 0.15-0.46 g, respectively in frequency distribution curve for fruits and kernels are important values for transport, loading, unloading *etc*. activities.

The fruit shape is determined in terms of its sphericity and aspect ratio. The sphericity of *Thevetia* fruit and kernel are 0.62 and 0.69, respectively. These values are closer to the corresponding values of 0.85 and 0.68 as reported for *Jatropha* (Sirisomboon *et al*., 2007). Bal and Mishra (1988) and Dutta *et al*. (1988), have considered the grain as spherical when the sphericity value is more than 0.8 and 0.7, respectively. The determined sphericity value indicates that *Thevetia* fruit should not be treated as an equivalent sphere for calculation of the surface area. Garnayak *et al*. (2008), reported similar results for *Jatropha* seed.

The surface area to volume ratio (SA/Vol) values which are 0.481 and 0.698 mm^{-1} for fruit and kernel, respectively, indicates that the drying (George *et al*., 2007) of kernel will require less time than fruits.

The high aspect ratios (which relate the ratio of width to length) indicated that *Thevetia* fruit and kernel will not roll like gram, but will slide along its flat surface like oil bean seed (Oje and Ugbor, 1991). The designing of hoppers depends on the rolling or sliding tendency of the fruit. Similarly, the angle of repose of *Thevetia* fruit is 1.75% higher than that of kernel. This value indicates a lower flow ability of the fruits compared to the kernels. The angle of repose of the *Thevetia* fruit and kernel are lower than that of *Jatropha* (Pradhan *et al*., 2008).

The higher surface area, lower bulk density, and less numbers per unit volume indicate that fruits need more space per unit mass than kernels. The true density of the fruit is more than the density of water may be due to the closely packed shell and kernel. This indicates that separation of fruit shells from kernels after decortications could not be done by blowing air (winnowing) or floating in water. The porosity values shows that a bulk of kernel possesses lower volume of void space than that of fruits. Since, the variation in porosity depends on the magnitude of true and bulk densities, the aeration of the bulk of fruit is easier than that of kernel.

CONCLUSIONS

1. Though the kernel fraction in fruit of *Thevetia peruviana* J. is only 16.14%, the amazingly high oil content (62.14%) for use in different industrial purposes is an incentive for its postharvest processing.

2. Fruit possess higher values of length, width, thickness, surface area, geometric mean, arithmetic mean, true density and angle of repose than kernel but at the same time, kernel has higher values of sphericity, aspect ratio and bulk density than that of fruit.

3. Transport and long term storage of kernels would be beneficial than fruits in terms of quality and economy of feed stock.

4. The physical properties of the fruit and kernel are unique and different from other tree born oilseeds *ie* the storage, transport handling etc. activities related to the fruits and kernels will require modifications in the processes and structures prevailing for other tree born oilseeds.

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