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A comprehensive study of Sal seed properties and oil composition

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Abstract
The study was conducted to determine the physiochemical properties of Sal seed and its oil. The triglyceride content of Sal oil is well-suited for the food industry. The dimensions of the Sal seed, including its average length, width and thickness, were determined to be 20.25 mm, 12.79 mm and 11.99 mm, respectively. The average value of sphericity and geometric mean diameter was found to be 0.72 and 14.58 mm, respectively. The values of bulk density, true density and porosity were 463.73 kg/m³, 1051.76 kg/m³ and 55.89%, respectively. The angle of repose was found to be 30° and the coefficient of friction for different surfaces, such as glass sheet, galvanized steel, stainless steel and mild steel, was 0.30, 0.35, 0.42 and 0.44, respectively. The Sal seeds contained 10.67% moisture (wb), 13.82% oil, 9.04% protein, 2.12% fiber, 2.89% ash and 61.15% carbohydrates. The specific gravity, refractive index, acid value, free fatty acid, saponification value and peroxide value were found to be 0.91, 1.452, 2.70 mg KOH/g oil, 1.36%, 191.47 mg KOH/g oil and 4.02 meq/1000 g, respectively.

Keywords: Sal seed, properties, oil extraction, quality analysis

Introduction

Sal, scientifically known as *Shorea robusta*, is a significant multipurpose and commercial tree species in India that is native to Southeast Asia and the Indian subcontinent. It belongs to the *Dipterocarpaceae* family and covers approximately 14% of India's total forest area, with a growth area of 10 million hectares (Chitale and Behera, 2012) [10]. Chhattisgarh ranks third in terms of forest cover area, with a total of 0.24 lakh km^2 (Singh *et al.*, 2014) [28]. Sal trees can reach heights of up to 30-50 meters and are a significant source of timber and non-timber forest produce (NTFPs) in India. They can withstand temperatures between 11-44 ℃ and require an average annual rainfall of 1000-3500 mm. The Planning Commission of India has identified Sal seed as a potential NTFP for enterprise development with an estimated 1.5 million tons of seed availability (Patnaik and Mohapatra, 2013) [20] and 35 thousand tons of seeds have been collected in Chhattisgarh. In India, the potential availability of Sal fat is 0.18 million tons which is suitable for the food industry due to its symmetrical triglyceride content (Patnaik and Mohapatra, 2013) [20].

To guarantee the quality of Sal oil production and enhance trade opportunities, it is essential to employ suitable machines and methods for extracting the available oil. Oil extraction necessitates the breaking of the outer shell of the seed, which is followed by decortication. The physical properties of the seed, such as size and shape, are vital for the development of equipment for screening, separation, handling, storage, drying, decortications and oil extraction.

Several physical properties, such as bulk density, true density and porosity, are indispensable for the design of seed hoppers and storage facilities (Sahoo *et al.*, 2009) [26]. The angle of repose is a critical parameter for determining the belt conveyor width and designing the shape of storage bins. The static coefficient of friction determines the magnitude of the frictional force, which affects the power required and the maximum inclination angle on various surfaces of the conveyor and storage bin (Sahay and Singh, 2013; Sirisomboon and Kitchaiya, 2009) [25, 29].

Furthermore, to extract the oil, it is crucial to determine the physiochemical properties of the seed, such as dimensions, frictional properties and proximate composition, which are essential in assessing its total qualitative value (Rahman *et al.*, 2017) [22]. The physicochemical properties of oil, including its overall quality, stability and economic value, are also critical factors that must be considered (Chandra *et al*., 2016) [8]. In this study, a comprehensive analysis of the major physical and proximate properties of the seed and the physicochemical properties of Sal oil was conducted.

Materials and Methods

Sample preparation

Sal seeds were procured from the Forest Office, Gariyaband District situated in Chhattisgarh. The seeds were cleaned manually to remove foreign materials like dust, sticks, broken and immature seed. The cleaned and graded Sal seeds were sun dried and the initial moisture content was determined using the Hot-air oven method at 105±1°C for 24 h (Ozarslan, 2002; Yalcin *et al*., 2007) [17, 31]. The average moisture content was found to be 10.67% (wb).

Sal seed with wings

Decorticated sal seed

Splitted sal kernels

Fig 1: Sal seed

Seed dimensions

To determine axial dimensions, 100 seeds were randomly selected. The three principal dimensions, namely, length L, breadth B and thickness T, were measured using a Vernier caliper (Mitutoyo Corporation, Japan) with a least count of 0.01 mm. Seed sphericity (ϕ) was calculated using the following relationship (Mohsenin, 1986) [14]:

$$\varphi = \frac{(LBT)^{1/3}}{L} \times 100 \qquad (1)$$

The geometric mean diameter (mm) of the seeds was calculated using the following relationships (Mohsenin, 1986) [14]:

$$D_g = (LBT)^{1/3} \qquad (2)$$

Thousand seed mass

The one thousand seed mass was determined by using of an electronic balance reading to 0.001 g. The measurement was done in triplicate and the mean value was calculated.

Density and porosity

Bulk density is the ratio of the mass sample of the seed to its volume. It was determined by filling a 250 ml graduated measuring cylinder with a known quantity of seed sample. The true density of the seeds was determined using the toluene displacement method. A weighed sample was immersed in toluene in a 250 ml measuring cylinder. The displaced volume was noted and the true volume of the seed sample was determined. Porosity is the ratio of the internal pores in the particle to its bulk volume. It was calculated as the ratio of the difference between the true density and bulk density to the true density (Mohsenin, 1986) [14].

$$\text{Porosity (\%)} = 1 - \frac{\text{Bulk density}}{\text{True density}} \times 100 \qquad (3)$$

Frictional properties

The angle of repose was measured using a fixed-height funnel fitted at a height of 10cm from the base of the circular disc (D). A 500g seed sample was allowed to flow through the funnel into the base and a pile (H) was formed at the base. The angle of repose was calculated using the following formula:

$$\theta = \tan^{-1} \frac{2H}{D} \qquad (4)$$

Sal seeds were placed in a bottomless, open-topped cubical container on different surfaces. The box was pulled onto the test surfaces to measure the horizontal force using a mechanical driving unit. The maximum friction force was obtained when the box started moving and was used to calculate the static coefficients of friction, as per the formula (Sacilik *et al*., 2003) [23].

$$\mu = \frac{F}{N_f} \qquad (5)$$

Where,
μ = coefficient of friction
F = friction force (N)
N_f = normal force (N)

Proximate Composition of Sal Seed

Fat content

The oil extraction was done using Soxhlet (SoxTRON Sox-6) automatic fat estimation system according to AOAC, 2010 [4]. The ground Sal seed were weighed placed in a thimble and then placed in an oven-dried beaker. The beaker was filled with 80 mL of hexane, partially immersed, and boiled at 100°C for 45 min and 180°C for another 45 min, allowing the evaporated hexane to condense and mix with the sample. The beakers containing oil was then dried in aim to remove solvent completely then beakers were cooled and weighed. The percentage of oil was calculated using the following formula:

$$\text{Fat content (\%)} = \frac{W_2 - W_1}{W_S} \times 100 \qquad (6)$$

Where,
W_1 = Weight of empty beaker (g)
W_2 = Weight of beaker containing oil (g)
W_s = Initial weight of sample (g)

Protein content

The protein content was determined using the Kjeldahl apparatus). The ground seed samples were weighed and digested at 420 °C for 3-4 h, in the presence of H_2SO_4 and the catalyst, which was then converted into ammonium sulfate. It was further distilled with 40% NaOH solution and the vapor was condensed in 4% boric acid solution and then titrated against 0.1 N Hydrochloric acid upto a light pink color. The nitrogen value was then multiplied by conversion factor 6.25 to obtain the protein content (Sadasivam and Manickam, 2005) [24].

$$N\,(\%) = \frac{14.007 \times (SR - BR) \times 0.1 \times 100}{1000 \times Ws} \quad (7)$$

Where,
Molecular weight of nitrogen = 14.007
SR = Titrated reading of the sample (mL)
BR = Titrated reading of the blank sample (mL)
W_s = Initial weight of the sample (g)

Fiber content

The fiber content was determined using method (AOAC, 2010) [4] by automatic fiber estimation system. The process involves two steps acid and alkali washes. The defatted sample was placed in a crucible, heated, and boiled in a solution of H_2SO_4. The residue was then rinsed with distilled water to make it acid free. The residue was boiled with NaOH and washed with distilled water to make it alkali-free. The boiling process for both the washes was 45 min at 450°C. The crucibles were dried and then ashed in a muffle furnace at 550°C for 3hr, cooled in desiccators and weighed. The crude fiber content was calculated by calculating the difference in weights.

$$\text{Fiber content}\,(\%) = \frac{W_1 - W_2}{W_S} \times 100 \quad (8)$$

Where,
W_1 = Weight of sample after oven drying (g)
W_2 = Weight of sample after ashing (g)
W_s = Initial weight of sample (g)

Ash content

Ash content was determined using the method described by Nielsen (2017) [16]. The sample was weighed in an oven-dried silica crucible, charred on a heating coil and kept in a muffle furnace at 550°C for 4 h until white ash formed. Ash content was calculated using the following formula:

$$\text{Ash content}\,(\%) = \frac{W_2 - W_1}{W_S} \times 100 \quad (9)$$

Where,
W_1 = Weight of empty crucible (g)
W_2 = Weight of crucible and ash (g)
W_s = Initial weight of sample (g)

Carbohydrate content

The Anthrone reagent method was used to determine carbohydrate content (Sadasivam and Manickam, 2005) [24]. The sample was hydrolyzed with 2.5 N HCl, neutralized with sodium carbonate and centrifuged. The working standard was prepared using glucose, and the sample was boiled in water for 8 min. Absorbance was measured using a double-beam spectrophotometer at 630nm. A graph was plotted between the X-axis as the concentration of the standard and the Y-axis as absorbance to determine the carbohydrate content in the sample.

$$\text{Amount of carbohydrates present in 100 mg sample} = \frac{\text{mg, of glucose}}{\text{Volume of test sample}} \times 100\,(\%) \quad (10)$$

Oil extraction methods

The Soxhlet apparatus was utilized to extract oil from the ground seed sample. A weighed amount of Sal seed powder was placed in a thimble, and n-hexane was employed as the solvent for extraction. The process was conducted at a constant temperature of 68°C for 3 hours within the Soxhlet extraction unit. Following the extraction, the obtained oil was collected using a distillation unit to separate it from the solvent.

Physicochemical Properties of Sal Seed Oil

Specific gravity

The specific gravity of the oil was determined using a pycnometer or a density bottle. This indicates the quality of the oil and is influenced by its chemical composition (AOAC Method 985.19, 2000).

Refractive index

Refractometer is used to determine the refractive index which measures the bending of a ray of light when passing from one medium into another. The RI indicates the possible chances of rancidity development and spoilage due to oxidation in oil (AOAC Method 921.08, 2000).

Acid value

The acid value can be defined as the number of potassium hydroxide (KOH) in milligrams required to neutralize free fatty acid in one gram of oil sample. It is a relative measure of rancidity, as free fatty acids are normally formed during the decomposition of triglycerides (AOCS Method Cd 3d-63, 2009).

Free fatty acid

Free fatty acids are a measure of the acid present in oil samples. A small quantity of free fatty acids is usually present in oils along with triglycerides. It increases during storage; therefore, the quality of oil depends on the free fatty acid content (AOCS Method Ca 5a-40, 1997).

Saponification value

Saponification is a process by which fatty acids in the glycerides of oil are hydrolyzed by an alkali. The saponification value is the number of milligrams of alkali solution required to saponify 1 g of the oil sample (AOCS Method Cd 3-25, 2013).

Peroxide Value
The peroxide value is a measure of the peroxides contained in the oil. This indicates the deterioration of the oils. The peroxides present were determined by titration against a sodium thiosulfate solution in the presence of a KI solution. Starch was used as the indicator (Oluremi *et al.,* 2013)

Results and Discussion
Seed dimensions
The study found that the mean dimensions of 100 randomly selected seeds were 20.25 mm, 12.79 mm and 11.99 mm in length, breadth and thickness, respectively, with 86% having lengths between 19-21 mm, 92% having breadths between 12-13 mm and 89% with thicknesses between 11-13 mm. The results showed that the length and breadth of the sal seed were lower than *those of Jatropha curcas* (Sirisomboon *et al*., 2007) [29] and higher than those of the flax seed (Pradhan *et al*., 2010) [21] and groundnut seeds (Mpotokwane *et al*., 2008) [15].

The average geometric mean diameter and sphericity of sal seed was found to be 14.58 mm and 0.72±0.03 respectively. The sphericity was lower than that of the groundnut seed (Mpotokwane *et al*., 2008) [15], but considered spherical when sphericity values more than 0.70 (Garnayak *et al*., 2008) [12]. Hence, a sal seed can be considered equivalent to a sphere.

The average thousand seed mass of seeds without wings and kernels was 1115.67±10.20 g and 967±12.50 g respectively. This value was higher than that of mahua seeds (Sahu *et al*., 2022) [27].

Density and Porosity
The average bulk density, true density and porosity of the seed were 463.73 kg/m^3, 1051.74 kg/m^3 and 55.89, respectively. The bulk density was lower, whereas the true density was higher than that of groundnut (Mpotokwane *et al*., 2008) [15], while the bulk density of pea (Yalcin *et al*., 2007) [31] and true density of soybean (Wandkar *et al*., 2017) [30] were higher than those of sal seeds. The porosity was higher than that of soybean seeds (Wandkar *et al*., 2017) [30] but was near to 56.00% (Chandra *et al*., 2016) [8].

Table 1: Physical properties of sal seed

S.no	Properties	Values
1.	Dimensions	
	Length (mm)	20.25±1.25
	Breadth (mm)	12.79±0.66
	Thickness (mm)	11.99±0.76
2.	Sphericity	0.72±0.03
3.	Geometric mean diameter (mm)	14.58±0.66
4.	Bulk density (kg/m^3)	463.73±8.12
5.	True density (kg/m^3)	1051.74±16.08
6.	Porosity (%)	55.89±1.03
7.	Angle of repose (degree)	29.90±3.01
8.	Coefficient of friction	
	Glass sheet	0.30±0.02
	Galvanised sheet	0.35±0.02
	Stainless steel sheet	0.42±0.03
	Mild steel sheet	0.44±0.03

Frictional properties
The average angle of repose for seed was 29.90 degree ranged from 26.65º to 32.72º which was higher than flaxseed (Pradhan *et al*., 2010) [21] but lower than mahua seed (Sahu *et al*., 2022) [27]. The mean coefficient of friction on four surfaces (glass sheet, galvanized iron, stainless steel and mild steel) was 0.30, 0.35, 0.42 and 0.44 respectively.

Proximate Composition
Fat content
The study found average oil content of 13.82% in sal seed, while comparing to other researches where oil content was 14.8%, 15.39% (Hasan *et al*., 2020) [13] and 13-14%, which indicates oil content vary with variety to variety and region to region.

Protein content
The protein content of sal seed was 9.04%, similar to the findings of Kumar *et al.* (2018) [32] with 8% and Chandra *et al*. (2016) [8] with 9.39% of protein. Sal seed is considered as proteinaceous meal as it contains 9% protein.

Fiber content
The average fiber content of sal seed was 2.13%, similar to previous studies by Kumar *et al.* (2018) [32] to be 1.4% and Chandra *et al.* (2016) [8] as 2.41%, fiber content. The fiber content describes the plant cell wall components, which are usually not or barely digestible by the animals.

Ash content
Ash content used to determine the amount of minerals which was also found to be 2.89%, similar to values reported by Kumar *et al.* (2018) [32] and Rahman *et al.* (2017) [22] about 2.3% and 3.14% respectively.

Carbohydrate content
Sal seeds are also a rich source of carbohydrates, with an average carbohydrate content of 61.15%, similar to 62.70% carbohydrate determined by Kumar *et al.* (2018) [32]. This indicates that sal seed is an energy-rich seed suitable for cattle and poultry feed.

Table 2: Chemical properties of sal seed

S.no	Properties	Values (%)
1	Fat Content	13.82
2	Protein Content	9.04
3	Ash Content	2.89
4	Fiber Content	2.13
5	Carbohydrate Content	61.15

Physicochemical Properties of Sal Oil
Specific gravity
Specific gravity describes the purity of oil, where lower value suggests that oil is of high purity. Sal oil has a specific gravity of 0.91, similar findings were obtained by Kumar *et al.* (2018) [32] where specific gravity ranged from 0.8-0.915 and Pali *et al.* (2013) [18] got value of 0.899. According to Indian standards, oil's specific gravity should range between 0.90-0.920.

Refractive index
Oil was found to have a mean refractive index of 1.452. Kumar *et al.* (2018) [32] and Hasan *et al.* (2020) [13], reported sal seed oil has similar refractive index value of 1.45-1.46 and 1.470 respectively. According to the Indian standards' guidelines, oil's refractive index should range between

1.4600-1.4800. Higher the RI value higher is the chances of spoilage due to oxidation. It also indicates that the sal oil is thinner than other similar type of oils (Akinhanmi *et al*., 2008) [2].

Acid value

The acid value of sal oil was found to be 2.70 mg KOH/ g oil. It is lower than that of palm oil and ground nut oil (Akinhanmi *et al*., 2008) [2]. Lower acid value signifies lower degree of unsaturation. The oil may contain fats that can go rancid because of the possibility of rancidity, which occurs when triglycerides are converted to fatty acids and glycerol, raising the acid value.

Free fatty acid

The FFA value of Sal oil was found to be 1.36%. The FFA is the primary quality attributes for edible grade oil. The Prevention of Food Adulteration Act specify a maximum acceptable limit of FFA as 3% while BIS specify a range of acceptable limit of FFA as 0.5 to 3.0% (FSSAI, 2021) [11].

Saponification value

The mean saponification value of Sal oil was found to be 191.27 mg KOH/g. Kumar *et al.* (2018) [32] and Hasan *et al.* (2020) [13], reported sal seed oil has similar saponification value of 187-193 and 192.14 respectively. According to FSSAI (2021) [11], the permissible value of oil ranges between 180-195 mg KOH/g. Saponification value of sal oil is within the same range of some edible oils namely, palm oil, ground nut oil and corn oil (Calisir *et al*., 2005 and Abdel *et al*., 2014) [7, 1].

A higher saponification value is a measure of low molecular weight of triaceylglycerols of edible fats and oils. The higher the saponification values 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) [5].

Peroxide value of oil

The mean peroxide value of sal oil was found to be 4.02 meq/ 1000 g. Chandra *et al.* (2016) [8], reported sal seed oil has similar peroxide value of 4 and 3.80 meq/ kg oil respectively. It is lesser than that of the palm oil (Pandurangan *et al*., 2014) [19]. According to FSSAI (2021) [11], the permissible value of saponification value for oil ranges between 180-195 mg KOH/g. According to Indian Standard guidelines fresh oils usually have peroxide values well below 10 meq/kg. A rancid taste often begins to be noticeable when the peroxide value is above 20 meq/kg (between 20-40 meq/kg).

Table 3: Physicochemical properties of oil

S.no	Physicochemical properties	Values
1	Specific gravity	0.91
2	Refractive index	1.452
3	Acid value (mg KOH/ g)	2.70
4	Free fatty acid (%)	1.36
5	Saponification value (mg KOH/g)	191.27
6	Peroxide value (meq/ 1000 g)	4.02

Conclusion

In conclusion, the physical characteristics of Sal seeds are vital for designing equipment used in storage, decortications and oil extraction processes. Compared to other oil seeds, Sal seeds possess good nutritional value, making them an alternate source of edible oil and protein. The acid value, FFA value and peroxide value of the extracted oil were all found to be well below the maximum permissible limit. The results of the physico-chemical properties of the oil indicate its quality for cooking and its potential for industrial use.

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