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Comparative Cold and Hot Extraction of Cashew Nut Shell Liquid Using Green and Conventional Solvents

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Abstract
In this study, cashew nutshell liquid has been extracted from cashew nut shells using Ethylacetate, cyclohexane, and petroleum ether as solvents. Cold and hot extraction methods were used using these solvents. The results of the percentage yield for the cold extraction methods are 27.92%, 13.88%, 20.38%, 17.2%, and 11.32% for Ethylacetate, Cyclohexane, Ethylacetate: Cyclohexane (1:1), Ethylacetate: Cyclohexane (1:2), and petroleum ether, respectively, while the percentage yield for the hot extraction methods is 29.54%, 28.94%, 29.94%, 29.40%, and 26.26% for Ethylacetate, Cyclohexane, Ethylacetate: Cyclohexane (1:1), Ethylacetate: Cyclohexane (1:2), and petroleum ether respectively. Clearly, with the results above for cold and hot extraction it showed that other solvents used for the extraction i.e. ethylacetate and cyclohexane gave higher percentage yield than the petroleum ether's yield. However, the study also highlighted the danger associated with the usage of petroleum-based solvent e.g. pet. ether despite its low cost advantage, this has called for the shift to using bio-based solvent or better named "green solvents" that pose little or no danger to the user and to the environment at large. The FT-IR spectra revealed that the extracted CNSL is a polymeric compound that contains phenolic components. The decarboxylation was equally confirmed by the difference between the spectra of the recovered CNSL and the decarboxylated CNSL with the disappearance of C=O peak from a carboxylic acid confirming the evolution of CO2.

Keywords: Cashew Nutshell, Ethylacetate, Cyclohexane, Petroleum Ether, Phenolic, CNSL.

Introduction

The cashew nut shell liquid (CNSL) extraction is an exciting convergence of agro-waste value and sustainable chemical processing and the characterization of materials. CNSL is a phenolic-rich resin, which is extracted out of the outer shell of the Anacardium occidentale, and is gaining popularity as a renewable, low-cost feedstock to polymers, coating, antioxidants, adhesives and specialty chemicals. The cashew nut shell historically was considered waste in agriculture, but thanks to the high concentration of anacardic acids, cardols, and cardanols bioactive compounds that have an industrial and therapeutic potential, it has gained prominence (Kyei et al., 2019). Essentially, the quality and efficiency of CNSL extraction are controlled by the selection of solvent system and process of extraction. Hot oil methods and solvent extraction with petroleum-based organic solvents have been the most widespread industrial operations because of their familiarity of operation and capability to generate technical CNSL rich in cardanol by decarboxylation at high temperatures (CashewPlus, 2025). Conversely, cold extraction technologies are used to maintain the native composition of CNSL especially the anacardic acid component through reduced thermal degradation throughout the procedure. Solvents selection in both categories of systems is very important in extract yield, composition and future use. The recent studies that were conducted between 2020 and 2025 have shown great progress in the area of understanding and optimization of both cold and hot extraction methods, especially with comparative studies conducted on systems of solvents and implementation of the green chemistry concepts. Some of the conventional soxhlet and hot extraction methods based on the use of solvents, such as petroleum ether, chloroform, and hexane, have shown different efficiencies in extraction; ethanol, hexane, and petroleum ether extracted 40.1, 38.2, and 24.6 CNSL, respectively, and the variation was due to the polarity of the solvents as well as their selectivity to the phenolic constituents (Nyirenda, J. et.al, 2021) There has been a major development in the use of greener solvents like ethyl acetate and cyclohexane blends. A comparative study of 2024 showed that ethyl acetate on its own or mixture with cyclohexane gave higher yields of CNSL than petroleum ether in both cold and hot extraction procedures. Importantly, applying the ethyl acetate cold extraction provided almost twice as much CNSL than the conventional solvents that are not green, providing a less harmful and more responsible option to extract the same amount (Michael et. Al., 2024).

Cold versus Hot Extraction

Cold extraction which is usually performed at ambient temperatures and over prolonged periods is geared towards maximizing recovery of native CNSL components by reducing any chemical changes brought about by heat. The low-energy method increases retention of thermally sensitive phenolic compounds, and maintains anacardic acid content an important precursor to down-stream chemical modification. As an example, cold systems based on solvents using ethyl acetate have produced CNSL with significant concentrations of anacardic acid and cardanol mediating that cold extraction can produce compositionally rich extracts without the degradation seen in high-temperature extraction (Michael et. al., 2024). Hot extraction techniques such as Soxhlet extraction, and thermal oil baths, in contrast, take advantage of high temperatures to enable a fast diffusion of the solvent and a speedy diffusion of the solute, often leading to higher extraction efficiencies with fewer cycles. Nevertheless, such circumstances are more likely to induce decarboxylation of anacardic acids to cardanol, which changes the chemical signature of the extract and could undermine some functional properties that could be desirable as high-performance materials (Alara et. al., 2021).

Green versus Conventional Solvents.

In the interval between 2020 and 2025, environmental and health issues have spurred the research into more green solvents that are consistent with concepts of sustainability and regulation compliance. Replacement of petroleum ether and chloroform with ethyl acetate and cyclohexane and mixtures of the two has had encouraging outcomes in yield as well as compositional integrity of CNSL extracts. Ethyl acetate, in particular, has proven to be one of them, producing the highest percentages of CNSL in cold extraction, and it is the most environmentally-friendlier of these in terms of solvent nature, energy demand and cost effectiveness (Michael O. A., et. al, 2024). This shift to greener solvent systems represents a larger industry trend of rejection of toxic, volatile organic solvents most of which are being limited by chemical regulatory frameworks around the world to bio-based, biodegradable, and less-toxic solvents (Abbattista et. al., 2021; Kyei. et.al. 2025). Green solvents do not only cause minimal environmental impact, they also decrease the risks of occupational exposure thus making industrial work safe.

FT-IR Characterization of CNSL.

Fourier-transform infrared (FT-IR) spectroscopy has been one of the pillars of the analytical method of characterizing functional groups in CNSL extracts. The FT-IR profiles can give extensive information on the occurrence of phenolic groups of hydroxyl, aromatic rings, aliphatic values and other vital chemical groups that characterize the application of CNSL in several applications. As an example, FT-IR data reveal the polymeric structure of the extracted CNSL with the typical carboxylic and hydroxyl groups, which is used as a fingerprint in quality measurement and subsequent chemical manipulation (Kyei. et.al, 2019).

More recent combined analyses have paired FT-IR with nuclear magnetic resonance (NMR) and ultra-high performance liquid chromatography mass spectrometry (UHPLC-MS) to more comprehensively profile the compositions, and show the insignificant impact of extraction temperature on the qualitative composition with the use of greener solvent systems (Michael et. al., 2024). Nevertheless, some critical loopholes persist in the comparison of cold and hot extraction of CNSL in green and conventional solvents. To begin with, although a number of studies have shown increased extracts with greener solvents, there is no consensus on the standardized conditions such as the ratio of solvents, length of time, and solid-liquid ratio to maximize both yield and purity simultaneously in cold and hot systems. The absence of standard experimental procedures makes it difficult to compare studies directly and difficult to scale laboratory to industrial experiments (Bhatia et. al., 2024). Also, the majority of the available literature concentrates on quantitative yield and overall compositional attributes, and less research has compared and contrasted extraction conditions with specific functional performance outcomes that are pertinent to the ultimate applications of the polymer precursors like polymer precursor quality, antioxidant activity, or bioactivity. FT-IR characterization provides useful qualitative information, but the relationship between quantitative structure composition and predictive CNSL performance models have not yet been developed (Bhatia et. al., 2024). Additionally, whereas green solvents have become popular, studies on deeply eutectic solvents (DES), ionic liquids and supercritical fluid systems with reference to CNSL are still in their early stages, and most studies have focused on the extractions of model compounds, and not full-scale operational benchmarks in CNSL manufacturing scenarios. Supercritical CO_2, such as, has demonstrated better quality result in other oil extraction environments, but its implementation in commercial operations to CNSL extraction needs additional techno-economic and energy research (Bhatia et. al., 2024).

The insufficient management of agricultural waste poses a serious challenge in emerging nations like Nigeria. A significant quantity of agricultural debris, including corn cob, banana stem, and rice husk, is generated through

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incorrect disposal practices. Cashew nutshell is an additional byproduct that is produced by agro-based enterprises. The improper disposal of this material results in significant environmental degradation on a broad scale (Kyei et al., 2019). Researchers have been utilizing agro-based waste from many businesses to generate additional useful goods, including resin, chemicals, renewable energy, and various value-added chemicals (Agwu and Akpabio, 2018). Cashew (Anacardium Occidentale L.) is a prominent cash crop that is extensively planted across various regions of the globe, particularly in Asia and Africa, where it exhibits a substantial production rate (Swain and Ray, 2006). The cashew tree is responsible for the production of the cashew apple, which serves as the primary product of the tree. The cashew apple serves various purposes. The apple is consumed in its raw form in various regions across the globe, and it is also utilized for the production of several important commodities, including apple fruit beverages, jelly, jam, syrup, and juice (Oyeyinka et al., 2019). The consumption of raw cashew apple and the processing of this fruit into a valuable product result in a significant quantity of cashew agro-based waste. To ensure the management of this waste, it is necessary to implement an effective recycling procedure. The cashew nut is a product derived from the cashew tree. Cashew kernels, which are the raw nuts without shells, undergo a roasting procedure to get the final kernel product. These kernels are known to be a valuable source of CNSL (cashew nut shell liquid). The primary derivative of the cashew business is known as Cashew nut shell liquid (CNSL) (Oyeyinka et al., 2019).

There are two classifications of Cashew Nut Shell Liquid (CNSL), namely Natural CNSL and Technical CNSL. These classifications are determined based on the specific extraction processes employed. Cardanol, also known as Decarboxylated Cardanol Nut Shell Liquid (CNSL), constitutes a substantial portion of Technical CNSL. Conversely, Anacardic acid serves as the primary constituent of Natural CNSL. According to Telascrêa et al. (2014), the two main methods employed for the extraction of CNSL are the cold and hot extraction procedures. Steam processing and roasting can be classified as instances of the hot extraction method, whereas solvent extraction is considered as the cold extraction approach. According to Patel et al. (2006), various procedures, including cold extrusion, solvent extraction, open pan roasting, drum roasting, and hot oil roasting, have been employed for the extraction of cashew nut shell liquid (CNSL) from cashew nutshell (CNS). In their study, Das et al. (2004) documented the utilization of pyrolysis as a means to extract CNSL. The extraction of cashew nut shell liquid (CNSL) can also be achieved using the supercritical carbon dioxide (SC-CO2) method, as demonstrated by Smith et al. (2003). According to Das (2004), the primary constituents of cashew nut shell liquid (CNSL) produced using cold extraction procedures consist of around 90% anacardic acid and roughly 10% cardol. According to the findings of Risfaheri et al. (2009), anacardic acid, cardanol, and cardol were identified as the primary constituents of cashew nut shell liquid (CNSL). Cashew nut shell liquid (CNSL) is a versatile substance that finds application in various industries, including the production of friction linings, paints, primers, and varnishes. Additionally, CNSL is utilized in the manufacturing of wood preservatives, laminating resins, polyurethane-based polymers, surfactants, epoxy resins, and rubber compounding resins (Dholakiya et al., 2012). The objective of this research is to extract cashew nut shell liquid from cashew nutshell through cold and hot extraction methods, employing three distinct solvents (Ethyl acetate, Cyclohexane, and pet ether). The resulting extracts obtained from these techniques are subsequently characterized using Fourier-transform infrared spectroscopy (FT-IR). Lastly, the genetic, environmental and agronomic influences on a regional cashew shell compositions are rarely incorporated in the optimization of extraction research. Considering the fact that CNSL chemistry can differ depending on the source, the use of larger datasets including the global cashew sources is necessary to establish universal robust extraction protocols.

Materials and Methods

Chemicals and Reagents

Petroleum ether, Cyclohexane, Ethyl acetate, Hydrochloric acid, N-hexane, Ammonium hydroxide (25%), Methanol, Celite, Activated charcoal, and Distilled water. All chemicals were of analytical grade and were used as received.

Cashew Nut Collection

Large quantities of cashew Nutshell wastes were collected from Huxley Industrial Limited, Lagos – Sagamu Expressway, Nigeria**.**

Cashew Nut Pre-treatment

The collected nuts were sorted and washed thoroughly. The samples were then kept in clean bags and transferred to the Federal University of Technology Akure Chemistry Laboratory at room temperature. The cashew nuts were removed from the shell using a knife, and the nuts were sundried for 12 hours to remove the moisture present. The nuts were milled into a powdered form using a milling machine. The powdered is then stored in the laboratory oven for 96 hours at 60ºC to remove the remaining moisture.

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Extraction from Cashew nut shell Liquid using Cold Extraction Method

The extraction of CNSL from cashew nut was carried out using cold extraction. 50 g of milled CNS was submerged into 1 liter of pet ether in a cleaned Winchester (2.5 L) bottle. The extraction was carried out in triplicate using three other bottles, and the bottles were left for three days. The extracted CNSL was filtered, and the residues were kept for further use. The percentage yield of the oil was calculated. Greener solvent, cyclohexane, and ethyl acetate were also used for the cold extraction using the above procedure. The process was also carried out in triplicate after the first extraction process. The combination of the greener solvents cyclohexane and ethyl acetate was used for another cold extraction, in the 1:1 and 1: 2 for ethyl acetate and cyclohexane, respectively. The extraction was carried out in triplicate using three other bottles, and the bottles were left for three days. The extracted CNSL was filtered, and the residues were kept for further use. The percentage yield of the oil was calculated (Bharat et al*.*, 2012).

Extraction from Cashew nut Shell Liquid using Hot Extraction Method

CNSL was extracted from CNS using the soxhlet extractor apparatus. The apparatus was thoroughly cleaned and assembled, and 1 liter of the pet ether solvent was transferred into the round bottom flask of the instrument. Fifty grams (50g) of the milled cashew nutshell was weighed and moved into the fitted thimble part of the soxhlet extractor. The pet ether solvent in the apparatus was heated up using the boiling mantle part of the apparatus. The solvent was allowed to boil to its boiling point. During the process, vapor was produced and condensed with the water inlet and outlet fitted to the extractor. The extraction process lasted 8 hours until sufficient CNSL was obtained. Simple distillation was used to recover the oil from the solvent. The process was carried out in triplicate after the first extraction process. The percentage yield was calculated from the results obtained. Greener solvent, cyclohexane, and ethyl acetate were also used for the hot extraction methods after the conventional solvent. The combination of the greener solvents cyclohexane and ethyl acetate was used for another hot extraction in the 1:1 and 1:2 for ethyl acetate and cyclohexane, respectively. The extraction was carried out in triplicate after the first extraction process, and the percentage yield was calculated from the results obtained (Bharat et al., 2012).

Determination of Percentage Oil Yield

The percentage oil yield from the CNSL was calculated after the cold and hot extraction methods. The percentage yield was calculated using the mathematical expression below.

$$\%\text{ yield} = \frac{Mass\ of\ extracted\ oil}{Mass\ of\ cashew\ nut\ shell} \times 100$$

Decarboxylation of CNSL

Anarcadic acid, cardanol, cardol, and traces of 2-methyl cardol are the major constituents of CNSL. Decarboxylation of CNSL was carried out to remove Anarcadic acid from the oil. 500gram of the oil was heated on a heating mantle for 3 hours at a temperature of 200^0C. TLC experiment was carried out to determine the total decarboxylation of CNSL, i.e., to indicate the absence of Anarcadic acid. This study used a mixture of cyclohexane and methanol in a ratio of 1:3 was used as the mobile phase. The Rf values were calculated for CNSL and decarboxylated oil.

Isolation of Cardanol and Cardol

Cardanol isolation: 100g of decarboxylated CNSL was dissolved in 320mls of methanol and 200mls of ammonium hydroxide (25%) stirred for 210mins (3½ hours). N – hexane (4 x 200mls) was used to extract the resulting solution. 5% HCl (100mls) was used to wash the organic layer, followed by 100mls distilled water. 10g of activated charcoal was added to the organic layer and stirred for 10mins. The solution was filtered in a column through 15g of celite, and anhydrous sodium sulfate was used to dry the filtrate. The filtrate was concentrated using a rotary evaporator to obtain pure cardanol (Makame et al*.*, 2016).

Cardol Isolation: Cardol was extracted by further extracting the methanolic ammonia solution (aqueous layer) with an ethyl acetate-hexane mixture in a ratio of 4:1 (2 x 200mls). The resulting organic layer was removed using 5% HCl (100mls), followed by 100mls distilled water. The resulting solution was dried over sodium sulfate and concentrated to yield pure cardol (Makame et al., 2016).

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Fourier Transform Infrared Spectroscopy (FTIR)
The extracted cashew nut shell liquid was characterized using the Fourier transform infrared spectroscopic (FTIR) model Perkin Elmer to identify the various functional groups in the liquid. The instrument was cleaned, the sample was scanned, and the spectrum generated.

Results

Percentage Yield
Tables 1 and 2 show the mean and the percentage yield of cashew nut shell liquid extracted from Cashew nutshell waste using different organic solvents using the cold and hot extraction process. Extraction of Cashew nut shell liquid using pet ether during cold extraction has a percentage yield of 11.32%. In comparison, ethyl acetate has the highest percentage yield among the greener solvent, with a value of 27.92%. Extraction of Cashew nut shell liquid using pet ether during cold extraction has a percentage yield of 26.26%. In comparison, ethyl acetate has the highest percentage yield among the greener solvent, with a value of 29.54%. The Extraction methods using various solvents indicate that the hot extraction process produced a better product than the cold approach. The comparative studies also suggested that the greener solvent has a higher result than the conventional pet ether, which yields a low yield.

Figures 1a to 2b also show the chart and graphical representation of the mean and the percentage yield of the cold and the hot extraction methods.

Table 1: Extraction of cashew nut shell liquid using Cold Extraction method

Solvent	Mean ± S.D	% Yield
Ethylacetate	13.96 ± 5.48	27.92%
Cyclohexane	6.94 ± 1.05	13.88%
Ethylacetate: Cyclohexane (1:1)	10.19 ± 1.75	20.38%
Ethylacetate: Cyclohexane (1:2)	8.60 ± 0.72	17.2%
Pet. Ether	5.66 ± 0.90	11.32%

Table 2: Extraction of cashew nut shell liquid using Hot Extraction method

Solvent	Mean ± S.D	% Yield
Ethylacetate	14.77 ± 2.30	29.54%
Cyclohexane	14.47 ± 1.31	28.94%
Ethylacetate: Cyclohexane (1:1)	14.97 ± 1.53	29.94%
Ethylacetate: Cyclohexane (1:2)	14.70 ± 0.98	29.40%
Pet. Ether	13.13 ± 0.65	26.26%

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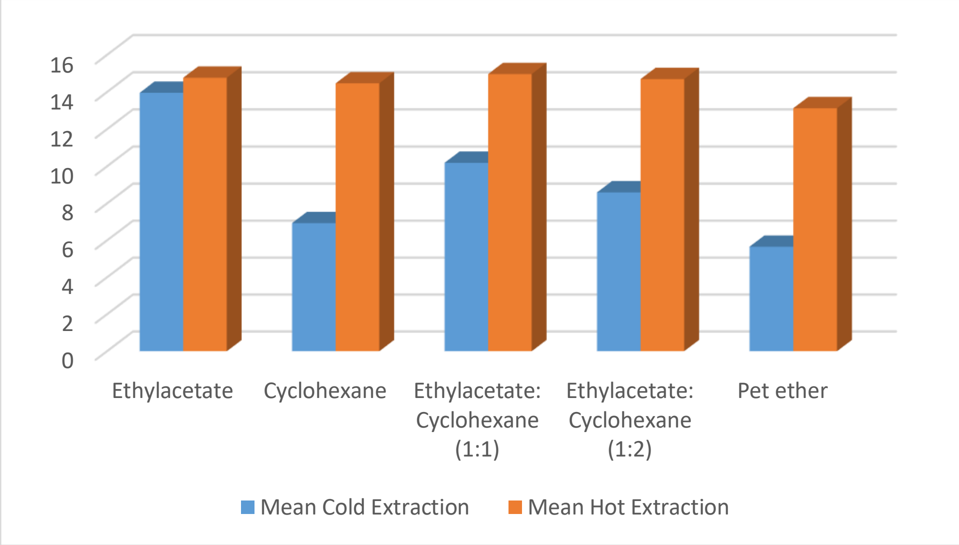

Figure 1a: Mean of extracted cashew nut shell liquid using Cold and Hot Extraction method

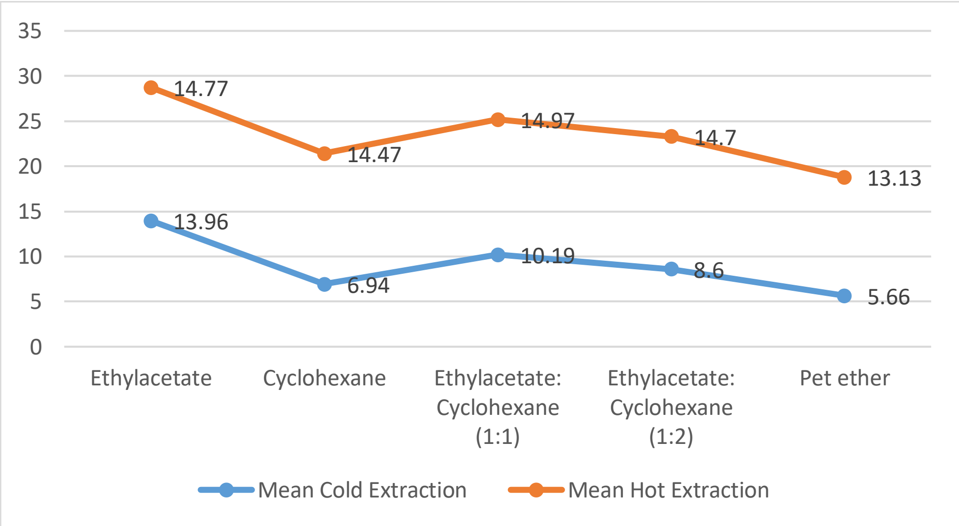

Figure 1b: Mean of extracted cashew nut shell liquid using Cold and Hot Extraction method

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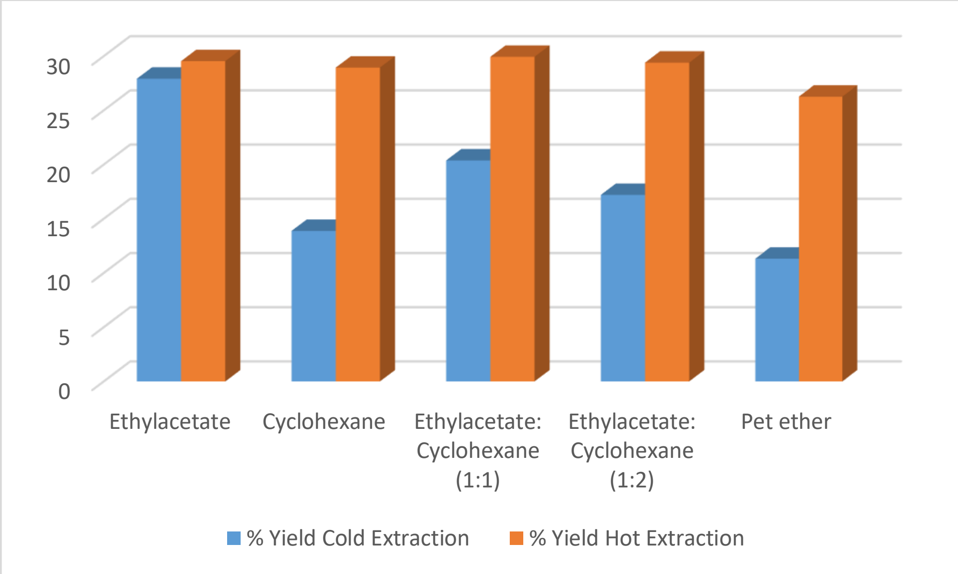

Figure 2a: Percentage yield of extracted cashew nut shell liquid using Cold and Hot Extraction method

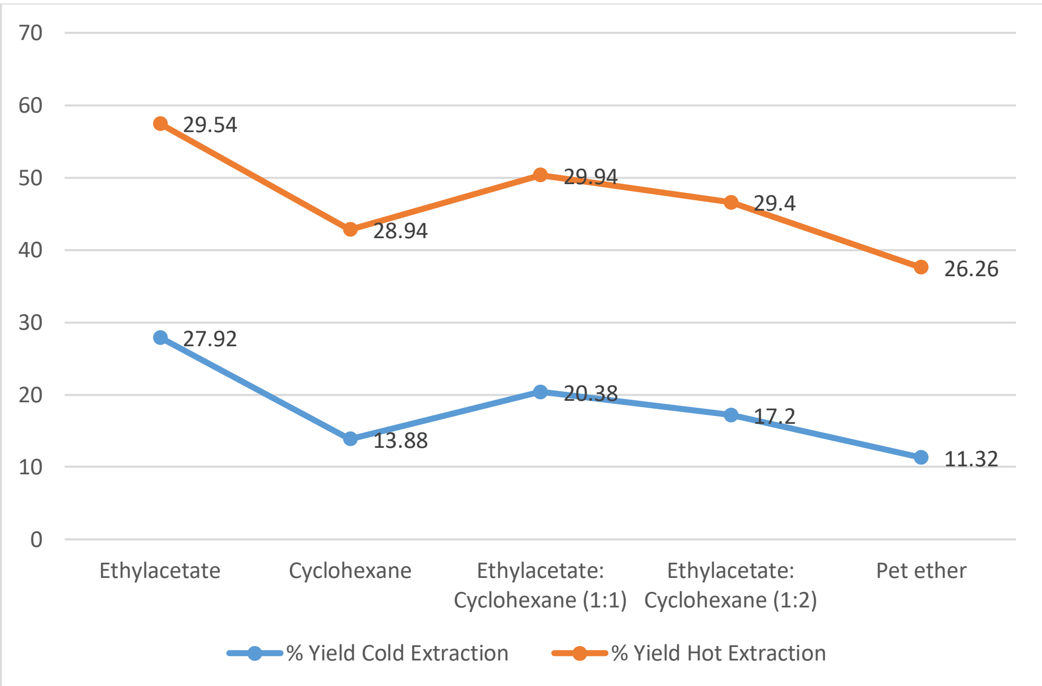

Figure 2b: Percentage yield of extracted cashew nut shell liquid using Cold and Hot Extraction method.

Analysis of FT – IR Spectra of Extracted CNSL with different solvents, Isolated Cardol and Cardanol

The FT-IR spectra of Cashew Nut Shell liquid are presented as categorized below: Fig 3a shows spectra of raw CNSL, recovered CNSL and decarboxylated CNSL. As expected, the broad peak at 3333 cm^{-1} in fig. 3a is due to hydrogen bond of O – H stretching involved in all the phenolic components in the recovered CNSL. Also noticeable are the aromatic = C – H stretching at 3009 cm^{-1} and the C – H stretching peaks common to the recovered and decarboxylated CNSL. Appearance of peaks around 1630 – 1800 signifies C = O stretch from a carboxylic acid. This fact was noticed at 1645 cm^{-1} in fig 3a, confirming that a carboxylic acid C = O stretch is present as a result of Anacardic acid as one of the phenolic components in the recovered CNSL. Fig 3b represent the Isolated Cardol and Cardanol. The peaks at 3354, 3008, 2923 and 2852cm^{-1} are all in conformity with previous spectra in line with the structure under review. However, the O – H peak at 3354 cm^{-1} is not as sharp as what was

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observed in cardol. This confirmed that cardanol has only 1 OH group as against 2 in cardol. Hence the broad peak in cardol was sharper than what is seen in cardanol.

However, the disappearance of this peak at around 1630 – 1800 cm^{-1} was observed in fig. 3a which represents the decarboxylated CNSL. This confirms the complete removal of CO_2 in the decarboxylation process which invariably removes the Anacardic acid leaving the decarboxylated CNSL with only cardol and cardanol. Notable peaks were observed at 3008.85, 2923.28, 2852.85cm^{-1} and common to all the spectra in the figs. Peak 3008.85cm^{-1} indicates the C – H stretch of an aromatic compound SP^2 C – H stretch which indicates the presence of alkenes. 2923.28cm^{-1} shows the alkyl C –H stretch which is expected from the diagram of all phenolic components of CNSL. Also, 2851.70cm^{-1} peak indicates the C – H stretch. SP^3 C – H stretch (Saturated alkyl end) No triple bond, peak was detected at the region 2500 – 2000cm^{-1} of all the spectra. This shows that the phenolic components do not contain triple bonds as shown in their diagrams.

Also notable amongst the spectra in the figs are peaks at 1645 and 1605cm^{-1}. Peak 1645cm^{-1} may be attributed to the C = O, carbonyl group of a carboxylic acid which is contained in the CNSL as Anacardic acid. A dual interpretation of the presence of the peak at 1645cm^{-1} may be possible to be C = C stretch which is equally expected. 1448 cm^{-1} peak indicates O – H bend. Fig. 3a has a broad peak at 3333 cm^{-1} which represents that H – bonding indicating O – H bond which is noticeable in the diagrams of the components. Fig. 3b is the spectrum of isolated cardol which in its structure contains two (2) hydroxyl groups (OH). This is manifested in the spectrum as a sharper broad peak appears at 3384 cm^{-1} characteristics of O – H. Worthy of note is the peak at 1708 cm^{-1} which may be attributed to the presence of an Ester due to interference of the solvent used in the isolation i.e. Ethyl acetate.A C-H bend peak is noticed at 1455 cm^{-1}. Below this peak is forest of peaks in the finger bring region. A C – H bend peak is also observed at 1453/1455 cm^{-1} in fig. 3a and 3b.

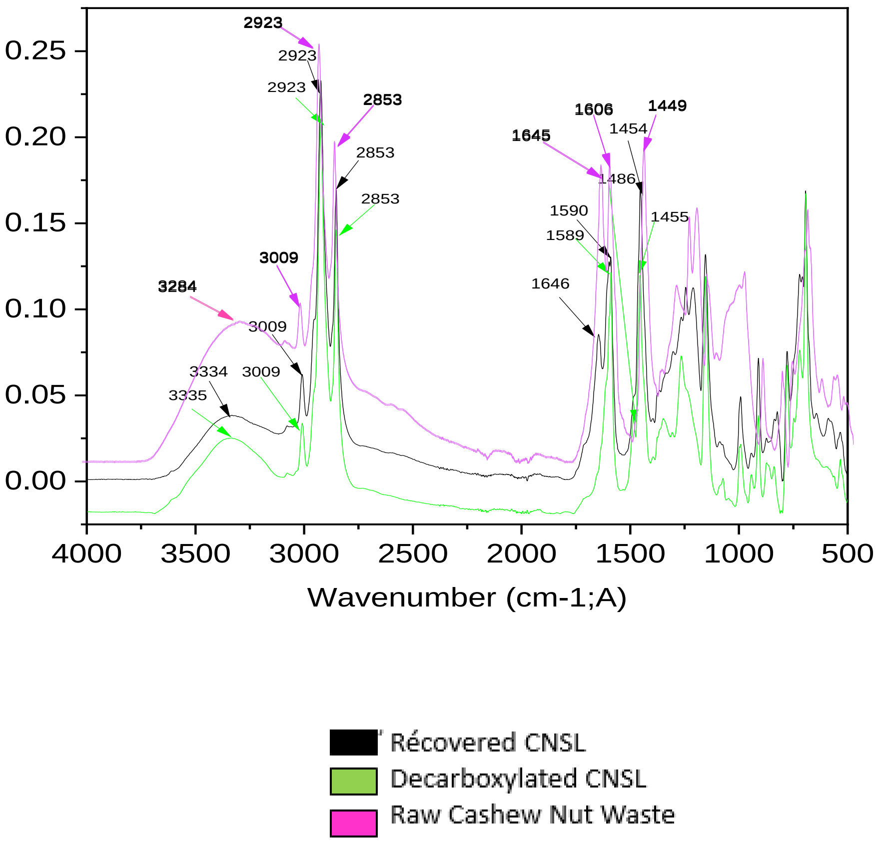

Figure 3a: FT – IR Spectra of Recovered CNSL, Decarboxylated CNSL, Raw Cashew Nut Waste

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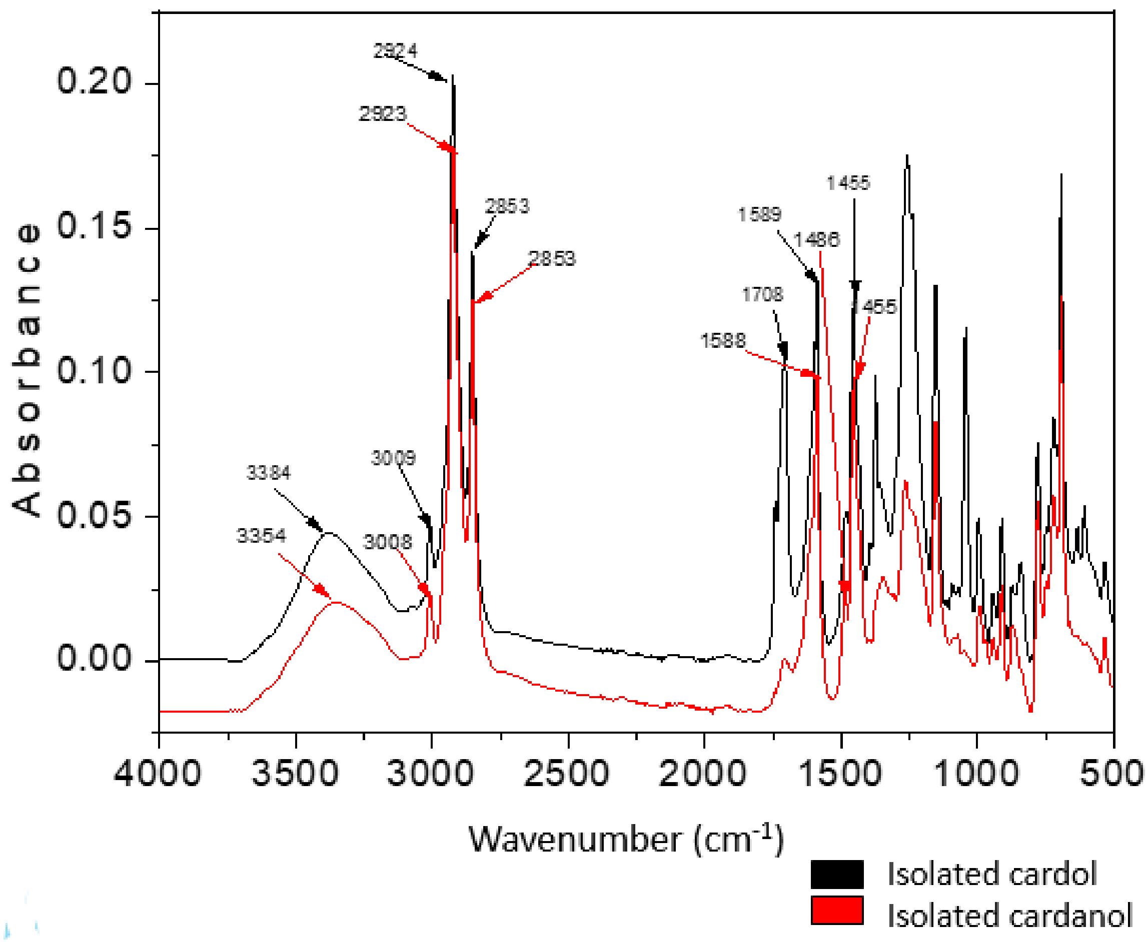

Figure 4b: FT – IR Spectra of Isolated cardol and cardanol

Discussion

Cost Implication and Environmental Impact of Petroleum-Based Solvents E.G. (Petroleum Ether)

The cost of extraction of the CNSL using ethylacetate, cyclohexane and petroleum ether is calculated based on the market survey gotten in Nigeria. The worth of Ethylacetate, cyclohexane and petroleum ether used in the extraction of a CNSL are ₦500, 000. 00, ₦500,000.00 and ₦350,000.00 respectively per drum. The cost of ethylacetate and cyclohexane though are higher than that of petroleum ether, but it is more convenient to extract with non-petroleum based solvent.

Petroleum ether is a group of aliphatic hydrocarbons having boiling point in the range of 40-80^{0}C. Usually, petroleum ether is provided with a suffix which indicates about its boiling point range such as petroleum ether 30-50 indicates that its boiling range is 30-50^{0}C. It is highly flammable and irritant in nature. It has been used as solvent for extraction of oil and in varnish and rubber industry (Zhou et. al., 2019; Anderson 2019). Because of ease in availability, and reduced cost, petroleum–based solvents e.g. petroleum ether are most commonly used for solvent extraction but their health hazard has also been well documented. Solvent extraction has been used conventionally for isolation and recovery of oil, flavouring compounds, antioxidants etc. Easy and economic availability of petroleum – based solvents makes them the ideal choice for commercial applications, however their environmental and health effects have emphasized on the search for alternative solvents.

Green solvents, a group of bio-based solvents having lower toxicity and environmentally safe are explored as a potential candidate for this (Writdhama et. al., 2022). A potential candidate as an alternative to these solvents could be the green solvents. For a solvent to be considered green, it should be derived from renewable feedstock which will not remain for long in the environment and does not lead to the formation of hazardous products during

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its preparation or process. (Anasta and Kirchhoff, 2022). As they are prepared from bio-based materials they are readily degraded in the environment friendly and do not possess human health hazard. Examples of green solvents include ethanol, cyclopentyl methyl ether, ethyl acetate, 2 – methyltetrahydrofuran etc.

Ethylacetate is a colourless liquid with sweet smell and used in nail polish remover, glues, decaffeinating, in cigarettes paint (as an activator of hardener) perfume and confections (as an artificial flavor) etc. In laboratory, the mixture of ethylacetate with other solvents are commonly used for column chromatography and extraction. It is low toxic solvent with LD50 for rat in 5620mg/kg (Sifniades et. al., 2011). Crinnion (2010) said that short – term exposure of these i.e. petroleum based solvents leads to nausea, and dizziness while long term exposure might lead to malfunctioning in liver, kidney and even in the nervous system. Agata (2017) also reported that long-term exposure of petroleum based solvents may result into harmful effect on human beings well-being by affecting respiratory/nervous system. In view of the above dangers to researchers and the environment, this had led to increased concerns about the health of the workers employed in solvent extraction units and on the impact on environmental pollution and calls for search of an alternative to these petroleum based solvents.

Conclusion

The CNSL extracted was subjected to FT – IR analysis involving the cold and hot extracted oil, the recovered and decarboxylated oil. Notable peaks were observed in conformity to the structures of the phenolic components in cashew nut shell liquid. Most importantly, there was clear disappearance of the peak representing the carbonyl group due to carboxylic acid observed in the deoxygenated CNSL. However, the market survey showed that petroleum ether was lower in cost compared to ethyl acetate and cyclohexane, but Jutz et. al., (2011) reported that each year, more than twenty million tons of waste residues from organic solvents are emitted into unnecessary wastage of solvents and pollution of the environment by petroleum based solvents e.g. petroleum ether. This calls for the urgency to look for alternative solvents which could extract the compounds of interest as like the conventional petroleum based solvents without having detrimental effects on the human health and the environmental at large. Hence, this necessitated the use of green solvents like ethylactate and cyclohexane and percentage yield of CNSL by these solvents have proved that higher yield can be obtained by these solvents with little or no harm to the researcher and the environment as a whole. To conclude, the years spanning 2020 to 2025 represent a positive advancement in the study of CNSL extraction via comparative cold and hot system analysis, increased use of greener solvents, and further characterisation of the analytical results with FT-IR and complementary methods. Nevertheless, functional performance, investigation of new green solvent technology, and assimilation of feedstock variability continue to face substantive constraints in the standardized methodology, quantification of functional performance, and exploration of functional performance. These areas of weaknesses will have to be addressed in order to transform CNSL extraction as an academic pursuit to a sustainable industrial practice.

Recommendations

According to the results of the current research, the following recommendations are put forward:

1. Industries that deal with the production of CNSL should gradually substitute petroleum ether with more environmentally friendly solvents like ethyl acetate or ethyl acetate blended with cyclohexane particularly in hot extraction which yielded higher yields.
2. More studies are required on how to maximize solvent ratios, extraction time, solid liquid ratios and temperature so that there is standardization protocol to be used in a large scale industrial application.
3. Further research is required on the effects of extraction conditions on the functional properties of CNSL derivatives (e.g. polymer properties, antioxidant activity, resin strength), rather than percentage yield perse.
4. New green solvents like deep eutectic solvents, ionic liquids, and supercritical CO_2 extraction have to be investigated further to extract CNSL to increase sustainability and efficiency.
5. Safe laboratory and industrial practices should be promoted by the regulatory bodies and research institutions through green solvent use and exposure to petroleum-based solvents should be reduced.
6. Since Nigeria is a large producer of cashew, the government and other stakeholders in the industry ought to invest in sustainable CNSL processing plant to transform agro-waste into industrial raw material with high value to lessen environmental wastes and maximize economics.With the following recommendations in place, CNSL extraction can become more than a laboratory level study and become a viable, economical, and environmental friendly industrial practice.

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