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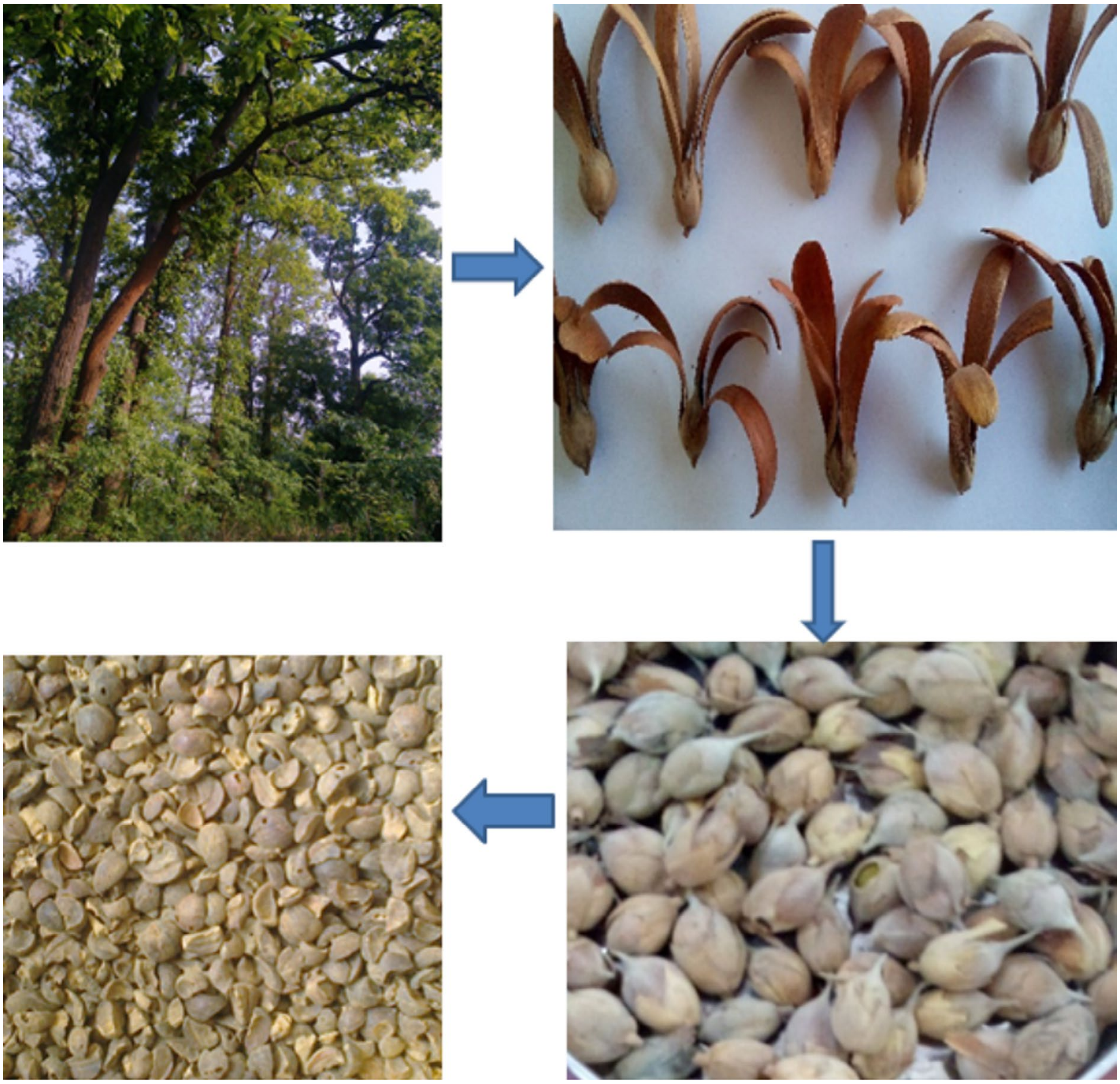

FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

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Exploration of *Shorea robusta (Sal)* seeds, kernels and its oil[i]

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Abstract: Physical, mechanical, and chemical properties of *Shorea robusta* seed with wing, seed without wing, and kernel were investigated in the present work. The physico-chemical composition of sal oil was also analyzed. The physico-mechanical properties and proximate composition of seed with wing, seed without wing, and kernel at three moisture contents of 9.50% (w.b), 9.54% (w.b), and 12.14% (w.b), respectively, were studied. The results show that the moisture content of the kernel was highest as compared to seed with wing and seed without wing. The sphericity of the kernel was closer to that of a sphere as compared to seed with wing and seed without wing. The hardness of the seed with wing (32.32, N/mm) and seed without wing (42.49, N/mm) was lower than the kernels (72.14, N/mm). The proximate composition such as moisture, protein, carbohydrates, oil, crude fiber, and ash content were also determined. The kernel (30.20%, w/w) contains higher oil percentage as compared to seed with wing and seed without wing. The scientific data from this work are important for designing of equipment and processes for post-harvest value addition of sal seeds.

Subjects: Food Chemistry; Food Engineering; Processing; Product Development

Keywords: physical properties; mechanical properties; sal oil; free fatty acid

1. Introduction

Shorea robusta, commonly known as sal, belongs to the *Dipterocarpaceae* family. Sal is an important non timber forest product (NTFP) and it is available in many south Asian countries like India, Pakistan, Nepal, Bhutan, Bangladesh, and Myanmar. The planning commission of India has recommended sal

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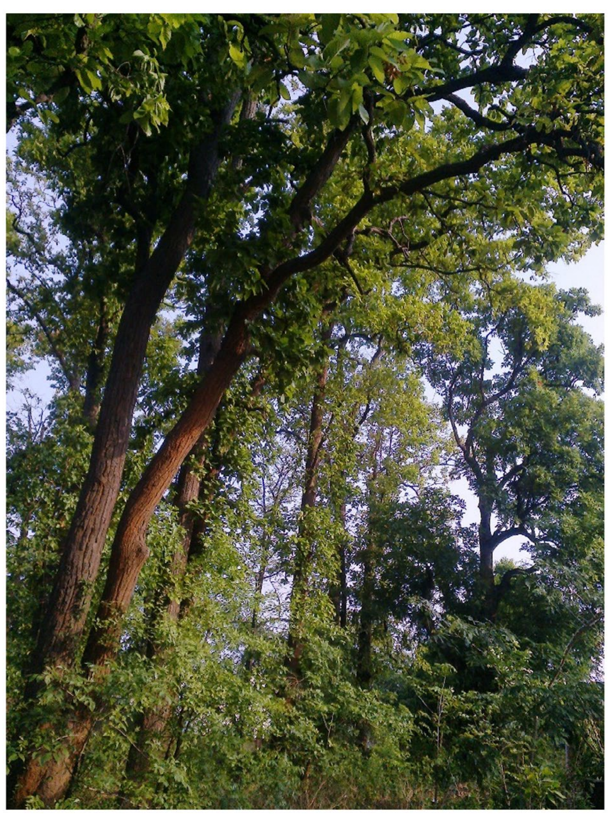
PUBLIC INTEREST STATEMENT

Shorea robust is commonly known as sal, is a non timber forest product of India. The sal is a major source of income generation in rural and tribal areas. Apart from the timber and its leaves, sal seeds were major source of oil (oil contains around 30.20%). The sal oil can be used for manufacture food and non-food industries. The sal oil can be used as cooking oil and substitute for cocoa butter in chocolate industry after refining process. The sal seed and its oil are in underutilized stage because of its low price and lack of technology for its processing activities. By exploring this sal, various physical, chemical properties of this seed and its importance can be known. These results would add to the scientific database for use to develop and design processing equipment and development operation for new products.

seed as potential NTFPs for enterprise development in India. The estimated availability of sal seed in India per year is 1.5 million tons. About 20–30 million forest dwellers depend on collection of sal seeds, leaves, and resins (Patnaik, 2015). Sal is a large deciduous tree and it grows up to 50 m height (Figure 1). Sal tree requires well-drained, moist, and sandy loam soil. It is mostly propagated through cutting. Sal sheds leaves under dry condition from February to March and new leaves appear in the month of April and May. Fruiting and ripening occurs in summer between June and July. Sal seeds are around 10–15 mm in length and 10 mm in diameter and have five wings of unequal size and shape. The sal seed contains about 34.6%, (w/w) oil, 8.46% (w.b) moisture, and 6% ash (Singh, Soni, Kumar, & Singh, 2014). It is primarily processed for its oil and significantly constitutes (up to 69%) for production of symmetrical triglycerides. This makes them potentially useful for the food and non-food industries.Sal fat provides an alternative to cocoa butter, as Cocoa Butter Equivalent and Cocoa Butter Replacer, in confectionery (Patnaik, 2015). It is also used as a primary ingredient in oil, soap, animal feed, and pharmaceutical industries (Patnaik, 2015). Sal oil has also been utilized for bio-diesel production (Chhibber, Joshi, & Saxena, 2012).

The dimensional properties such as length, width, and thickness of the seed, and kernel are important for designing the de-hulling or decorticating machines. These data can be used to determine the lower size limit of the conveyors such as belt conveyor, bucket elevator, and screw conveyor. Bulk density, true density, porosity, and surface area affect the resistance to airflow through the bulk material bed. These data are necessary in designing a dryer and the drying process. Bulk density is also used in determining the size of the storage bin. Coefficient of friction on various surfaces affects the maximum inclination angle of conveyor and storage bin. The magnitude of frictional force affects the amount of power required to transfer the materials. Angle of repose is an important parameter for calculation of width of a belt conveyor and for designing the shape of storage bin (Sahay & Singh, 2004; Sirisomboon, Kitchaiya, Pholpho, & Mahuttanyavanitch, 2007).

Figure 1. Sal plants in Odisha, India.



Mechanical properties such as hardness, deformation at hardness, deformation at hardness percentage, fracturability, 1st fracture at deformation, and energy for fracture used for rupturing the seed and kernel are necessary for designing the de-shelling or decorticating machine and oil extractor. Hardness value is used to calculate the maximum compression force required to crush the seed (Giczewska & Borowska, 2003). Fracturability indicates the minimum force required for de-shelling the seed for seed coat removal. The deformation can be used for the determination of the gap between the seed coat and kernel while compressing the seed during decortication or de-shelling (Sirisomboon et al., 2007; Swain & Gupta, 2013).

The sal seeds undergo a series of unit operations like cleaning, grading, sorting, separation, and expression during de-shelling and oil extraction. Physical, mechanical, and chemical properties of sal seeds are essential to design the processes and equipment for these unit operations (Sahay & Singh, 2004). The aim of this research was to evaluate these properties of sal seed, kernel, and the oil. These results would add to the scientific database for use to develop and design further processing and development operation for new products.

2. Material and methods

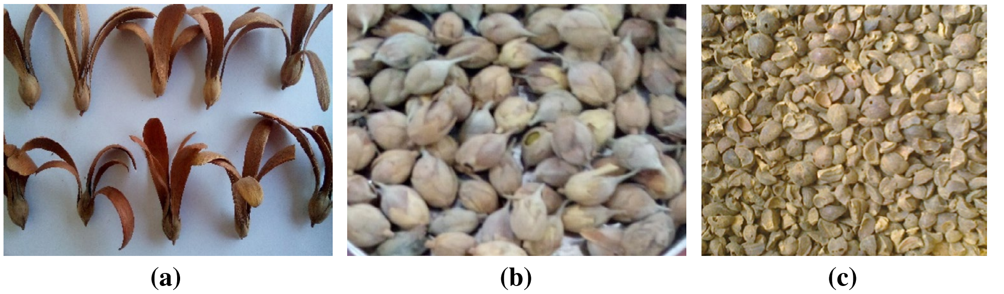
2.1. Sal seeds

Sal seeds with wing were collected from the local forest in Rourkela, Sundergarh, Odisha, India (located at 84.54 E longitude and 22.12 N latitude). These seeds were cleaned manually and sun-dried. The wings and seed coats were separated manually to obtain the seeds without wing and kernels (Figure 2). Seeds with wing, seeds without wing, and kernels were separated and stored in airtight containers under ambient condition. Samples from each type were grounded to fine powder and the moisture content and oil content were determined. The grounded seeds were packed in airtight polyethylene bags and stored at 4°C for use in further experiments.

2.2. Determination of physical properties

Ten kilograms of samples of each type were selected randomly from the bulk and were used for determination of physical properties. One hundred each of seeds with wing, seeds without wing, and kernels were taken for the experiments. Dimensional properties like length and width (Figure 3) of the seeds with wing, seed without wing, and kernels were measured with a digital Vernier caliper with an accuracy up to ± 0.01 mm. The unit sample mass (g) was measured by using electronic weighing balance (Wensor ISO 9001: 2000 certified, India) with an accuracy up to ± 0.001 g.

Seed size is an important parameter in processing. The samples were classified into three categories namely small, medium, and large size based on their length. The average dimensions ($\bar{X}$) and the associated standard deviation (σ_x) were used for this classification. The grouping was done based on whether their particular X dimension satisfies the following inequalities (Pradhan, Meda, Naik, & Tabil, 2010; Sharma et al., 2011).



(a) (b) (c)

Figure 2. Types of sal samples. (a) Seed with wing. (b) Seed without wing. (c) Kernel.

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Small size group $X < \bar{X} - \sigma_x$

Medium size group $\bar{X} - \sigma_x < X < \bar{X} + \sigma_x$

Large size group $X > \bar{X} + \sigma_x$

Some other physical properties such as arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (φ),aspect ratio (*As*), bulk density (ρ_b), true density (ρ_v), and 1,000 sample mass were also determined by standard methods (Kibar & Ozturk, 2008; Patel, Pradhan, & Naik, 2011; Shirkole, Kenghe, & Nimkar, 2011). The surface area (mm^2), angle of repose), and the coefficient of friction (μ) of seed with wing, seed without wing, and kernel was determined on five different surfaces i.e. plastic, glass, galvanized iron, ply wood, and aluminum sheet (Abdulkarim, Long, Lai, Muhammad, & Ghazali, 2005; Baryeh, 2001; Kiani, Minaei, Maghsoudi, & Varnamkhasti, 2008; Pradhan et al., 2010; Sahoo, Pradhan, Pradhan, & Naik, 2009; Sirisomboon & Kitchaiya, 2009; Sirisomboon et al., 2007; Taghi Gharibzahedi, Mousavi, & Ghahderijani, 2011).

2.3. Determination of mechanical properties

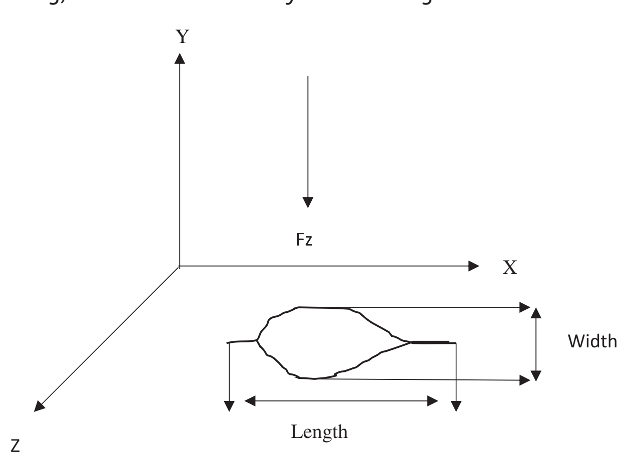
Mechanical properties such as hardness, deformation at hardness, deformation at hardness percentage, fracturability, 1st fracture at deformation, and energy for fracture or rupture of seed with wing, seed without wing, and kernel were evaluated. For each experiment, ten replicates were used. The flat plate compression test (Figure 3, *Fz*) was done in a texture analyzer (CT3, Brookfield, USA). The samples were horizontally aligned from stem end to the apex and placed on the platform. An aluminum plate (88 mm × 100 mm × 12.5 mm) was used to compress the sample at the deformation speed of 0.5 mm/s. TA44 cylinder probe (4 mm dia) was used for the experiment. The load cell range was 10 kg. The probe compressed the sample to different distances (1.93, 1.55 and 1.82 mm) for seed with wing, seed without wing, and kernel. The hardness, deformation at hardness, deformation at hardness percentage, fracturability, 1st fracture at deformation were evaluated by the in-built software of the texture analyzer. Hardness (Figure 4) is the ratio of rupture force and deformation at rupture point. Deformation at hardness is the deformation at the particular distance (Sirisomboon et al., 2007). Deformation at hardness percentage is the percent of deformation at hardness. Fracturability is the minimum force required to crack the sample. 1st fracture at deformation (Figure 4) is the first fracture of the sample at a particular distance. 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 & Müller, 2010; Manuwa & Muhammad, 2011; Swain & Gupta, 2013; Vursavuş & Özgüven, 2005).

2.4. Determination of proximate composition of sal

The proximate composition such as moisture content M_c (%, w.b), protein P_c (%), crude fiber C_f (%), oil O_c (%), total carbohydrates C_c (%), and ash A_c (%) content of the seed with wing, seed without wing, and kernel were analyzed following standard methods and three replications.

Figure 3. Graphical representations of length and width of sal seed.

Note: *Fz* is the axial force.



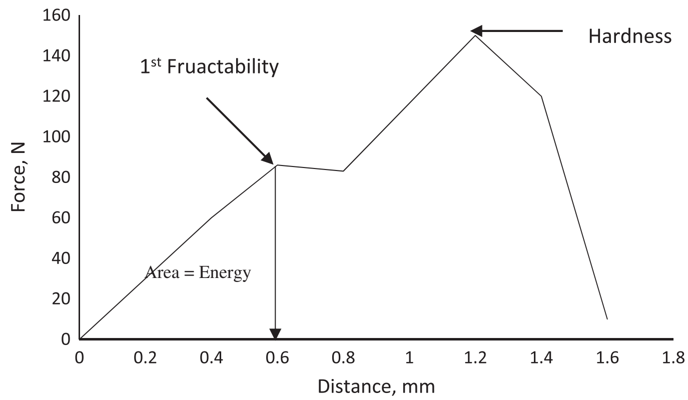


Figure 4. Typical force–deformation curve for compressed sal sample.

The samples were grounded to a fine powder with a home blender. Ten grams of the sample was used for determination of the wet basis moisture content (Horwitz & Latimer, 2000). Protein content was determined by Lowry method using 0.5 g of samples (Dulley & Grieve, 1975). Carbohydrates were determined by the Lane and Eynon method. Crude fiber content was evaluated by sequential hot digestion of the defatted samples with dilute acid and alkaline solution. Ash content was determined by muffle furnace method at 550°C (Horwitz & Latimer, 2000). Dried samples were used for oil extraction. Samples were packed in (26 mm × 60 mm) thimble and transferred into a soxhlet apparatus. The oil was extracted using n-hexane at 60°C. The extracted samples were de-solventized by rotary evaporator (IKA, RE 10, Germany) at controlled temperature. The oil content was determined as a percentage of the extracted oil relative to the sample weight (w/w). The samples were analyzed in triplicate and the mean and standard deviations were calculated. The oil obtained was stored at 4°C for further investigation. Analysis was carried out according standard methods (Abdulkarim et al., 2005; Horwitz & Latimer, 2000).

2.5. Physico-chemical characteristics of sal oil

The sal oil was extracted by soxhlet extraction method. Physico-chemical characteristics of oil such as moisture, acid value, iodine value, free fat acid value, peroxide value, saponification value, refractive index, color, insoluble matters, and viscosity were determined by standard methods (Abdulkarim et al., 2005; Akinhanmi, Atasie, & Akintokun, 2008; Horwitz & Latimer, 2000; Indian Standard, 1975).

2.6. Free fatty acid analysis of sal oil

Free fatty acid analysis of sal seed oil was determined by conversion of triacylglycerol's to fatty acid methyl esters (FAME) followed by gas chromatography according to AOAC (Horwitz & Latimer, 2000). FAMEs were analyzed on a Fisons 8000 series gas chromatography (Fisons Co. Italy), equipped with a Flame Ionization Detector and a fused silica capillary column (100 m × 0.25 mm i.d), coated with 0.20/m SP2560 (Super Inc., Bellefonte, PA) as the stationary phase. Injector and detector temperatures were set at 260°C. A reference standard FAME mix (Supelco Inc.) was analyzed under the same operating conditions to determine the peak identity. The FAMEs were expressed as relative area percentage (Abdulkarim et al., 2005; Belhaj, Arab-Tehrany, & Linder, 2010; Tan, Ghazali, Kuntom, Tan, & Ariffin, 2009).

3. Results and discussion

3.1. Seed description

Sal seed consists of mainly seed with wing, seed without wing, kernel and seed coat. The following flow chart represents the component of sal seed (Figure 5). The average moisture content of seed with wing, seed without wing, and kernel at the time of the experiment were 9.50, 9.54, and 12.14%, (w.b.), respectively. Table 1 shows the size distribution of seed with wing at the moisture content of 9.50% (w.b). The length of the seed with wing ranged from 90.2 to 51.2 mm. About 67% of the seeds were of medium size with length ranging from 60.6 to 80.8 mm, while about 20 and 17% were large

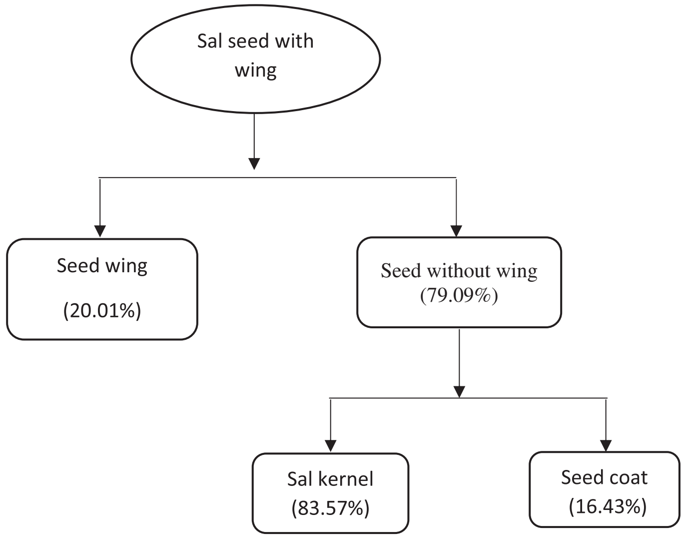


Figure 5. Components of sal seed.

Table 1. Size distribution of seed with wing at the moisture content of 9.50% (w.b)

Particulars	Ungraded	Size category		
		Large	Medium	Small
Length of the seed (mm)	90.2–51.2	> 80.8	80.8–60.6	< 60.6
Percentage of sample (No)	100	20	67	13
Average dimension				
Length (*L*), mm	70.7 ± 10.1	71.5 ± 10.2	71.0 ± 10.1	70.9 ± 10.2
Width (*W*), mm	49.0 ± 18.9	48.9 ± 18.6	49.4 ± 18.8	49.5 ± 19.0
Arithmetic mean diameter, mm	40.5 ± 07.5	40.7 ± 07.3	40.7 ± 07.4	40.7 ± 07.4
Geometric mean diameter, mm	17.1 ± 05.1	17.2 ± 05.3	17.2 ± 05.1	17.2 ± 05.2

Note: ± is the standard deviation.

Table 2. Size distribution of seed without wing at the moisture content of 9.54% (w.b)

Particulars	Ungraded	Size category		
		Large	Medium	Small
Length of the seed (mm)	33.1–21.2	> 29.3	24.1–29.3	< 24.1
Percentage of sample (No)	100	18	68	14
Average dimension				
Length (*L*), mm	26.7 ± 02.6	26.5 ± 02.6	26.7 ± 02.6	26.6 ± 02.6
Width (*W*), mm	12.8 ± 01.0	13.0 ± 01.0	12.8 ± 01.0	12.8 ± 01.0
Arithmetic mean diameter, mm	19.8 ± 01.5	19.8 ± 01.5	19.8 ± 01.5	19.7 ± 01.5
Geometric mean diameter, mm	16.3 ± 01.1	16.4 ± 01.1	19.7 ± 01.5	16.3 ± 01.1

Note: ± is the standard deviation.

size (> 80.8 mm) and small size (< 60.6 mm) seeds, respectively. Table 2 shows the size distribution of seed without wing at the moisture content of 9.54% (w.b). The length of the seed without wing ranged from 33.1 to 21.2 mm. About 68% of the seeds were of medium size with length ranging from 24.1 to 29.3 mm, while about 18 and 14% were in the large size (>29.3 mm) and small size (<24.1 mm) category, respectively. Table 3 shows the size distribution of kernel at the moisture content of 12.14% (w.b). The length of the kernel ranged from 17.9 to 14.35 mm. About 68% of the seeds were of medium size with length ranging from 15.5 to 13.1 mm, while about 19 and 13% were

Table 3. Size distribution of kernel at the moisture content of 12.14% (w.b)

Particulars	Ungraded	Size category		
		Large	Medium	Small
Length of the seed (mm)	17.9–14.35	> 15.5	15.5–13.1	< 13.1
Percentage of sample (No)	100	19	68	13
Average dimension				
Length (*L*), mm	14.35 ± 1.20	14.35 ± 1.20	14.35 ± 1.20	14.13 ± 1.15
Width (*W*), mm	10.82 ± 0.98	10.82 ± 0.98	10.82 ± 0.98	10.71 ± 0.95
Arithmetic mean diameter, mm	12.59 ± 0.94	12.59 ± 0.94	12.59 ± 0.94	12.42 ± 0.89
Geometric mean diameter, mm	11.59 ± 0.94	11.59 ± 0.90	11.59 ± 0.90	11.45 ± 0.85

Note: ± is the standard deviation.

in the large size (>15.5 mm) and small size (<13.1 mm) category, respectively. The frequency distribution curve of length and width of the seed with wing, seed without wing, and kernel are shown in Figures 6–8. These frequency distribution curves show that there is no significance difference between seed with wing, seed without wing, and kernel.

Some physical properties of seed with wing, seed without wing, and kernel are presented in Table 4. The average length, and width of seed with wing, seed without wing, and kernel were 70.20 ± 10.7, 26.75 ± 0.06, 14.35 ± 1.20 mm, and 48.95 ± 18.8, 12.88 ± 18.80, 10.82 ± 0.98 mm, respectively. It was higher than the *Thevetia peruvuana* fruits and kernel (Sahoo et al., 2009), *Jatropha curcas* kernel (Sirisomboon & Kitchaiya, 2009), Jatropha *curcas* fruits and nuts (Sirisomboon et al., 2007) and sal kernel was smaller than the *Jatropha curcas* kernel (Sirisomboon et al., 2007) and mahua flower (Patel et al., 2011). The average arithmetic mean diameter and geometric mean diameter was calculated to be 40.30 ± 7.50, 19.8 ± 1.5, 12.580.94 mm, and 17.00 ± 5.10, 16.3 ± 1.1, 11.58 ± 0.89 mm, for seeds with wing, seeds without wing, and kernels, respectively.

The experimental values of sphericity and aspect ratio for seed with wing, seed without wing, and kernel was found to be 0.24, 0.61, 0.83, and 71.00%, 48.00%, 75.63%, respectively (Table 4). It was higher than the bottle guard seeds (Pradhan, Said, & Singh, 2012), water melon seeds, and pumpkin seed (Altuntaş, 2008). Food grains or seeds are considered spherical when the sphericity value is more than 0.70 (Garnayak, Pradhan, Naik, & Bhatnagar, 2008). Hence, sal kernel can be treated as an equivalent to sphere. Considering the low aspect ratio relating the seed width to length, it may be deduced that the sal seed would slide on their flat surfaces rather than roll (Pradhan et al., 2010). The surface area of the seed with wing was larger than the sal seed without wing and kernel (Table 4). The mass or energy transfer rate through the surface of the seeds might be slower than

Figure 6. Frequency distribution of seed with wing at 9.50% moisture content (w.b).

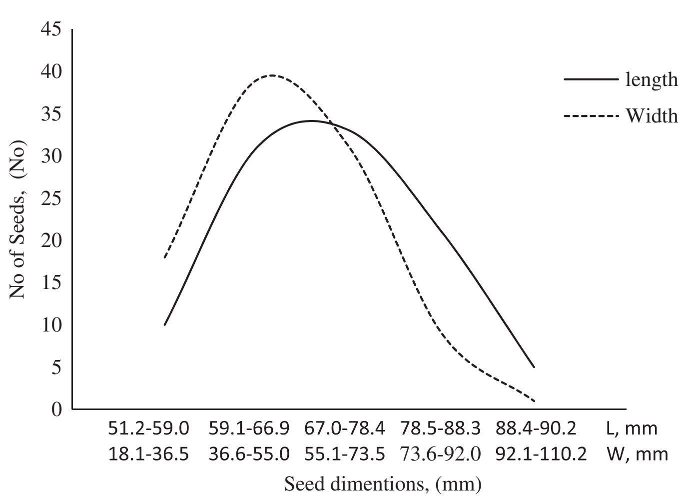


Figure 7. Frequency distribution of seed without wing at 9.54% moisture content (w.b).

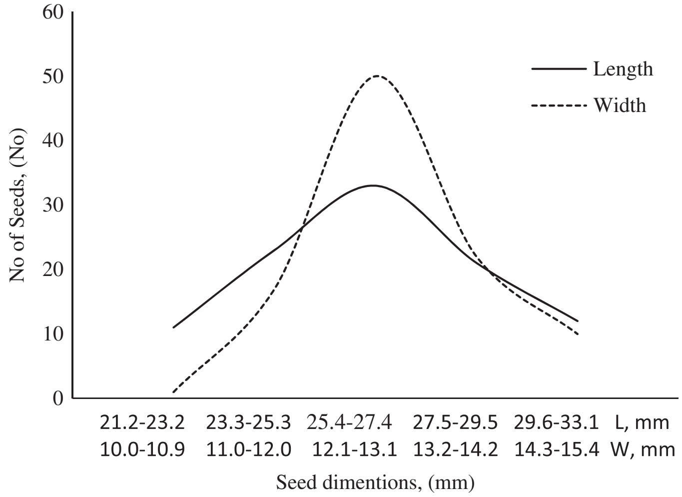


Figure 8. Frequency distribution of kernel at 12.14% moisture content (w.b).

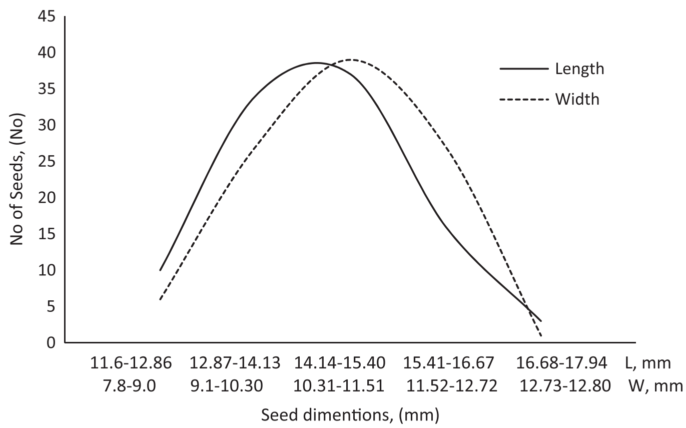


Table 4. Physical properties of seed with wing, seed without wing, and kernel at 9.50, 9.54, and 12.14% of moisture content (w.b), respectively

S. No.	Properties	*N*	Seed with wing	Seed without wing	Kernel
1	Length, mm	100	70.20 ± 10.7	26.75 ± 10.70	14.35 ± 1.20
2	Width, mm	100	48.95 ± 18.8	12.88 ± 18.80	10.82 ± 0.98
3	Arithmetic mean diameter, mm	100	40.30 ± 7.50	19.8 ± 1.5	12.58 ± 0.94
4	Geometric mean diameter, mm	100	17.00 ± 5.10	16.3 ± 1.1	11.58 ± 0.89
5	Sphericity, (decimal)	100	0.24 ± 0.60	0.61 ± .4	0.83 ± 0.05
6	Aspect ratio, %	100	71.0 ± 3.00	48.00 ± 0.5	75.63 ± 6.89
7	Surface area, mm^2	100	998.01 ± 15.00	840.00 ± 11.6	424.10 ± 6.51
8	1,000 seed mass, g	10	1,135 ± 2.00	955 ± 5.89	772.8 ± 12.62
9	Bulk density, kg/m^3	10	127.8 ± 10.39	382 ± 31.90	580 ± 24.94
10	True density, kg/m^3	10	937 ± 12.7	935 ± 28.4	1,073.4 ± 42.46
11	Porosity, %	10	85.00 ± 0.03	56.00 ± 0.05	45.46 ± 3.70
12	Angle of repose, degree	10	62.43 ± 0.09	58.61 ± 1.05	54.26 ± 4.61

Note: *N* is the number of the sample, ± is the standard deviation.

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Table 5. Frictional properties of seed with wing, seed without wing, and kernel at moisture content of 9.50, 9.554, and 12.14% (w.b), respectively

S. No.	Coefficient of friction	*N*	Seed with wing	Seed without wing	Kernel
1	Galvanized iron steel	10	0.58 ± 0.04	0.34 ± 0.03	0.36 ± 0.05
2	Ply wood	10	0.31 ± 0.02	0.27 ± 0.03	0.28 ± 0.05
3	Glass sheet	10	0.39 ± 0.03	0.29 ± 0.04	0.30 ± 0.04
4	Plastic sheet	10	0.38 ± 0.02	0.30 ± 0.05	0.34 ± 0.03
5	Aluminum sheet	10	0.29 ± 0.03	0.40 ± 0.02	0.20 ± 0.03

Note: *N* is the number of the sample, ± is the standard deviation.

that of the kernels as the surface area of seeds with wing and seeds without wing is higher that of the kernels.

The average 1,000 sample mass was found to be 1,135 ± 2.0, 955 ± 5.89, and 772.8 ± 12.62 g for seeds with wing, seeds without wing, and kernels, respectively. It was lower than the bottle gourd seed (Pradhan et al., 2012). The bulk density and true density of seeds with wing, seeds without wing, and kernelswere 127.8 ± 10.39, 382 ± 31.90, and 580 ± 24.94 kg/m^3 and 937 ± 12.7, 935 ± 28.4 and 1,073.4 ± 42.46 kg/m^3, respectively. The respective porosity of seeds with wing, seeds without wing, and kernelswere found to be 85.00 ± 0.03, 56.00 ± 0.05 and 45.46 ± 3.70%. The porosity of the bulk of kernel was lower than that of seed with wing and seed without wing. The bulk density, true density, and porosity was lower than that of *bambara* groundnuts (Mpotokwane, Gaditlhatlhelwe, Sebaka, & Jideani, 2008) and coriander seeds (Coşkuner & Karababa, 2007) and higher than the hazel nuts (Aydin, 2003). These parameters are important to determine the capacity of storage bins (Sahoo et al., 2009).

The average angle of repose of the seeds with wing, seeds without wing, and kernels were found to be 62.43°, 58.61°, and 54.26°, respectively. The angle of repose for seed with wing was higher than the seed without wing and kernel. This might be due to the surface characteristics of seeds leading to the higher cohesion among the individual seeds and therefore the higher value of angle of repose. The results of the coefficient of friction, which may directly and indirectly affect the design of the processing machine, was determined on five different surface namely ply wood, galvanized iron, plastic, aluminum, and glass sheet, and tabulated in Table 5. It was observed that coefficient of friction was highest for seeds with wing as compared to seeds without wing and kernels. This might be explained by the rough surface of the seed with wing. The seeds have smoother surface allowing them to slide easily on the surfaces.

The mechanical properties of seeds with wing, seeds without wing, and kernels including hardness, deformation at hardness, deformation at hardness percentage, fracturability, 1st fracture at deformation, and energy for fracture are presented in Table 6. The hardness of the seeds with wing

Table 6. Mechanical properties of seed with wing, seed without wing, and kernel at 9.50, 9.54, and 12.14% of moisture content (w.b), respectively

S. No.	Properties	Seed with wing	Seed without wing	Kernel
1	Hardness, N/mm	39.32 ± 22.08	42.49 ± 12.01	72.14 ± 16.34
2	Deformation at hardness, mm	1.93 ± 0.79	1.55 ± 0.51	1.82 ± 1.54
3	% of Deformation at hardness	15.20 ± 6.90	12.40 ± 4.20	20.50 ± 15.30
4	Fracturability, N	29.31 ± 17.92	23.32 ± 14.77	53.19 ± 33.32
5	1st Fracture at deformation, mm	1.09 ± 0.44	0.63 ± 0.16	0.62 ± 0.37
6	Energy for fracture, N-mm	69.20 ± 8.66	56.45 ± 23.67	79.60 ± 13.62

Note: ± is the standard deviation.

and seeds without wing was lower than the kernels. This can be explained by the smoother surface of the seed coat and wings in contrast of the hard texture of the kernel. Similar results were reported by Sirisomboon (Sirisomboon et al., 2007). Deformation at hardness and deformation at percentage seeds with wing, seeds without wing, and kernels are listed in Table 6. The hardness and deformation at hardness show higher values for kernels due to the hard surface of the kernel, that is 1.82 ± 1.54 mm and 20.50 ± 15.30%, and lesser value for seed with wing (1.93 ± 0.79 mm and 15.20 ± 6.90%), and seed without wing (1.55 ± 0.51 mm and 12.40 ± 4.20%), respectively.

The force needed to fracture the kernel was higher than the seed with wing and seed without wing that is 53.19 ± 33.32 N for kernel and, 29.31 ± 17.92 N and 23.32 ± 14.77 N for seed with wing and seed without wing, respectively. It was lesser than the drum roasted cashew nut (Swain & Gupta, 2013) and apricot pit (Vursavuş & Özgüven, 2004). This is because kernel has a harder surface. The 1st fracture at deformation was also reported in Table 3. Energy for fracture for sal seeds, whole seeds, and kernels is calculated and tabulated in Table 3. Energy required for sal kernel was higher than the sal seed and whole seed. It was lesser than that of the *Jatropha curcas* fruit, nuts, and kernel. This value indicates how easily the material can broken. These indicate that the mechanical properties of the seeds and kernels depend, to some extent, on its original size and minimum clearance between the taper compression surfaces needed for de-hulling or de-shelling of the seeds.

The proximate composition of seeds with wing, seeds without wing, and kernels are tabulated in Table 8. It was observed that the moisture content of the kernels was higher than the seeds with wing and seeds without wing. It indicated that seeds with low moisture content can be stored for a longer time without spoilage. The oil content of the seed with wing, seed without wing, and kernel are presented in Table 7. The oil content of kernel (30.20%, w/w) was higher than the seeds with wing (14.60%, w/w) and seeds without wing (23.36%, w/w) as the oil-free shell and wings are removed. The high percentage of oil makes this seed a distinct potential for the oil industries. Seeds with wing, seeds without wing, and kernels also contained protein, carbohydrates, crude fiber, and ash content. Fat content of seed with wing was higher than *akee* seed (Akinhanmi et al., 2008) and lower than the *citrullus lantus* seed (Ahmadi, Fathollahzadeh, & Mobli, 2009). Table 7 shows that protein content in kernels was higher than the seeds with wing and seeds without wing. Similar results were obtained for *Jatropha curcas* (Karaj & Müller, 2010). The crude fiber content of seed with wing, seed without wing, and kernel are reported in Table 8. It shows that seed without wing contained more crude fiber than the kernel and seeds with wing. Crude fiber helps in the maintenance of normal peristaltic movement of the intestinal tract; hence, diet containing low fiber could cause constipation and eventually lead to colon diseases (Akinhanmi et al., 2008). Ash content of kernels was generally higher than the seeds with wing and seeds without wing; this indicates the kernels contain more inorganic matter than the sal seeds and whole seeds. The results show that the carbohydrate content of seeds with wing is higher than the seeds without wing and kernel (Table 8). According to the proximate composition analysis *Shorea robusta* seeds are good source of fat, protein, crude fiber, and carbohydrates compared to other oil seeds. These seeds can be utilized as an alternate source of edible oil and protein.

Table 7. Proximate composition of seeds with wing, seed without wings, and kernels

S. No.	Composition (%)	Seeds with wing	Seeds without wing	Kernels
1	Moisture	9.50 ± 0.12	9.54 ± 0.11	12.14 ± 0.07
2	Protein	8.42 ± 0.10	8.95 ± 0.01	9.39 ± 0.11
3	Carbohydrates	62.53 ± 0.96	52.06 ± 0.05	42.11 ± 0.61
4	Oil	14.60 ± 0.20	23.36 ± 0.11	30.20 ± 0.05
5	Crude fiber	2.34 ± 0.03	2.59 ± 0.05	2.41 ± 0.04
6	Ash	3.11 ± 0.13	3.93 ± 0.08	3.75 ± 0.10

Note: ± is standard deviation.

Table 8. Physico-chemical properties of sal oil

S. No.	Properties	Unit	Sal oil
1	Moisture (w.b)	%	0.75 ± 0.01
2	Acid value	mg KOH/g	32.05 ± 0.2
3	Iodine value	mg/100 g	7.6 ± 0.12
4	Saponification value	mg KOH/g	189.2 ± 1.04
5	Peroxide value	Eq. O_2/kg	3.80 ± 0.10
6	Specific gravity	40°± C	0.88 ± 0.01
7	Refractive index	40°± C	1.44 ± 0.01
8	Viscosity	Pa/s	1.83 ± 0.01
9	Insoluble matters	%	2.7 ± 0.10
10	Color	L	12.95 ± 0.48
		a	1.02 ± 0.05
		b	1.3 ± 0.07

Note: ± is standard deviation.

The physico-chemical properties of the oil extracted from the sal seeds are presented in Table 8. It is lesser than the moisture content of rubber seed oil (Asuquo, Anusiem, & Etim, 2012) and caster seed oil (Asuquo, Anusiem, & Etim, 2010). Low moisture content is an indication of good shelf life for the oil. Acid value of the oil was 32.05 mg KOH/g. It is lower than that of palm oil and ground nut oil (Akinhanmi et al., 2008). Lower acid value signifies lower degree of unsaturation. Iodine value of the sal oil was found to be 7.6 mg/100 g (Table 8). It is lesser than that of the *Lophira lanceolate* seed and *Detarium microcarpum* seed (Kyari, 2008). It determines the stability of oils to oxidation, and allows the overall unsaturation of the fat to be determined qualitatively (Asuquo et al., 2012). The low iodine value indicates that the oil has low content of unsaturated fatty acids. The saponification value of sal oil was 189.2 mg/KOH. It was lesser than that of the *Spondias mombin* seed oil (Eromosele & Paschal, 2003) and saponification value is within the same range of some edible oils namely, palm oil, ground nut oil, and corn oil (Çalışır, Hacıseferoğulları, Özcan, & Arslan, 2005). The higher the saponification value of oil, the higher the lauric acid content of that oil. The lauric acid content and the saponification value of oil serve as important parameters in determining the suitability of oil in soap making (Asuquo et al., 2010). Hence, the oil can be used for soap making and cooking.

Peroxide value of 3.80 Eq.O_2/kg was obtained for this study. Peroxide value is an indication of deterioration of oils. It is lesser than that of the palm oil (Pandurangan, Murugesan, & Gajivaradhan, 2014). This value helps to understand the keeping quality of the oil. The specific gravity of sal oil was 0.88. The specific gravity index is an indication of purity of the oil. Lower value of specific gravity

Table 9. Fatty acid composition of sal oil

S. No.	Fatty acids	% Composition
1	Palmitic acid (16:0)	5.91
2	Palmtoleic acid (16:1)	0.12
3	Margaric acid (17:0)	0.23
4	Stearic acid (18:0)	45.11
5	Oleic acid (18:1)	36.2
6	Linoleic acid (18:2)	1.86
7	Linolenic acid (18:3)	0.44
8	Arachidic acid (20:0)	7.07
9	Eicosenoic acid (20:1)	0.26

suggests that sal oil is of high purity as compared to many other non-conventional oils. The refractive index of the sal oil (1.44)was within similar range of other edible oils from sesame seeds and sunflower seeds (Mariod, Mustafa, Nour, Abdulla, & Cheng, 2015). It also indicates that the sal oil is thinner than many other similar type of oils with refractive indices between 1.475 and 1.485 (Akinhanmi et al., 2008).

Viscosity of sal oil was found to be 1.83 pa/s which is lesser than the castor oil and shear butter oil (Asuquo et al., 2010). It is a measure of resistance to shear. Lower the viscosity, higher is the flow. Insoluble matter of the sal oil was only 2.7%. The oil is light green in color (Table 9). The color of the oil is used primarily to judge the quality of the oil.

The free fatty acid profile of sal oil was determined by gas chromatography. The sal oil is composed of saturated and unsaturated fatty acids. The saturated fatty acid included stearic acid, arachidic acid, palmitic acid, and margaric acid. The unsaturated fatty acids are palmtoleic acid, oleic acid, linoleic acid, linolenic acid, and eicosenoic acid (Table 9). Stearic acid was the predominant fatty acid in the studied sample and accounted for 45.11% of total fatty acid. Oleic and linoleic acid contents were 36.2% and 1.86%, respectively. These two fatty acids are known to reduce the chances of cardiovascular disease and increase the immune defense system (Lès-Nancy, 2014). The high percentage of oleic acid in the sal oil makes it desirable in terms of nutrition and high stability while cooking and frying. It can be used as an alternate to corn and sunflower oil (Abdulkarim et al., 2005; Tan et al., 2009). Other fatty acids found were palmitic acid (5.91%), palmtoleic acid (0.12%), margaric acid (0.23%), linolenic acid (7.07%), arachidic acid (7.07%), and eicosenoic acid (0.26%). It shows that the sal oil can be a good source of saturated and unsaturated acids with health benefits. The results of the present study will help the oil processing industries to find out the most economically viable oil blends for cooking purpose, with maximum nutrition as well as desirable physico-chemical properties.

4. Conclusion

The present work investigated various physical, chemical, and mechanical properties of sal seeds with wing, seeds without wing, and kernels. Physical properties such as length, width, arithmetic mean diameter, geometric mean diameter, aspect ratio, surface ratio, 1,000 seed mass, bulk density, true density, porosity, and coefficient of friction on various surfaces were determined and their importance were highlighted. Mechanical properties such as hardness, deformation at hardness, deformation at hardness percentage, fracturability, 1st fracture at deformation, and energy for fracture were determined and their importance were also highlighted. The proximate composition of seeds with wing, seeds without wing, and kernels, namely, moisture, protein, oil, carbohydrates, crude fiber, and ash content were determined. The chemical properties of sal oil were determined. The free fatty acid composition of sal oil was evaluated. The results showed that kernel contains high percentage of moisture compared to seeds with/without wings. The results also show that 68% of seeds with wing, seeds without wing, and kernels come under medium size group. The energy required to fracture the kernel (79.60 N-mm) was higher than the seeds with wing (69.20 N-mm) and seeds without wing (56.45 N-mm). The kernel (23.36%) contains high percentage of oil compared to seeds with wing (14.60%) and seeds without wing (23.36%). The sal oil has high percentage of saturated and unsaturated fatty acids. The physico-chemical and mechanical properties of sal oil indicate that it can be used for the production of cocoa-based products, confectionery products, and various other food and non-food products. Sal seeds have the potential to become a new source of oil.

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Note
[i] This study was conducted to determine various engineering and chemical properties of sal seeds and their components, which provide the necessary data to researchers, scientists, industry people for design and development of equipment.

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