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Evaluation of Physicochemical Properties, Fatty Acid Profile and the Utilization Potential of *Terminalia catappa* Seed Oil in the Cosmetics Industries.

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Abstract

Terminalia catappa Linn (Indian almond) is planted extensively in many countries. The seeds are edible but their domestic and industrial utilization is hampered by the difficulty of extracting the seed, thus creating an environmental nuisance during fruiting season. To enhance the utilization of the seed, this study evaluated the physicochemical properties and fatty acid profile of the *T. catappa* seed oil. It also assessed the quality of soaps and body creams produced with the oil. *Terminalia catappa* fruits were collected and sundried. The extracted seeds were either dried or roasted and oil was extracted with n-hexane, purified, and bleached. The physicochemical properties of the oil, the bar soap, and the body cream produced from the oils were determined. The fatty acid profile of the oil was determined using GC-MS analysis. The extracted oils from dried and roasted *T. catappa* seeds had physicochemical characteristics indicative of edible vegetable oil: free fatty acid (0.06%, 0.54%); saponification value (195.02, 190.26mgKOH/g); peroxide value (9.17, 9.38meq/kg); acid value (0.11, 1.07mgKOH/g); iodine value (93.59, 93.33wijs); and smoke point (172 ^{O}C, 170 ^{O}C). The fatty acid profile of both oils showed that oil from roasted *T. catappa* seeds contained mainly unsaturated fatty acids compared to the dried seed oil. Analysis of the body creams and soaps produced with the two varieties of oils showed that products containing roasted *T. catappa* oil had better parameters, but all the products were within the ranges recommended by the industrial standard specifications. The thermal stability and dermatological safety tests of both varieties of cream were satisfactory. These results demonstrated the suitability of the processed *T. catappa* seed oils for use in the food and cosmetics industries

Keywords: *Terminalia catappa,* Indian almond, physicochemical properties, fatty acid profile, cosmetics.

Introduction

Fats and oils provide the highest energy density per weight individuals can consume (Valenzuela et al., 2020). Aside from being a source of stored energy, fat deposits insulate the body against heat loss and protect essential organs from mechanical harm (Lean, 2019). They are vital dietary sources for humans and are also widely employed for nutritional, aesthetic, and drug dispersion in treatments, as well as being an essential dietary source of key fatty acids like linoleic and arachidonic acids in addition to being used for industrial purposes (Burns et al., 2018).

Analysing the physicochemical characteristics of oils obtained from plant sources has become more important. It assists in ensuring that these oils satisfy legal requirements, are uncontaminated, and have the appropriate qualities for a variety of uses in sectors ranging from food and medicines to cosmetics and environmental sustainability. Some nut oils are edible while some are not (Al-Kheraif et al., 2021; Bai et al., 2018). The widespread use of these oils as essential components, in the commercial or chemical industry, has been

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confirmed by numerous research(Al-Kheraif et al., 2021; Eduardo et al., 2021; Singh et al., 2019).

Terminalia catappa L. is a species of Combretaceae. It is popular in the tropics and is known as Indian almond or tropical almond (Donoso et al., 2018; Oudhia et al., 2008). It is also very nutrient-dense (Barku et al., 2012; Loveless, 1983). The tree is frequently planted primarily for shade, ornamental, and nut-eating purposes. *Terminalia catappa* ripe fruit has an edible nut that tastes like that of almonds (Ravi, 2020). However, the nuts' diminutive size and difficult procedure for extraction have been noted as probable causes for their underutilization (Ladele et al., 2016; Thomson et al., 2006), thus creating an environmental nuisance during fruiting season.

The bulk of oils obtained from animals (butter, cheese, and whole milk) and plants such as palm oil, coconut oil, and palm kernel oil are quite high in saturated fats compared to tropical almond oil. Saturated fats on the other hand have been known to raise cholesterol levels by inhibiting the LDL receptors which take the cholesterol out of the blood and into the liver to be broken down, resulting in heart disease and stroke(Agunbiade et al., 2006).

T. catappa seed is rich in vitamin E, low in saturated, and high in unsaturated fatty acids (Orhevba et al., 2016). This oil offers a lot of health benefits when added to foods such as salads, rice, stew, and a variety of other foods. *Terminalia catappa* oil has numerous attributed health-positive effects, such as its capacity to reduce cholesterol in particular by reducing low-density lipoprotein (LDL) cholesterol while maintaining healthy high-density lipoprotein (HDL), easing inflammation, and stabilizing heart rhythms. *T. catappa* seed oil has been proposed as a likely source of nutritional oil(Jahurul et al., 2022; Janporn et al., 2015) and with high industrial potential (Adu et al., 2013). However, work on the physicochemical properties of cosmetic products from oven-dried and roasted *T. catappa* seed oil has not been published.

Therefore, the purpose of this work was to use oven-dried and roasted *T. catappa* seed oil as a main source of fatty material in bar soap and body cream formulations and to determine the quality characteristics of the oil, soap, and body cream produced.

Materials and Methods

***Fruits collection and Pre-processing*:** Fresh ripe *T. catappa* fruits were collected from various locations within the Lagos metropolis, the Lagos State University, Ojo campus, and its environs. The fruits were identified and authenticated (Voucher No: LSH 001172) by experts from the Botany Department of Lagos State University, Ojo, Lagos. Ethical approval was secured from the LASU Research Ethics Committee (Approval No: LASU/23/REC/07/001), before proceeding with this research. The fruit outer flesh was manually removed with a scalpel and the hard-shelled nuts were sun-dried for 7 days. The kernels (nuts) were extracted by manually breaking the dried shells with the aid of a vice. The total seeds were weighed and then portioned into two equal parts. A portion of kernels was dried in an oven at 125^{O}C for 25 min, allowed to cool, then milled in a power blender and weighed. The second portion of seeds was transferred in batches into a stainless-steel frying pan and roasted over a smokeless flame for 20 min. After cooling, the roasted sample was likewise milled with a blender and weighed.

***Extraction and purification of oil*:** The oil was extracted with n-hexane using a Soxhlet extractor. 100g of milled kernels were packed in the thimble of the Soxhlet extractor and the extractor was filled with 400 ml of n-hexane. Oil extraction was performed at the temperatures of 50^{O}C, for 6hrs in two batches for both dried and

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roasted samples. The oil yield obtained at the end of every extraction time for every extraction condition was calculated and recorded. After each extraction process, the solvent was removed in each case at 60 ^{O}C using a rotary evaporator. The solute-to-solvent ratio that was used for the entire extraction was 1:4 (100 g: 400 ml). The entire extraction process was carried out under every set of conditions in triplicates and the average values were reported.

The oil yield of *T. catappa* was calculated using the formula:

$$\%\text{Oil yield} = \frac{\text{Weight of oil extracted (g)}}{\text{Weight of } T.\ catappa \text{ seed (g)}} \times 100$$

The extracted crude oil samples were purified using the method of Ogunsua and Badifu (1989). Two millilitres (2ml) of distilled water were added to the crude Indian almond oil and heated at 70^{o}C in a water bath for 30min. The substance, which comprises 0.07ml of acetic anhydride ($C_4H_6O_3$), was left to cool after it had been shaken for 30 minutes at 70^{O}C. The content was separated at 2000rpm by gradually pouring it for 30 minutes to enhance its gumming. After the oil has gummed, 7.55g, 1M potassium hydroxide (KOH) solution was added. The substance also underwent a ten-minute mixing process. This was done using Stuart's magnetic stirrer (model 8186) and the temperature of the mixing was 25^{O}C. The congealing of the soap was also done by heating the mixture for 45 minutes at 80^{O}C. The content was subsequently centrifuged for 20 minutes using a Heraeus sepatech centrifuge at 2000 rpm. 80 ml of distilled water was also used to wash the extracted substance. To do this, a separating funnel was used to forcefully stir the mixture and then allowed to rest for 15 minutes. Following that, the lower aqueous layer was dispersed and discarded. The oils obtained from the dried and roasted samples were labelled "degummed".

To the degummed oil was added 0.56g of Fuller's earth and the mixture was heated for 10 min at 100^{o}C. Thereafter, the mixture was vacuum filtered using Whatman No. 1 filter paper. Following an hour of bleaching with steam, the oil was dried in an oven (Gallenkanp model 300 plus) at 80 ^{O}C for 30 minutes.

Determination of Physicochemical Properties of *T. catappa oil*

Physical properties

Refractive Index

The refractive indices of the two varieties of *T. catappa* seeds oils respectively (at room temperature) were determined with an Abbey refractometer. The angle at which light is bent when it passes through a small layer of melted fat is known as the refractive index, and it is one of the physical characteristics of triglycerides. A typical fat's refractive index is determined by both its degree of unsaturation and glyceride structure. When fatty acids are unsaturated, their molecular weight causes the refractive index to decrease, and otherwise when saturated.

Slip Melting Point

This is the temperature at which oil begins to melt. This number indicates the types of fatty acids included in triglycerides. Low molecular weight and unsaturated fatty acids have low melting temperatures, while large molecular weight and saturated fatty acids have high melting points. To ascertain the sample's slip melting point, a differential scanning calorimeter (DSC; Diamond; PerkinElmer, Waltham, MA, USA) was used. (Janporn et al., 2015; Tan et al., 2000).

Specific Gravity

The Association of Official Analytical Chemists (AOAC) method No. 40.1.08 (1990) (AOAC, 1990) was used

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to determine specific gravity. The following equation was used to get specific gravity:

Specific gravity = $(W_1-W_0) / (W_2- W_0)$

Viscosity

This is a measure of fluid's resistance to flow. The viscosity of dried and roasted *T. catappa* kernel oil was measured by utilizing Brookfield DV-I with a spindle of S00 at 100 rpm at room temperature.

Colour

The Hunter Lab DP9000 S/N 90905 was used to directly read the CIELab coordinates (L*, a*, and b*) to identify its state and colour.

Chemical Properties

Acid value, free fatty acid, peroxide value, iodine value, saponification, and unsaponification values of the extracted oil were determined according to the AOAC official methods(AOAC, 1990).

Fatty Acid Composition of the Extracted Oils

The extracted oil samples were converted to Fatty acid methyl esters (FAMEs) using the method described by (Hall et al., 1986; Oshodi, 1996). The fatty acid profile was determined according to AOAC 996.06 (AOAC, 1990). An HP 6890 gas chromatography system was used in the procedure to identify fatty acid methyl esters. The identified fatty acid methyl esters were evaluated with standard compounds. The percentage area of each fatty acid methyl ester was used to estimate the quality of each fatty acid.

Production of Body Cream and Bar Soap

The soap was produced using a modified soap cal.com formulation. 50g soap batches were produced respectively using the extracted oven-dried and roasted *T. catappa* seed oil. Water: lye ratio of 2.03:1. The product was allowed to cure by air-drying for 14 days before analysis was carried out (Shahinuzzaman et al., 2016).

The body cream was produced using a modified double boiler method and then blended with a stick blender. The cream produced was stored at 4^oC in a refrigerator till further analysis(Suwandi et al., 2020).

Quality Determination of Cosmetics Products

pH level test

This was done using the pH meter (Inolab, WTW, Germany, pH 7310). One gram of soap or body cream was weighed out respectively, dissolved in ten millilitres of distilled water, and then the volume was adjusted to one hundred millilitres to produce a homogenous soap solution and cream solution respectively with a concentration of one per cent (w/v) '(Chauhan et al., 2020; Umar, 2002).

. The electrode of the pH meter was then inserted into the solutions respectively (Idoko et al., 2018). The stages were replicated for each soap and cream sample, including the commercial soap utilized as a standard.

Soap Reaction with Hard Water

Two beakers were used for this study. Each of the beakers contains dissolved 1g and 8g of Ca $(HCO_3)_2$ and 1L of distilled water. They served as the hard water for the experiment. In 100 ml beakers, 80 ml of two different hardness levels of water was measured. Confirmation of changes was noted through the breaking down of all the soap bars prepared from dried and roasted *T. catappa* kernel oil in low and high hard water concentrations.

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Soap Solubility Test:

80 millilitres of tap water were chilled to 7°C. The water was poured into 100-millilitre beakers and the solubility of the soap was also established. This was achieved through the use of 0.2g of soap samples. They were poured into beakers for confirmation.

Soap Flame Test

A small quantity of the soap produced with oven-dried and roasted *T. catappa* seed oil respectively was extracted. The flame colour of each soap was checked after they were burnt(Shahinuzzaman et al., 2016).

Soap Foaming (lathering) Ability Tests

10 millilitres (10ml) of distilled water were poured into a 100-millilitres measuring cylinder. Then 0.2 grams of each soap sample were added to the respective cylinder. The liquid was agitated rapidly for 2 minutes to create foams, after which the cylinder rested for around 10 minutes, during which time the height of the foam was measured and recorded (Mabrouk, 2005; Warra et al., 2010). These steps were performed on both soaps produced with oven-dried and roasted *T catappa* kernel oil.

Moisture Content:

Official method 981.11 of AOAC was applied to dry 10g of the sample to a constant weight at 105°C. The purpose is to confirm the moisture content of the oil (AOAC, 2000). After the substance had dried, the samples of the soap were weighed again.

The formula below was used to compute the percentage of the moisture content.

W1 / W2 equals 100% moisture content.

where W2 is the weight of the soap before drying and W1 is the weight of the soap after drying.

Determination of Thermal Stability and Dermatological Safety Test of Cream:

For determination of the thermal stability of body cream produced with oven-dried and roasted *T. catappa* seeds oil respectively, six glass tubes with a diameter of 15 mm and a height of 150 mm were taken, and they were filled with 2/3 the volume of the subjected samples and placed in the thermostat TC-80M-2 at 40–42°C for 24 h. If the formation of an aqueous phase was not observed in any glass tube, the bases were considered stable (Satisfactory)(Strus et al., 2018).

Determination of Cream Behaviour at Storage: A closed container of the sample was kept in an oven at 40°C for 6 weeks. Alternatively, a closed sample container was kept in the humidity chamber at 60 to 70% relative humidity. The cream was observed, and it passed the storage test if no oil separation at the end of the examination period (NIS 681-2010 Appendix A).

Determination of dermatological Safety test: twenty volunteers (human subjects) were subjected to the patch skin. Patches that can fit on the skin with the two varieties of body cream produced with *T. catappa* seed oil applied on the patch were suitably cut and left attached on each volunteer initially for 1-3 days, then removed and the skin area was observed for immediate reaction if there is no adverse reaction is observed, the skin is re-examined after 7 days and on the 8th day the patches are reapplied and examined as described above. The product passes if the product has no adverse reaction to the skin (NIS 681:2010 Appendix k).

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Total Fatty Matter (TFM):

The method described by (Mak-Mensah et al., 2011) was used. The total fatty matter test was carried out by reacting the soap with acid in the presence of hot water and measuring the fatty acids obtained. 10g of soap produced with extracted oven-dried and roasted *T. catappa* seed oil respectively were weighed and 150 distilled water was added and then heated. The soap was dissolved in 20mL of 15% H_2SO_4 while heating until a clear solution was obtained. Fatty acids on the surface of the resulting solution were solidified by adding 7g of bee wax and reheated. The setup was allowed to cool to form a cake which was removed and blotted to dryness and the total fatty matter was obtained as follows.

$$\%TFM = \frac{(A-X)\times 100}{W}$$

where; A = weight of wax + oil.

X = weight of wax.

W = weight of soap.

The standard total fatty matter of soaps is 76%(Abba et al., 2021).

Matter Insoluble in Alcohol:

Five grams of each soap sample were dissolved in 50 ml of hot ethanol and quantitatively transferred in a pre-weighed filter paper. The residue was dried in the oven at 105^{O}C for 30 minutes, cooled, and weighed again then a reading was taken. The calculation of matter insoluble in alcohol (MIA) was carried out using

$MIA = (W_S\text{-}FP) * 100/W$

where: Ws is the Weight of the sample + filter paper, FP is the Weight of filter paper and W is the Weight of the sample. If the MIA value is high then it means the soap contains a high level of impurities(Idoko et al., 2018).

Total Alkali:

The total alkali was determined by titrating excess acid contained in the aqueous phase with standard volumetric NaOH solution. 10 g of the finished soap was weighed and 100mL of neutralized alcohol was added to it, then 5mL of 1 N H_2SO_4 solution was added to the mixture and heated till the soap sample dissolved. The test solution was titrated against 1N NaOH using phenolphthalein as an indicator. The total alkali was obtained using the formula.

$$\%\text{Total alkali} = \frac{VA - VB \times 3.1}{W}$$

Where; V_A = Volume of acid.

V_B = Volume of base.

W = weight of soap.

3.1 = milliequivalent of Na_2O

Good quality soaps must have no more than 5% alkali content(Idoko et al., 2018).

Free Caustic Alkali:

A method prescribed by (Milwidsky et al., 1982) and modified by (Mak-Mensah et al., 2011) was used. 5g of the

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finished soap was weighed and dissolved in 30 mL of ethanol. A few drops of phenolphthalein indicator were added and 10ml of 20% BaC_{12} was also added. The resulting solution was titrated against 0.05M H_2SO_4. Free caustic alkali was calculated as follows;

$$NaOH = \frac{3.1 \times VA}{W}$$

where; V_A = Volume of acid.

W = weight of soap.

3.1 = milliequivalent of Na_2O.

The free caustic alkali must not exceed a value of 5%(Idoko et al., 2018).

Specific gravity:

100 ml of water and body cream produced with oven-dried and roasted *T. catappa* seed oil respectively were measured into different beakers using a weighing balance. The weight of the weight of the respective body cream was then divided by the weight of water(Ritonga et al., 2020).

Statistical Analysis

A statistical package for social science SPSS version 25.0 was used. All experiments were performed in triplicate and the results were expressed as mean ± SD (standard deviation). Statistical comparisons were performed using an Independent- Samples T -Test. Differences were considered significant at ($p<0.05$).

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Results

Table 1: Physicochemical Properties of Dried and Roasted *T. catappa* kernels oils

Oil Parameters	Dried *T. catappa* kernel oil	Roasted *T. catappa* kernels oil	Prescribed/Expected
Appearance (Sensory)	Light yellow liquid	Light yellow liquid	
Odour (Sensory)	Characteristic of product	Characteristic of product	Characteristic of product
Moisture & Volatile matter (%)	0.09±0.00[a]	0.06±0.00[a]	0.10 (maximum)
Viscosity@28.5^{O}C (cps)	55.00±0.00[a]	55.00±0.00[a]	
Specific Gravity@ 25^{O}C (Gravimetric)	0.92±0.00[a]	0.91±0.00[a]	0.910-0.920
Refractive Index	1.46±0.00[a]	1.46±0.00[a]	
Flash Point (^{O}C)	>200	>200	
Free Fatty Acid (%)	0.06±0.00[a]	0.54±0.00[b]	2.0 (maximum)
Acid Value (mgKOH/g)	0.11±0.01[a]	1.07±0.01[b]	4.0 (maximum)
Iodine Value (g/100g)	93.59±0.01[b]	93.33±0.04[a]	92-106
Peroxide Value (mEq/kg)	9.17±0.01[b]	9.38±0.01[a]	10.0 (maximum)
Rancidity	Negative	Negative	Positive/ Negative
Saponification Value (mgKOH/g	195.02±0.81[b]	190.26±0.09[a]	188-200
Unsaponifiable Matter (g/kg)	0.78±0.02[b]	0.50±0.03[a]	0.90 (maximum)
Slip Melting Point (^{O}C)	49.00±0.00[a]	49.30±0.00[a]	
Smoke Point (^{O}C)	172.00±0.00[a]	170.00±0.00[a]	

Values are means of triplicate determinations with standard deviation of mean. [a,b]Values with different superscripts are significantly different at $p<0.05$

Table 1 Showed the physicochemical properties of dried and roasted *T. catappa* kernels oils. Dried *T. catappa* kernel oil had significantly higher Iodine, Peroxide, Saponification and Unsaponifiable Matter Values but lower Free Fatty Acid value ($p<0.05$) compared to the Roasted kernel oil. The values of other parameters were not significantly different. However, values of all the physicochemical parameters for both oils were within the stipulated National Industrial Standards specifications for edible oil.

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Table 2: Fatty Acid Composition of Oven dried and Roasted *T. catappa* kernel oil

Fatty Acid Composition	Oven Dried *T. catappa* kernel oil (%)	Roasted *T. catappa* kernel oil (%)
Saturated Fatty acids		
C6:0	0.029	0.138
C12:0	<0.001	<0.001
C16:0	1.028	0.714
C17:0	<0.001	10.260
C18:0	0.142	0.106
C20:0	51.518	2.216
C22:0	<0.001	<0.001
C23:0	<0.001	<0.001
C24:0	0.324	<0.001
∑SFA	**53.041**	**13.434**
Monounsaturated Fatty acids		
C14:1 Cis-9	<0.001	<0.001
C15:1 Cis:10	<0.001	<0.001
C16:1 Cis-9	<0.001	9.954
C17:1 Cis-10	0.013	<0.001
C18:1 Trans-9	<0.001	<0.001
C18:1 Cis-9	<0.001	50.811
C20:1 Cis-11	26.008	9.830
C22:1 Cis-13	<0.001	<0.001
C24:1 Cis-15	3.698	<0.001
∑MUFA	**29.719**	**70.595**
Polyunsaturated Fatty acids		
C18:2 Trans-9,12	<0.001	<0.001
C18:2n-6 Cis-9,12	12.238	13.198
C18:3 Cis-9,12	<0.001	1.654
C18:3 Cis-9,12,15	2.163	<0.001
C20:3 Cis-8,11,14	0.097	<0.001
C20:3 Cis-11,14,17	0.178	0.121
C20:4 Cis-5,8,11,14	<0.001	<0.001
C22:2 Cis-13,16	0.012	0
C24: Cis-4,7,10,13,16,19	0.051	<0.001
∑PUFA	**14.739**	**14.973**

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As shown in Table 2, oven-dried *T. catappa* seed oil contained more saturated fatty acids (SFA)>Mono unsaturated fatty acid (MUFA)>Poly unsaturated fatty acid (PUFA). Arachidic acid (C20:0) was present in the highest concentration (51.52%), followed by Godonic acid (C20:1) (26.01%), then Linoleic acid (C18:2 Cis 9,12) (12.24%). Roasted *T. catappa* seed oil contained majorly MUFA (70.60%)>PUFA (14.97%)>SFA (13.43%). Oleic acid (C18:1 Cis-9) was present in the highest concentration, followed by Linoleic acid (C18:2n-6 Cis-9,12) (13.20%) and margaric acid (C17:0) (10.26%).

Table 3: Quality Parameters of Body Cream Produced with Dried andRoasted *T. catappa* kernels oil.

Parameters	Oven-dried *T. catappa* kernels oil	Roasted *T. catappa* kernels oil	Prescribed/Expected NIS 681:2010
Appearance	Creamy semi -solid cream	Creamy semi -solid cream	
Specific Gravity	0.91±0.00[a]	0.95±0.00[a]	0.8-1.0
pH (10% Suspension)	7.30±0.01[b]	7.01±0.02[a]	5.0-8.0
Total Fatty Substance (%)	67.76±0.11[a]	72.07±0.04[b]	
Non-Volatile Matter (%)	89.53±0.00[a]	88.75±0.00[a]	
Water Content (%)	10.47±0.00[a]	11.25±0.00[a]	
Oil Content (%)	67.76±0.11[a]	72.07±0.00[b]	
Thermal Stability	Satisfactory	Satisfactory	Satisfactory/Failed
Rancidity	Negative	Negative	Negative/Positive
Dermatological Safety Test	Satisfactory	Satisfactory	

Values are mean ± Standard deviation, n = 3. [a,b]Values with different superscripts are significantly different at $p<0.05$

Quality parameters of body cream produced with dried and roasted *T. catappa* kernel oil (Table 3) showed that the body cream produced with Oven-dried *T. catappa* kernel oil had a significantly higher pH than the product from Roasted *T. catappa* oil ($p<0.05$). Values of total fatty matter and oil content of the oven-dried *T. catappa* seed oil product were significantly lower. There was no significant difference in specific gravity, non-volatile matter, and water content of both products. Similarly, the parameters determined were all within the specified Industrial Standard range.

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Table 4: Quality Properties of Soap Produced with *T. catappa* kernel oil

Parameters	Oven-dried *T. catappa* kernels oil	Roasted *T. catappa* kernels oil	Expected/ Prescribed NISARS-490-2:2019
Appearance	Creamy solid bar	Creamy solid bar	
pH (1% Solution)	9.28 ± 0.25^{a}	9.49 ± 0.01^{b}	
Total Fatty Matter (%)	67.56 ± 0.17^{a}	72.82 ± 0.01^{b}	62.0%(minimum)
Matter Insoluble in Ethanol (Gravimetric) (%)	1.97 ± 0.10^{b}	1.92 ± 0.02^{a}	2.5%(maximum)
Free Caustic Alkali (as NaOH)) (Titrimetric) (%)	$<0.00^{a}$	$<0.00^{a}$	0.1%(maximum)
Total Free Alkali (as NaOH) (Titrimetric) (%)	$<0.00^{a}$	$<0.00^{a}$	0.2%(maximum)
Unsaponifiable fatty matter (Titrimetric) (%)	0.18 ± 0.01^{b}	0.13 ± 0.01^{a}	0.2%(maximum)
Moisture &Volatile matter 105^{O}C (%)	19.46 ± 0.09^{b}	15.96 ± 0.17^{a}	30.0%(maximum)
Chloride Content (as NaCl) (Titrimetric) (%)	0.20 ± 0.01^{a}	0.23 ± 0.00^{a}	1.5%(maximum)
Lather Volume(millilitre)	210.00 ± 1.00^{b}	205.00 ± 1.00^{a}	
Staining ability	Passes	Passes	Shall pass the test

Values are mean ± Standard deviation, n = 3. ^{a,b}Values with different superscripts are significantly different at $p<0.05$

The result in Table 4 showed a significantly lower pH and total fatty matter in the oven-dried *T. catappa* oil-based soap compared to the roasted oil product ($p<0.05$). On the other hand, values of Matter Insoluble in Ethanol, Unsaponifiable fatty matter, Moisture & Volatile matter as well as Lather Volume of the oven-dried based products were significantly higher than those of the roasted kernel-based products ($p<0.05$). There was no significant difference in the Free Caustic Alkali, Total Free Alkali, and chloride content of bar soap produced with oven-dried and roasted *T. catappa* seed oil. All parameters analyzed also had values within the specified range.

Discussion

The physical and chemical properties of a substance are indirectly a reflection of its quality. The commercial significance of oils depends mostly on these physiochemical properties which provide baseline data to determine their suitability for consumption(Bamgboye et al., 2010; McCarthy et al., 2009; Parthiban et al., 2011).

Terminalia catappa seed oil extracted in this study was a light-yellow liquid, and this suggested the presence of more yellow pigments (carotenoids). These carotenoids are beneficial since they stimulate the appearance of lipids without the use of primary colourants such as carotenes, annattos, and apo-carotenals commonly used in the oil and fat industry(Nehdi et al., 2010).

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The percentage of oil yield in this study is 53.22% for oven-dried and 45.05% for roasted *T. catappa* seed oil respectively. Previous studies have reported between 35 and 59 per cent of a light-yellow oil that is edible and identical to true almond oil (*Prunus amygdalus*) produced when the *T. catappa* fruit kernel is sun-dried; however, the oil becomes turbid when left to stand(Adu et al., 2015; Adu et al., 2013; Howes, 1948; Orhevba et al., 2016)

Free fatty acids are most likely formed by the hydrolytic activity of lipolytic enzymes during the preparation of seeds for oil production. It can act as a pro-oxidant in oils by speeding up the rate of hydroperoxide decomposition. The more free fatty acid (FFA) an oil contains, the quicker it will break down and start smoking (Satyarthi et al., 2013). Thus, high FFA content in the oil may cause further oxidation and lead to the development of an offensive taste and flavour in the oil. Oils with low free fatty acid levels would possess, according to this point, a proven nutritional quality for consumption. The oil extracted has a free fatty acid content of 0.06% and 0.54% in the oven-dried and roasted seeds respectively, which is less than the maximum 2.0% acceptance value. The values are less than those obtained for the oils of *Chrysophyllum albidum* (African star Apple) 2.78% for *Dacryodes Edulis* (African plum), 7.06% for *Elaeis guineensis* (African oil palm), 7.70% for *Landolphia owariensis* (white Rubber Plant), and 2.60% for *Napoleonaea Imperialis* (Napoleon hat) ((Akubugwo et al., 2007).

The acid value of oil is dependent on the amount of free fatty acids present or the degree of hydrolysis of the oil. The acid value of oil suitable for edible purposes should not exceed 4 mgKOH/g (Esuoso et al., 1995). The acid value of (0.11 mgKOH/g oil) and (1.07 mgKOH/g oil) for the dried and roasted *T. catappa* seed oil shows a comparatively low value due to its low content of free fatty acid, and it confirmed their suitability for consumption.

The iodine value for the extracted dried and roasted *T. catappa* seed oil in this study was (93.59, 93.33 wijs) which is, 93.59 g/100 g of oil and 93.33 g/100 g of oil respectively. The iodine value is higher than typical iodine values obtained for coconut oil (25-40g/100g), and palm oil (37-54g/100g), but in the same range as that of olive oil (75-95g/100g) and peanut oil (85-100g/100g). The iodine value of this study is in sharp contrast to the value obtained (65g/100g) by Olatidoye et al. (2011)(Olatidoye et al., 2011) for the Indian almond nut oil collected in Nigeria which classified the oil as a non-drying oil. The acceptable international standard value set by the Codex Alimentarius Commission for the iodine value of seed oil suitable for consumption is between 92-106 g/100 g of oil.

Peroxide value is a measure of the reaction rate of lipid oxidation, which causes rancidity. Normally, oils become rancid when the peroxide value ranges from 20.0 mg/g oil to 40.0 mg/g oil (Babalola et al., 2011). The peroxide value of dried *T. catappa* seed oil (9.17 mEq/kg) was significantly lower than the roasted *T. catappa* seed oil (9.383 mEq/kg); however, the peroxide values of both oils are below the maximum acceptable value of 10 mEq KOH/kg set by the Codex Alimentarius Commission for oil seeds (Codex et al., 2001). Hence the oil of *Terminalia catappa* seeds is edible and nutritive properties cannot be destroyed during storage.

The rancidity indices derived from this study were negative for both dried and roasted *T. catappa* seeds oil, which collaborates with the peroxide value. The saponification value is inversely proportional to the mean molecular weight of the fatty acid in the glyceride present in the lipid. Saponification is a measure of oxidation during storage and also indicates deterioration of the oils(Neagu et al., 2013). The high values of saponification

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of this study (195.02, 190.26 mgKOH/g), indicated the presence of many fatty acids of low molecular weight, making possible the proposed utilization of these oils in soaps and cosmetics industry. The saponification values of dried and roasted *T. catappa* seed oil were comparable to that of sunflower, and corn oil, which have average saponification numbers ranging between 191 mg KOH/g oil and 250 mg KOH/g oil (Babalola et al., 2011). However, the dried and roasted *T. catappa* seed oil showed a low unsaponifiable matter. Unsaponifiable matter includes higher aliphatic alcohols, sterols, pigments, and hydrocarbons. These are substances frequently found dissolved in fatty acids. The unsaponication matters of this investigation were 0.78g/kg and 0.50g/kg for dried and roasted *T. catappa* seed oil respectively. The results indicated that acid, free fatty acid, and the saponification values of dried and roasted *T. catappa* seed oil were within acceptable levels based on the standard for edible oils.

Specific gravity is the heaviness of a substance compared to that of water, and it is expressed without units. The specific gravity obtained for all the oil samples (0.92, 0.91) is less than 1.0 when measured at 25°C. These values are less than that reported for racemosa seed oil (4.95) by Amoo et al. (2008), but the values of both almond oil compared well with that reported for cotton seed (0.92), coconut oil and sunflower seed (Barku et al., 2012). In consideration of the value of this study, the dried and roasted *T. catappa* seed oil is less dense than water.

The refractive index is an important characteristic that determines the degree of saturation or unsaturation of fat and oils. The mean refractive indices of 1.464 and 1.463 were obtained from the oil samples derived from dried and roasted almond seed respectively at the temperature of 25 °C. The value of the studied oil also indicates that the oil is less thick when compared with most drying oils whose refractive indices are between 1.475 and 1.485 (Olatidoye et al., 2011).

The fatty acid composition of oil is its most useful chemical feature. Many of the chemical tests for oil identity or purity can be related to the fatty acid content of the oil (Ajayi et al., 2009). (Ajayi et al., 2008) reported a higher concentration of unsaturated fatty acids in *T. catappa* oil. In this study, oven-dried *T. catappa* seed oil has a higher percentage of saturated fatty acids while roasted *T. catappa* seed oil was majorly unsaturated fatty acids. Studies have demonstrated that MUFA are better contributors to plasma cholesterol-lowering effects than saturated fatty acids (Ajayi et al., 2008). The presence of monounsaturated fatty acid can counteract the effect of the saturated fatty acid and the seed oil can be of nutritional benefit. The high linoleic acid content of the seed oils is significant since linoleic acid is undoubtedly one of the most important polyunsaturated fatty acids in human food due to its prevention of distinct cardiovascular disease. Cardiovascular disorders such as coronary heart disease, atherosclerosis, and high blood pressure are prevented by dietary fats rich in linoleic acid (Dagne et al., 1997; Vles et al., 1989). In comparison to other vegetable oils for consumption, like palm, soybean, sesame, olive, and coconut oils (Ladele et al., 2016), *T. catappa* seeds contain 1.2:1.1:1 equilibrium of fatty acid, MUFA: PUFA, which has been discovered to comply with the directive of the American Heart Association (AHA) and National Cholesterol Education Programme (NCEP) (Alemayhu et al., 2019) regarding fat in nutrition. NCEP and AHA have a guideline on the appropriate quantity of fatty acid in nutritional oil (Kaur and Myrie, 2020). However, it is very difficult to get such oils. These findings just suggest that there is a strong likelihood that *Terminalia catappa* kernel oil could be used to resolve this dilemma.

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The physicochemical analysis of the Body cream produced in this study was its pH (7.30, 7.01), total fatty matter (67.76, 72.07), specific gravity (0.908, 0.948), water content (10.470,11.250), oil content and non-volatile matter for both oven dried and roasted *T. catappa* seeds oil respectively. The pH value of body cream is an indicator of its level of alkalinity or acidity, The pH of the skin surface has repeatedly been shown to be acidic, varying from pH 4 to 6, depending on the anatomical site of the body (Dikstein et al., 1994; Rippke et al., 2002; Zlotogorski, 1987). Several moisturizing creams with worldwide acceptance among people with dry skin have pH values of about 7–8 (Buraczewska et al., 2005), the acceptable pH range for body cream and lotion by Nigeria industrial standard is between pH 5.0-8.0. Thermal stability is the ability of a compound to resist decomposing when heated, a molecule with more stability has more resistance to decomposition at high temperatures (Alvin et al., 2019; Kwak et al., 2015). The thermal stability results of creams produced in this study were satisfactory. The dermatological safety test gives a satisfactory result, which is an indicator that the products are safe to use and can not cause any harm to the skin. This test determines the safety of products from contaminants that could be harmful or cause damage to the skin (Iwegbue et al., 2015). All the parameters' values derived from both varieties of *T. catappa* seeds oil is within the Nigeria industrial Standard acceptance ranges.

The pH values of the Bar soap produced in this study were 9.28 and 9.49 for both oven-dried and roasted *T. catappa* respectively, comparably within the higher pH range of 9-11 set by the National Agency for Food and Drug Administration and Control (NAFDAC). Handmade soap is always alkaline with a safe range pH between 8-10 to use on the skin '(Umar, 2002). Any soap above pH11 will be too harsh for the skin and below pH 8 is not advised to be used on the skin, because it is an indicator that it has no more cleansing power and may result in skin damage (skin peeling). The pH results of this study are similar to the pH 9.50 of Lifebuoy soap (Commercial soap). The total alkali and free caustic content of *T. catappa* oil was <0.0001. Free caustic alkali is one of the parameters that determine the abrasiveness of any given soap. The determination of percentage chloride levels in soap is important as excess amount causes soaps to crack. The % Cl^- value (0.20% and 0.23%) reported in this study for dried and roasted oil respectively was less than that obtained (0.90%) from neem oil soap by (Taiwo et al., 2008) and lower than the standard maximum value of 1.5%. This indicates that the value obtained is enough to sustain soap and prevent it from cracking. Total fatty matter (TFM) is how much fat substance the soap has, which is an indicator of soap quality. The more it has, the better the quality of the soap. TFM of 67.56% and 72.82% for dried and roasted oil respectively, are similar to those obtained (65-70%) by (Mak-Mensah et al., 2011) and(Taiwo et al., 2008).

The health benefits of *T. catappa* seed oil such as its moisturizing effects, due to its being rich in vitamin E may be especially helpful for people who have dry or sensitive skin (Sumit et al., 2012). Animal studies have shown that when applied to the skin, vitamin E may help protect cells from sun damage and premature aging (Gyawali et al., 2022). The favorable physicochemical characteristics of the body cream and soap produced with oven-dried and roasted *T. catappa* seeds oil respectively suggest their suitability as raw materials in soap and cosmetics industries.

Conclusion

Terminalia catappa seed is an oil-rich seed. The roasted seed oil is richer in unsaturated fatty acid compared to

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the oven-dried seed oil. The physicochemical analyses of the oil indicate its potential for utilization as raw material in the food and cosmetics industries, and its application in body cream and bar soap formulation revealed high-quality products that meet industrial standards specifications. This confirms that this underutilized plant has huge industrial potential that can contribute significantly to the nation's economic growth.

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