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Research Article

Effect of extracting solvents on physicochemical properties of vegetable seed oils and their suitability for industrial applications

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Abstract The effects of extracting solvents on the physicochemical properties of vegetable oils extracted from four oil seed plants, namely *Dennettia tripetala*, *Dacryodes edulis*, *Cola rostrata*, and *Persea americana*, were studied. Vegetable oils were extracted using the Soxhlet method. The oils were used for determining % yield, acid value (AV), iodine value (IV), saponification value (SV), electrical conductivity (EC), and pH. The results revealed that the range of the mean % yield of oils extracted using hexane, carbon tetrachloride (CCl_4), petroleum ether, acetone, and methanol, respectively, were 7.5-12.0, 9.0-22.0, 7.5-27.5 and 12.0-37.5 for the four oil Seeds respectively. Mean AVs of oils in mg KOH/g across the solvents were 3.1-3.7, 3.1-3.8, 2.5-3.9 and 2.4-2.8 for *Cola rostrata*, *Dacryodes edulis*, *Dennettia tripetala* and *Persea americana* respectively. Mean IVs of oils in gI_2/100 g across the solvents were 33.25-33.97, 33.06-33.35, 32.06-33.76 and 33.00-34.00 for the four oil seeds, respectively. Mean SVs in mg KOH/g across the solvents were 191.00-197.44, 190.74-198.31, 194.11-202.52, and 182.23-199.44, respectively. Mean EC values ranged 0.31-0.32, 0.30-0.33, 0.30-0.33, and 0.31-0.32 μS/cm across the solvents, respectively. Mean pH values ranged from 6.1-6.4, 4.6-6.3, 6.2-6.4, and 6.1-6.3 across the solvents for the oils, respectively. The AVs of the oils suggest that they are edible oils, the IVs classify the oils as non-drying oils suitable for paint making, and SVs reveal that the oils are good for soap making. Hexane, petroleum ether, and CCl4 are suitable for oil extraction industrially, while *D. edulis*, *D. tripetala*, and *P. Americana* oils are economically viable oil resources due to their high percentage yield, SV and IV.

Keywords vegetable oils, extracting solvents, physicochemical properties of oils, palm kernel oil

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1. Introduction

Fruit seeds are the by-product of fruit processing into juice and other products. Despite being treated as waste, fruit seeds contain oil with health benefits comparable or even higher than the conventional seed oil from field crops (Kaseke et al., 2020). Seed oils are crude fats extracted from plant seeds, and they are important ingredients in many foods, medicine, cosmetics, fuel (Biodiesel), etc. (Vermaak et al., 2011). Nigeria is blessed with many oil seeds which are good supplements in food, oil paints, cosmetics, and other industrial purposes (Onyeike and Acheru, 2002). Examples of such seeds include soybean seed oil, tiger nut oil, peanut oil, palm oil, palm kernel oil, etc. Their yields, composition, and types of extraction solvents used determine their usefulness in various applications (Aluyor and Ori-Jesu, 2008). According to Roy et al. (2022), vegetable seeds that often constitute a hefty share in food waste generation, can be valorized as a food fortification and/or preservation agent. That is, vegetable seeds often discarded as waste can be processed and converted into valuable substances. Fruit seeds are leftovers from a variety

of culinary sectors. These seeds not only possess various nutritional attributes but also have many health-beneficial properties. One way to make use of these seeds is to extract their bioactive components and create fortified food items (Roy et al., 2024). One of the nutritional attributes and or bioactive components of seeds that can be extracted is oil or fatty acids.

Extraction of seed oils can be done through many methods such as ultrasonic-assisted extraction, microwave-assisted extraction, mechanical extraction, supercritical fluid extraction, aqueous enzymatic oil extraction, and also Soxhlet extraction (Felix and Clement, 2011). Soxhlet extraction method helps to recover a component from either a solid or liquid, and it is straightforward and inexpensive (Luque-Garcia and Luque de castro, 2004). Extracting solvents are liquids used to remove or separate some components from a substance during the extraction process. Examples are methanol, hexane, acetone, carbon tetrachloride, diethyl ether, petroleum ether, ethanol, etc. This research focuses on the extraction of *Dennettia tripetala* seed, *Dacryodes edulis* seed, *Cola rostrata* seed and *Persea americana* seed through the Soxhlet extraction method using methanol, hexane, acetone, carbon tetrachloride, and petroleum ether as solvents.

Cola rostata, commonly called monkey cola in Nigeria and "Ndiya" in Southern Nigeria, belongs to the genus *Cola,* which is the largest genus of the *sterculiaceae* family of flowering plants. *Cola rostrata,* commonly known as monkey cola, is from the *k. schum* species, a member of *malvaceae* family, *malvales* order, and also from the genus of *Cola*. *Cola rostrata* fruits are edible and have a sweet taste, the seed is reddish brown in color, and the fruit and seed of *C. rostrata* have not been reported to be used in folk medicine (Emmanuel et al., 2013). *Cola gigantean* leaves, as reported by Idu et al. (2010), help to improve the supply of blood in the body.

Dacryodes edulis known commonly as African pear, is always available for about six months in a year (Eka, 1997). *D. edulis* commonly called African or native pear is of the *D. edulis* species, *spindales* order, *burseraceae* family, and a genus of *Dacryodes*. Some animals feed on the seeds of native pears, while humans eat them when raw, roasted, or boiled in hot water (Kadji et al., 2016). African pear can be used as an alternative source of fats and oil for both domestic and industrial use. The oil of African pear contains linoleic acid, which is a vital polyunsaturated fatty acid that helps in the prevention of vascular heart diseases (Ajiwe et al., 1997), and it also has a greater amount of oxidative stability.

Dennettia tripetala, known as pepper fruit, belongs to the *magnoliate* order; it's a member of the *annonaceace* family; it is *uvaropsis* genus and *uvariopsis tripetala* species. *D. tripetala,* commonly called pepper fruit, is cultivated throughout the tropical rainforest region of West Africa. It is red when ripped and green when unripe and has a spicy, pungent taste; the pepper fruit plant flowers at the beginning of the rainy season, especially during the months of April and May (Umoh, 1998). It is used traditionally for the entertainment of guests in Igbo land, Nigeria. Oyemitan et al. (2008) reported that the essential oil from *D. tripetala* contains anti-inflammatory and analgesic properties, as a result of this, the essential oil can be used for reducing body inflammation and pain.

Persea. Americana, commonly known as avocado, is a member of the Lauraceae family; it's of the Lauralis order, persea genus, and P. americana species. *P. americana* (Avocado) is among the plants contributing to health improvement due to the presence of bioactive chemicals that are essential to health (Okwu, 2001; Okwu and Morah, 2004). The biological effects of avocado seed extracts include its use as an anti-cancer agent (Abubakar et al., 2017).

The seeds of *D. edulis* (African pear) were also studied and reported by Obasi and Okolie (1993) to contain 76 kg^{-1} of carbohydrates, 126 kg^{-1} of lipids, and a high crude fiber of 273 kg^{-1}. Arisa and Lazarus (2008) investigated the possibility of producing good quality oil from the seeds of *D. edulis* (African pear) and reported the oil content of the native pear seed to be 50%, with an acid value of 9.6 mg KOH/g, saponification value of 172.8 mg KOH/g and iodine value of 33 mL/g. Thus the oil produced can be classified as a non-drying oil because of its range of iodine value.

According to Shirana et al. (2011), the soxhlet extraction of *Jatropha curcas L.* seed oil gave a maximum yield of 75% with hexane when compared with other solvents, Isopropanol yielded 59% of the seed oil while petroleum ether gave 53% yield. In search for alternative solvents for *Moringa oleifera* seeds extraction among hexane, isopropyl alcohol, and petroleum ether within a time range, the highest oil yield was obtained with petroleum ether followed by hexane before isopropyl alcohol (Efeobokhan et al., 2015). There is also a

report in which isopropyl alcohol yielded 94.7% while petroleum ether gave a yield of 72% in the extraction of coconut seed oil (Okene and Evbuomwan, 2014).

Despite the use of some of these seed oils extracted using different methods or some solvents domestically, there is at present little or no information or reports on the comparative effect of extracting solvents on the seed oils properties and the suitability of extracting solvents for a specific oil property and a particular industrial use over a wide range of different extracting solvents. The objective of this study is to determine the percentage yield and physicochemical properties of *C. rostrata*, *D. edulis*, *D. tripetala*, and *P. americana* seed oils extracted using five different solvents and determine their suitability for domestic or industrial use. Also, to compare their properties with palm kernel oil (PKO) that is usually used industrially and analyze the effect of extracting solvents on the oil properties and the suitability of a particular extracting solvent for a particular property and industrial use. This will provide a guide to solvent selection for seed oil extraction for a specific purpose.

2. Materials and methods

2.1. Sample collection

Fresh, ripped, and matured fruits of *Cola rostrata*, *Dennettia tripetala*, *Dacryodes edulis,* and *Persea americana* were obtained from Akim- Akim in Odukpani Local Government Area of Cross River State and were identified at the Herbarium Centre of Botany Department, University of Calabar, Nigeria.

2.2. Sample preparation

The fruit samples were taken to the laboratory of the Department of Pure and Applied Chemistry, University of Calabar, Nigeria, where they were peeled to get the seeds. The fresh seeds were washed with distilled water, sliced where applicable, and dried in an oven at 60℃ for 2 days (gradual drying) before being ground into powder. The powdered form of each sample was used for the extraction of oil (Akpe and Inezi, 2018).

This was done according to the procedures of (AOAC, 1998) where 100 g of each powdered dry seed sample was weighed, wrapped with filter paper and transferred into the thimble of the Soxhlet extractor fitted on a 250 mL round bottom flask containing 120 mL of the solvent (either hexane, petroleum ether, CCl_4, acetone or methanol, all produced from British Drug House, Poole, England) and anti-bombing granules. The flask was connected to a reflux condenser and placed on an electric heater at a temperature of 40-60℃ to reflux for 5 hours. After this period, the thimble was removed from the Soxhlet with the defatted sample, and the solvent was evaporated off the flask using a water bath at 30℃. The lipid extract in the flask was then cooled in a desiccator, weighed, and labeled.

2.3. Percentage yield

The percentage yield of each of the solvents used was measured as its extraction efficiency, which is the ratio between the actual or experimental value and the theoretical value. The actual yield is the amount of product actually obtained from the chemical reaction or experiment carried out. The theoretical yield (predicted yield) is the amount of product that could possibly be produced in a given reaction, calculated according to the starting amount of the limiting reagents.

$$\text{Percent yield} = \frac{\text{Experimental value}}{\text{Theoretical value}} \times 100 \quad (1)$$

Where, Experimental value = oil weight; Theoretical value = sample weight.

2.4. Physicochemical analysis

The physicochemical analysis deals with both the physical and chemical properties of the oil. The physical properties analyzed in the course of this research work were temperature, pH, and conductivity, while the chemical properties analyzed were the acid value, iodine value, and saponification value.

2.4.1. Acid value (AV)

Five grams (5 g) of oil extract was weighed accurately into labeled conical flasks, 50 mL of 95% ethanol was boiled in a second flask, and while still above 70℃, it was neutralized with 0.1 M KOH using phenolphthalein indicator (2 drops). The neutralized ethanol was poured into the flask containing the oil extract, and the contents of the flask were mixed while still hot. The mixture was titrated with 0.1 M KOH with vigorous shaking during the titration. The endpoint of the titration was detected when the addition of a single drop of phenolphthalein produced a slight but definite color change

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which persisted for about 20 sec (AOAC, 2002).

$$\text{Acid value} = \frac{56.1 \times V \times N}{W} \quad (2)$$

Where
W: The weight of the oil extract sample in grams
V: Volume in mL of potassium hydroxide
N: Normality of potassium hydroxide

2.4.2. Iodine value (IV)

One gram (1 g) of the oil extract was accurately weighed and dissolved with 10 mL of $CHCl_3$ in a glass stoppered flask, 25 mL of Hanus' iodine solution was added with the help of a pipette filled by suction with a rubber bulb. The blank determination was conducted in all respects, similar to that of the sample. The mixture was well mixed by swirling and was allowed to stand at room temperature for 30 minutes in a dark cabinet with occasional swirling. After 30 minutes, the mixture was removed from the dark cabinet and 10 ml of 15% KI solution was added, 50 mL of water was added to the mixture. The mixture was titrated with standard 0.1 N sodium thiosulphate solution using 50 mL burette until the yellow color of the solution was almost colorless; at this point, 2 mL of starch solution was added, which turned the solution to a deep blue color. The completion of the reaction was indicated by the disappearance of the blue starch iodine color, mixing well during the final stages of titration.

$$\text{Iodine value} = \frac{(X - Y) \times N \times 12.69}{W} \quad (3)$$

Where
X: Volume in mL of sodium thiosulphate solution required for blank titration
Y: Volume in mL of sodium thiosulpate solution required for sample
N: Normality of the sodium thiosulphate solution
W: Weight of sample
12.69: Miliequivalent weight of Iodine

2.4.3. Saponification value (SV)

One gram (1 g) of the oil extract was weighed and put into a 250 mL round bottom flask. Twenty-five mL of methanolic KOH was added to the flask content. The flask was then connected to a reflux condenser and refluxed in a water bath for one hour, care was taken to ensure adequate and complete saponification by swirling the contents of the flask at frequent intervals. The flask was removed from the boiling water after one hour. To each flask, 3 drops of phenolphthalein indicator were added, and the content was titrated against standard 0.5 M hydrochloric acid when it was still hot. A blank titration was carried out with the same quantity of methanolic KOH solution under the same conditions (AOCS, 1993).

Calculation:

$$\text{Saponification value} = \frac{56.1 \times M \times (Y - Z)}{W} \quad (4)$$

Where
M: Molarity of HCl in Mol/dm^3
Y: Volume of HCl required for blank titration in mL
Z: Volume of HCl required for real titration in mL
W: Weight of oil extract sample taken in grams

2.4.4. Determination of electrical conductivity

The conductivity meter (4510 JENWAY, Bibby Sci. Ltd., Dunmow, England) was used, and the probe was dipped into the sample after rinsing with distilled water. The value was read and recorded.

2.4.5. pH determination

The pH meter (pH meter SD20, Mettler-Toledo, India.) was used for the determination; the pH meter probe was dipped into the sample, and the value was recorded after stabilization.

2.5. Statistical analysis

Five replications of the experiment were carried out for each measured value, and the data was reported as the mean ±standard deviation (SD) (n=5), in the Table of results. IBM SPSS Version 20 software was used to carry out one-way ANOVA and significant tests (Duncan's new multiple range test) on the data obtained from the experimental procedure at $p<0.05$. The significance indication was also stated using superscript letters of alphabets in the Tables.

3. Results and discussion

The results of the physicochemical analysis of *Cola rostrata*, *Dacryodes edulis*, *Dennettia tripetala,* and *Persea*

americana seed oils are shown in Tables 1-5.

3.1. Percentage yield

The results of the percentage yield of the seed oils of *C. rostrata*, *D. edulis*, *D. tripetala,* and *P. americana* extracted with acetone, carbon tetrachloride, hexane, methanol, and petroleum ether are shown in Table 1.

The oil content of *C. rostrata,* when extracted with acetone, was 8% (Table 1). The results showed that *C. rostrata* seed oil extracted with hexane, carbon tetrachloride, petroleum ether, acetone, and methanol yielded 7.5%, 7.5%, 8.0%, 9.0%, and 12.0% respectively. From the result, it was observed that more oil was extracted with methanol, followed by acetone and petroleum ether. The results obtained were higher than the percentage yield of 6.55%, 4.95%, 1.24%, 0.64%, and 0.21% of *C. rostrata* obtained by Odion et al. (2013) when extracted with petroleum ether, chloroform, ethyl acetate, and butanol respectively. This variation in % yield could be due to the polarity difference of the solvents used. From the results obtained (Table 1), it can be said that hexane and carbon tetrachloride are not very good solvents for *Cola rostrata* seed oil extraction due to low % yield, especially when compared with that reported for *Allium satulum* L oil (22.5%) and *Lagenaria siceraria* seed oil (39.22%) extracted using hexane (Garfar et al., 2012; Sani and Hassan, 2007).

The results of the oil content for *D. edulis* seeds are presented in Table 1. The percentage yield shows that extraction of oil using acetone, carbon tetrachloride, hexane, methanol, and petroleum ether yielded 20%, 9%, 22%, 11%, and 22% of oil respectively. Apart from the fact that *D. edulis* seed appears oily, hexane and petroleum ether gave a higher oil yield (22%) after the extraction process.

The result obtained for the oil content of *D. tripetala* seed (Table 1) shows that the highest yield obtained was by extraction with methanol (27.5%) followed by hexane (17%), acetone (16%) and petroleum ether (16%) the least oil yield was seen in the extraction with carbon tetrachloride (7.5%). The result shows that methanol is a better solvent for *D. tripetala* seed oil extraction. These results obtained are lower than those reported by Swaroopa et al. (2013) on the comparative extraction of castor seed oil using polar and non-polar solvents; from their result, using 20 g of seeds, hexane yielded 43.9%, petroleum ether 42%, and methanol yielded 46.9%. The result indicated methanol as a better solvent for both *D. tripetala* seed and carrot seed oils extraction. These variations could be a result of the polarity difference of the extracting solvents or the lipids content of the oil seeds.

The oil content of *P. americana,* as shown in Table 1, has the highest yield of 27.5% when extracted with hexane. The difference in the amount of oil extracted could be due to the polarity difference of the solvents or the fatty acids composition of the oil seeds. Extraction with methanol yielded 27.0%, while that of acetone gave 16.8% oil yield; the result also showed that a yield of 21% was obtained when extracted with petroleum ether, while the least yield of 12.0% was from the extraction with carbon tetrachloride. From the result obtained, the values are closely similar to that of the percentage oil yield of cottonseed oil (15.0-24.0%), soybeans (17.0-21.0%), safflower (25.0-40.0%), and mustard (24.0-40.0%) (Pritchard, 1991). This similarity could be due to the fatty acid composition of the oil seeds.

However, the oil contents of the seed oils in the present study are highly lower than the percentage yield of *Moringa peregrina* seed oil (49.80%) reported from Saudi Arabia

Table 1. Percentage (%) yield of oil extracts using different solvents

Sample	Hexane	CCl_4	Petroleum ether	Acetone	Methanol
Control[1)]	27.00±0.20[2)b3)]	23.50±0.10[a]	26.00±0.20[b]	23.00±0.10[a]	24.00±0.20[a]
Cola rostrata	7.50±0.10[a]	7.50±0.10[a]	8.00±0.20[a]	9.00±0.10[b]	12.00±0.20[c]
Dacryodes edulis	22.00±0.20[c]	9.00±0.20[a]	22.00±0.10[c]	20.00±0.20[b]	11.00±0.20[a]
Dennettia tripetala	17.00±0.20[b]	7.50±0.10[a]	16.00±0.10[b]	16.00±0.20[b]	27.50±0.20[c]
Persea americana	27.50±0.20[d]	12.00±0.20[a]	21.00±0.10[c]	16.80±0.10[b]	27.00±0.10[d]

[1)]Commercial palm kernel oil (PKO).
[2)]Values are mean±SD (n=5).
[3)]Different superscript letters ([a-d]) indicate significant differences ($p<0.05$) between values in the same row by the Duncan's multiple range test.

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(Tsaknis, 1998) but slightly lower than the commercial PKO used industrially with mean 28% yield as reported by Akubugwo and Ugborgu (2007). For solvent output results generally, hexane > petroleum ether > methanol > acetone > CCl_4. Non-polar solvents tend to extract more oil, generally except in a few cases. There was a significant difference in the % yield of seed oils extracted with hexane and petroleum ether compared to others.

3.2. Acid value

The results of the acid value for *C. rostrata* seed oil extracted with acetone, carbon tetrachloride, hexane, methanol, and petroleum ether are presented in Table 2.

The results indicate that the acid value content of *C. rostrata*, *D. edulis*, *D. tripetala,* and *P. americana* seed oils was within 4 mg KOH/g acid value of oil suitable for edible purposes (Tan et al., 2002) as recommended by the Codex alimentarius for oil seeds (Abayeh et al., 1998), the values were lower than 14.0 mg KOH/g for palm kernel oil (PKO) by (Akubugwo and Ugborgu, 2007) similar to that used as control in this study, but greater than 0.50 mg KOH/g recommended for biodiesel (Arisa and Lazarus, 2008). The acid value gives an indication of the quality of fatty acids in oil (Gordon, 1993). The low acid values of the seeds indicate that the oil will be stable over a long period of time and is protected against rancidity and peroxidation, which may be a result of the presence of natural antioxidants in the seed, such as vitamin C and Vitamin A (Aremu et al., 2015). Acid value also indicates the edibility of an oil and its suitability for use in the paint and soap industries (Aremu et al., 2006).

However, a high acid value in oil indicates that the oil may not be edible but be useful for paint and soap production (Akintayo, 1997, Aremu et al., 2006), uses of acid value for biodiesel must be greater than the value of 0.50 mg KOH/g while appreciable acid value of oils is an indication of poisonous substance in the seed (Aremu et al., 2006). The acid value of the seed oils was in the order: *C. rostrate* > *D. edulis* > *D. tripetala* > *P. Americana*. For solvent output results, CCl_4 > petroleum ether > hexane > acetone > methanol in decreasing order. This could be due to the polarity difference of the solvents or the fatty acids composition of the oil seeds. There was no significant difference in the acid values of the oils except for the CCl_4, petroleum ether, and hexane extracts of some seed oils.

3.3. Iodine value

The results of the iodine value for *C. rostrata*, *D. edulis*, *D. tripetala,* and *P. americana* seed oils are shown in Table 3.

According to Ugbogu et al. (2013), iodine value is a measure of the unsaturated levels in fats and oils. High iodine values (95.00±1.00) in *J. Curcas* oil is an indication of the presence of high unsaturated fatty acids such as oleic and linolelic acid (Emil et al., 2010), The values obtained in the results are lower than iodine value of melon seed of 124.5 gl_2/100 g (Das et al., 2002). This could be due to the difference in the fatty acids composition of the oil seeds. High iodine values are usually above 190 gl_2/100g, iodine values between 80 gl_2/100 g-130 gl_2/100 g indicate a semi-dry oil, while a non-drying oil has iodine value below 80 gl_2/100 g (Fekarurhobo et al., 2009; Fernando and Akujobi, 1981). However, the results obtained for the four seed oils are higher than 16.00 gl_2/100 g reported by Bwade et al. (2013) for pumpkin seed oil, 26.09 gl_2/100 g reported by (Ogunsuyi and Daromola, 2013) for Almond seed oil and 20.30 reported by Belewu et al. (2010) for *Jatropha curcas* seed oil and even higher than 18.30 for the conventional PKO used

Table 2. Acid value of oils extracted using different solvents in mg KOH/g

Sample	Hexane	CCl_4	Petroleum ether	Acetone	Methanol
Control[1)]	14.50±0.50[2)b3)]	13.00±1.00[a]	14.00±0.50[b]	13.00±1.00[a]	13.50±0.50[a]
Cola rostrata	3.70±0.10[b]	3.70±0.20[b]	3.70±0.10[b]	3.10±0.10[a]	3.50±0.20[b]
Dacryodes edulis	3.40±0.10[b]	3.60±0.10[c]	2.60±0.10[a]	3.10±0.20[b]	3.80±0.20[c]
Dennettia tripetala	3.20±0.10[b]	2.70±0.10[a]	3.90±0.20[c]	3.80±0.20[c]	2.50±0.20[a]
Persea americana	2.60±0.10[a]	3.20±0.20[b]	2.80±0.10[a]	2.70±0.10[a]	2.40±0.20[a]

[1)]Commercial palm kernel oil (PKO).
[2)]Values are mean±SD (n=5).
[3)]Different superscript letters ([a-c]) indicate significant differences ($p<0.05$) between values in the same row by the Duncan's multiple range test.

Table 3. Iodine value of oils extracted using different solvents in gI_2/100 g

Sample	Hexane	CCl_4	Petroleum ether	Acetone	Methanol
Control[1)]	18.10±0.50[2)b3)]	16.10±1.00[a]	17.60±1.00[b]	16.20±0.50[a]	16.40±1.00[a]
Cola rostrata	33.25±0.15[a]	33.46±0.13[a]	33.97±0.13[b]	33.38±0.12[a]	33.63±1.02[a]
Dacryodes edulis	33.06±0.14[a]	34.10±0.15[b]	33.21±0.11[a]	33.35±0.15[a]	33.21±0.13[a]
Dennettia tripetala	33.06±0.12[a]	34.10±0.10[b]	33.76±0.14[a]	32.70±0.13[a]	33.50±0.10[a]
Persea americana	33.26±0.04[a]	34.00±0.15[b]	33.55±0.50[a]	33.00±0.13[a]	33.00±0.14[a]

[1)]Commercial palm kernel oil (PKO).
[2)]Values are mean±SD (n=5).
[3)]Different superscript letters ([a,b]) indicate significant differences ($p<0.05$) between values in the same row by the Duncan's multiple range test.

industrially (Akubugwo and Ugborgu, 2007), and similar to that used as control in this study. These variations are possible because different oil seeds have different fatty acid content. For iodine value, the seed oils were in the order of *D. tripetala* > *D. edulis* > *P. Americana* > *C. rostrata*. For solvent output results, CCl_4 > petroleum ether > methanol > hexane > acetone in decreasing order. However, the difference between methanol and hexane was not significant as far as iodine value is concerned. This slight variation in iodine value could be due to the polarity difference of the solvents or the fatty acids composition of the oil seeds. There was no significant difference in the iodine values of the seed oils, except carbon tetrachloride extracts of *D. tripetala*, *D. edulis,* and *P. americana*.

3.4. Saponification value

The results obtained for the saponification values of *C. rostrata, D. edulis, D. tripetala*, and *P. americana* are presented in Table 4. The result shows that the mean saponification values for *C. rostrata* were 193.0, 192.0, 197.44, 191.00, and 190.46 mg KOH/g when extracted using hexane, carbon tetrachloride, petroleum ether, acetone, and methanol respectively. The values obtained for *C. rostrata* were higher than 140.3 mg KOH/g for Tallow oil (Warra et al., 2010) and 179.52 and 185.00 mg KOH/g for *Cypenus esculentum* oil extracted using hexane reported by (Akpe and Inezi, 2018) and (Hassan et al., 2007), respectively. *D. edulis* seed oil showed mean saponification values of 190.74, 196.74, 192.00, 192.14, and 198.31 mg KOH/g when extracted using hexane, carbon tetrachloride, petroleum ether, acetone, and methanol, respectively. The values obtained for *D. edulis* seed oil are lower than 246.60 mg KOH/g, as reported by Akubugwo and Ugbogu (2007), and 249.90 mg KOH/g for PKO was used as a control in this study. The values obtained are comparable to soybean seed oil (192.30 mg KOH/g) reported by Akanni et al. (2005) and 195.0 mg KOH/g for groundnut seed oil (Ayoola and Adeyeye, 2010).

The mean saponification values for *D. tripetala* oil extracted using hexane, carbon tetrachloride, petroleum ether, acetone, and methanol shown in Table 4 were 202.52, 201.96, 194.11, 198.32, and 196.35 mg KOH/g respectively. The results obtained are comparable to that of African bush mango (202.90 mg KOH/g) reported by Igwenyi (2014) and 194.80 mg KOH/g (Melon seed oil) reported by Egbebi (2014).

The mean SVs for *P. americana* seed oil extracted using acetone, carbon tetrachloride, hexane, methanol, and petroleum ether as shown in Table 4, were 189.34, 182.23, 199.44, 198.32, and 196.71 mg KOH/g respectively. Also, from the result (Table 4), it is observed that the highest saponification values were obtained from *D. tripetala* (201.96 mg KOH/g and 202.52 mg KOH/g) when extracted with carbon tetrachloride and hexane respectively while the least saponification values of 182.23 and 190.46 mg KOH/g were obtained for carbon tetrachloride extraction of *P. americana* and *C. rostrata* respectively. The saponification value of the seed oils was in the order: *D. tripetala* > *P. Americana* > *D. edulis* > *C. rostrata*. For solvent output results generally, hexane > CCl_4 > petroleum ether > methanol > acetone in decreasing order. This trend may be due to the lipids content of the oil seeds or the polarity difference of the extracting solvents. Seed oils for soap making may be extracted using hexane, CCl_4, and petroleum ether because of the high saponification value of their oil extracts. There was a significant difference in saponification values of seed oils extracted with hexane, CCl_4, and petroleum ether. This may be due to the natural

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Table 4. Saponification value of oils extracted using different solvents in mg KOH/g

Sample	Hexane	CCl_4	Petroleum ether	Acetone	Methanol
Control[1)]	245.50±1.00[2)a3)]	241.60±1.00[b]	245.40±0.60[b]	241.40±0.50[a]	242.10±0.50[a]
Cola rostrata	193.00±1.04[b]	192.00±1.08[b]	197.44±1.06[c]	191.00±0.55[a]	190.46±1.04[a]
Dacryodes edulis	190.74±0.36[a]	196.74±1.00[c]	192.00±1.05[b]	192.14±1.02[b]	198.31±1.04[c]
Dennettia tripetala	202.52±1.03[c]	201.96±1.16[c]	194.11±0.50[a]	198.32±1.03[b]	196.35±1.05[b]
Persea americana	189.34±1.06[b]	182.23±1.12[a]	199.44±1.10[c]	198.32±1.02[c]	196.71±1.03[c]

[1)]Commercial palm kernel oil (PKO).
[2)]Values are mean±SD (n=5).
[3)]Different superscript letters ([a-c]) indicate significant differences ($p<0.05$) between values in the same row by the Duncan's multiple range test.

fatty acid composition of the oil seeds or the polarity difference of the extracting solvents.

3.5. pH

The mean pH values of the different seed oils are shown in Table 5. The result shows that *D. edulis* seed oil has a pH of 4.4-6.1. Oils extracted with methanol gave the lowest value of 4.4, with carbon tetrachloride giving a pH of 4.6, acetone gave 5.2, while petroleum ether and hexane gave 6.0 and 6.1, respectively.

C. rostrata seed oil extract shows slight acidity from the pH values (Table 5). The pH of 6.1, 6.4, 6.1, 6.3, and 6.2 was recorded for *C. rosrtata* seed oils extracted with methanol, carbon tetrachloride, hexane, acetone, and petroleum ether, respectively.

D. tripetala seed oil extract shows pH of 6.3, 6.2, 6.2, 6.4, and 6.3 using methanol, carbon tetrachloride, hexane, acetone, and petroleum ether, respectively.

The pH range for *P. americana* seed oil was 6.1-6.3. The result shows pH of 6.2, 6.3, 6.2, 6.3, and 6.1 for *P. americana* seed oils extracted with methanol, carbon tetrachloride, hexane, acetone, and petroleum ether, respectively. The slight and insignificant variation in pH may be due to the polarity difference of the solvents or the nature of the fatty acids in the oil seeds.

Since pH indicates the level of acidity and alkalinity, it ranges from 1 to 14 and pH less than 7 is considered to be acidic, while pH more than 7 is said to be alkaline, pH at point 7 is neutral. The results showed that the seed oils were slightly acidic since the pH values were mostly between 6.0-

Table 5. Conductivity (μS/cm) and pH of oils extract using different solvents

Sample	Property	Hexane	CCl_4	Petroleum ether	Acetone	Methanol
Control[1)]	Cond.	0.30±0.01[2)a3)]	0.27±0.02[a]	0.31±0.02[b]	0.28±0.01[a]	0.29±0.01[a]
	pH	5.10±0.10[b]	4.80±0.10[a]	5.00±0.20[b]	4.90±0.10[a]	4.70±0.20[a]
Cola rostrata	Cond.	0.32±0.01[a]	0.31±0.02[a]	0.31±0.02[a]	0.32±0.01[a]	0.32±0.03[a]
	pH	6.10±0.10[a]	6.40±0.10[a]	6.20±0.10[a]	6.20±0.10[a]	6.10±0.20[a]
Dacryodes edulis	Cond.	0.30±0.03[a]	0.31±0.01[a]	0.30±0.02[a]	0.33±0.02[a]	0.32±0.02[a]
	pH	6.10±0.20[c]	4.60±0.10[a]	6.30±0.10[c]	5.20±0.10[b]	4.40±0.20[a]
Dennettia tripetala	Cond.	0.33±0.01[a]	0.30±0.02[a]	0.30±0.01[a]	0.32±0.02[a]	0.32±0.02[a]
	pH	6.20±0.10[a]	6.20±0.10[a]	6.30±0.20[a]	6.40±0.10[a]	6.30±0.20[a]
Persea americana	Cond.	0.31±0.02[a]	0.31±0.02[a]	0.32±0.03[a]	0.32±0.03[a]	0.32±0.03[a]
	pH	6.20±0.10[a]	6.30±0.10[a]	6.10±0.10[a]	6.10±0.20[a]	6.20±0.20[a]

[1)]Commercial palm kernel oil (PKO).
[2)]Values are mean±SD (n=5).
[3)]Different superscript letters ([a-c]) indicate significant differences ($p<0.05$) between values in the same row by the Duncan's multiple range test.

6.4, except for *D. edulis,* which is a little more acidic with a pH range of 4.4-4.6. These values were slightly higher than PKO used as a control in this study, as its values ranged between 4.7-5.1 across the solvents. The slight acidity of most oils is an indication that they can be edible, as they naturally contain fatty acids. Highly acidic oils are not edible except after alkaline refining. The pH values obtained are higher than 3.6 (*Leganeria breviflora*) and 5.70 (*Colocynthis citrullus*) seed oils reported by Taiwo et al. (2016). The result is in the close range and slightly higher than 5.30 (Brachystegia eurycoma), 5.65 (Cucurbita pepo), 5.59 (Luffa cylindrical), and 6.07 (*Cucumis melo*) reported by (Ibeto et al., 2012). All the seed oils had no significant difference in their pH across the solvents except *D. edulis.*

3.6. Electrical conductivity

The electrical conductivity of the different seed oil extracts is also shown in Table 5. The result shows the seed oil conductivities to be between 0.30-0.33 µS/cm across the solvents. The mean range of values were 0.31-0.32, 0.30-0.33, 0.30-0.33, and 0.31-0.32 µS/cm for *C. rostrata, D. edulis, D. tripetala,* and *P. americana,* respectively, across the solvents. These values were slightly higher than PKO used as a control in this study, as its values ranged between 0.27-0.31 across the solvents. There was no significant difference in the electrical conductivity of the seed oils across the solvents. Conductivity is used to determine whether a substance is an electrical conductor or an insulator. Electrical conductivity is also an indication that the oil contains mobile ions or free radicals. The presence of radicals in oils can make them prone to decomposition of fatty acids, leading to fast deterioration. The mean conductivity values of the seed oils were generally low, and there is no available data for comparison at the moment. The low values of the seed oils indicate that they are poor conductors. For other physical properties, the oils were generally bright in color and attractive, non-offensive in odor, and liquid at room temperature.

4. Conclusions

The results of this study revealed that *D. edulis* and *P. americana* seeds were better oil sources than *D. tripetala* and *C. rostrata* based on percentage yield. The acid values of the four seed oils suggest that they are edible oils irrespective of the extracting solvent; the iodine value classifies the seed oils as non-drying oils (suitable for paint making, especially with dehydration), and the SV reveals that the oils are good for soap making. The four seed oils compete favorably with PKO used industrially in some properties, especially IV. Vegetable oil properties are affected by extracting solvents to an extent, though not significant in some cases. For high percentage yield, hexane and petroleum ether were preferable solvents, while hexane, petroleum ether, and CCl_4 are preferable to methanol and acetone as extracting solvents for high AVs, IVs, and SVs. It was suggested that hexane, petroleum ether, and CCl_4 were suitable extracting solvents for industrial purposes, while *D. edulis*, *D. tripetala, a*nd *P. Americana* oils are economically viable due to their high % yield, SVs, and IVs.

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The authors declare no potential conflicts of interest.

Author contributions

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