Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT

SCHOLARLY, PEER REVIEWED

Volume 26 No. 2
February 2026

PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Afr. J. Food Agric. Nutr. Dev. 2026; 26(2): 28664-28688 https://doi.org/10.18697/ajfand.149.26200

Date	Submitted	Accepted	Published
	25th July 2025	28th January 2026	3rd March 2026

EFFECTS OF ETHANOL AND N-HEXANE AS SOLVENTS ON THE EXTRACTION YIELD OF COFFEE BEAN ESSENTIAL OIL

Artiningsih A[1]*, Mustafiah M[1], Aziza ZN[1] and N Huda[1]

Andi Artiningsih

*Corresponding author emai: andi.artiningsih@umi.ac.id

[1]Faculty of Industrial Technology, Universitas Muslim, Indonesia

ajfand Since 2001 AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

ABSTRACT

The primary objectives of this study were to investigate how different solvent types and solvent ratios affect both the extraction yield and quality of essential oil derived from coffee beans, with the ultimate goal of optimizing the process for higher yields and superior quality essential oil. This research was conducted in the Research Laboratory of the Chemical Engineering Study Program, where carefully weighed coffee bean samples served as the experimental material. Extraction was performed using two different solvents: 96% ethanol and n-hexane. The Soxhlet extraction technique was employed for a period of three hours, ensuring thorough extraction of the essential oils from the coffee beans. Following extraction, the mixture of coffee and solvent was subjected to distillation in order to separate and remove the solvent, thereby isolating the concentrated essential oil. Subsequent evaluation of the extracted essential oil included determining the percent yield, assessing organoleptic properties, and performing oil component analysis through Gas Chromatography Mass Spectrometry (GC-MS). The findings demonstrated that 96% ethanol provided a substantially higher extraction yield compared to n-hexane. Notably, the essential oil obtained using n-hexane appeared yellow to brown in color and possessed a very weak to weak coffee aroma. In contrast, the oil extracted with 96% ethanol exhibited a deep black color along with a slightly strong to strong coffee aroma, suggesting a richer and more desirable flavor profile. Furthermore, GC-MS analysis revealed that the total peak area of oil components extracted with 96% ethanol was 21.04%, whereas that extracted with n-hexane was only 0.95%. This pronounced disparity clearly highlights the superior efficiency of ethanol as a solvent for extracting high-quality essential oils from coffee beans. These results underscore the significant impact of solvent selection on both the yield and quality of coffee bean essential oil. Ethanol, in particular, shows promising potential for industrial applications in the production of coffee flavorings and fragrances. This study provides valuable insights into optimizing essential oil extraction processes and facilitating the enhanced utilization of coffee bean towards various commercial purposes.

Key words: Solvent, Coffee, Ethanol, N-Hexane, GC-MS, Oils, Solvents, Soxhlet, Industry

Citation: Artiningsih A, Mustafiah M, Aziza ZN and N Huda Effects of Ethanol and N-hexane as Solvents on the Extraction Yield of Coffee Bean Essential Oil. *Afr. J. Food Agric. Nutr. Dev.* 2026; **26(2):** 28664-28688. https://doi.org/10.18697/ajfand.149.26200

Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

INTRODUCTION

Indonesia has extraordinary biodiversity, making it one of the richest countries in the world [1, 2]. Among its diverse flora are essential oil-producing plants, with an estimated 150 to 200 species identified, some of which still offer significant potential for further development [3, 4]. Currently, Indonesia produces about 40 to 50 types of essential oil-producing plants that meet international export quality standards, including cloves, patchouli, eucalyptus, lemongrass, sandalwood, vetiver, and ylang-ylang [5]. Essential oils, also known as ethereal or volatile oils, are aromatic compounds that readily evaporate and are distinguished by their unique fragrances [6]. These oils are extracted from different parts of plants, including leaves, stems, seeds, roots, flowers, and peels [7]. Essential oils have a broad range of uses as raw materials in the perfume, pharmaceutical, and food industries, as well as in aromatherapy [8, 9]. Despite Indonesia's strength in essential oil production, the country is currently facing significant challenges in other agricultural sectors, particularly in coffee bean production. As the world's leading coffee producer, Indonesia faces climate change, pests and diseases [10]. These issues threaten local farmers' livelihoods and impact the global coffee supply chain, contributing to rising prices and potential shortages. This global coffee bean issue points out the importance of sustainable agricultural practices and the need for innovation across all of Indonesia's valuable plant-based industries, including essential oils, to ensure long-term productivity and export potential.

Various extraction techniques have been explored to optimize the yield and quality of coffee essential oils [11]. Steam distillation and solvent extraction are widely used, but newer methods such as supercritical Carbon Dioxide (CO_2) extraction and microwave-assisted extraction have shown promise for higher efficiency and preservation of thermolabile compounds [11, 12]. The coffee bean and roasting degree significantly influence the oil's composition and sensory profile. Coffee-derived essential oils are being explored for multiple applications. In the food industry, they serve as flavoring agents and natural preservatives due to antimicrobial and antioxidant activity [13, 14]. In cosmetics and perfumery, the pleasant aroma and bioactive profile are valued for formulations in skincare and fragrances and its use in aromatherapy for stress reduction and as eco-friendly pesticides in agriculture [15, 16]. Overall, global research indicates that coffee-derived essential oils present a versatile and sustainable resource through advanced extraction technologies and broader application development.

Coffee has essential oils containing a complex mixture of volatile compounds as characteristic aroma and bioactivity including furans, aldehydes, ketones, alcohols, esters, and phenolic compounds. For instance, studies from Brazil and Italy have identified key aroma compounds such as 2-furfurylthiol, guaiacol, and various pyrazines as dominant in roasted coffee oil [17, 18]. These compounds are recognized for their antioxidant, antimicrobial and anti-inflammatory properties, making coffee essential oils attractive for functional applications. In Indonesia, coffee is a leading commodity in the plantation sector, with Arabica coffee (Coffea arabica) and Robusta coffee (Coffea robusta) being the most widely cultivated varieties [19]. Apart from Indonesia, coffee is also processed into high-quality beverages and food products in various countries [20]. Coffee ranks as the second most widely used and traded commodity [21, 22]. Coffee from Indonesia has strong competitiveness, positioning the country as the fourth-largest coffee exporter in the world. However, Indonesia's coffee export volume is currently declining [23]. It is necessary to develop coffee processing in line with advancements in science and technology [24]. One such development is utilizing coffee as a source of essential oils to meet international export quality standards, considering that the development of essential oils derived from coffee in Indonesia is still relatively limited [25]. The essential oil content in coffee beans ranges from approximately 10% to 16% [26]. Due to their distinctive aroma, the essential oils contained in coffee beans are often used as raw materials in the perfume industry [27].

The process of obtaining essential oil extracts is closely related to the use of solvents, which serve to separate or dissolve other compounds, whether in liquid or solid form [28]. Solvents are generally classified into two types: polar solvents, which can dissolve polar compounds, and nonpolar solvents, which can dissolve nonpolar compounds. Solvents play a critical role in the extraction process, especially in separating essential oils from plant materials such as seeds or beans [29]. The selection of an appropriate solvent is essential, as it significantly affects the extraction yield and the quality of the essential oil obtained [30]. Therefore, solvents should meet specific criteria, including being easily accessible and safe to use [31]. Based on this background, this study was conducted to investigate the effect of solvent type and solvent ratio on the extraction yield and quality of coffee bean essential oil. The coffee beans were subjected to an initial roasting process as a preparatory treatment. This study aimed to obtain coffee bean essential oil with high yield and good quality through the appropriate selection of solvent type and solvent ratio.

MATERIALS AND METHODS

Research Procedures

Preliminary Treatment of Materials

The theoretical foundation for the preparation and analysis of roasted coffee bean samples is grounded in principles of mass transfer and analytical chemistry, emphasizing the need for uniform particle size and sample homogeneity to achieve reproducible and accurate extraction results [32, 33]. Cleaning, drying, roasting, grinding, and sieving the coffee beans facilitating the efficient diffusion during the coffee beans extraction. This approach aligns with standard practices in natural product extraction, where reducing particle size enhances solvent penetration and accelerates the transfer of bioactive constituents such as essential oils and phenolics from the plant matrix into the solvent phase.

These tools are not only robust and widely accepted in the scientific community but also appropriate for the scale and scope of the data collected, ensuring that the analysis remains both rigorous and interpretable [34]. This methodological choice is further supported by literature emphasizing the importance of statistical rigor and reproducibility in food and natural product chemistry research, ensuring that the findings are reliable and meaningful for both academic and practical applications. Samples were collected from Jangan-jangan Village, Pujananting Sub-district, Barru Regency. The coffee beans were cleaned to remove impurities, washed thoroughly with clean water, then dried and roasted. The roasted coffee beans were ground using a blender, and the resulting coffee bean powder was sieved to obtain particles of 100 mesh size [35]. The sieved coffee bean powder was weighed, with 40 g prepared for each variable, and placed into the extraction sleeve [36].

Robusta Coffee Bean Extraction

The Soxhlet apparatus was assembled with a condenser and a boiling flask [37]. A total of 40 g of coffee bean powder was placed into the prepared extraction sleeve and inserted into the Soxhlet extractor [38]. The extraction was performed using n-hexane and 96% ethanol solvents at varying volumes of 350 mL, 500 mL, 650 mL, 800 mL and 950 mL, which were added to the boiling flask. The Soxhlet apparatus was placed on a heater and operated at 69 °C for n-hexane and 78 °C for 96% ethanol. The extraction process was carried out for 3 hours to obtain a mixture of coffee bean essential oil and solvent. After the extraction was completed, the coffee bean essential oil was separated from the solvent through a distillation process. The extracted essential oil was then collected in sample bottles for further analysis. The extracted essential oil was evaluated for percent yield, organoleptic properties, and oil component analysis using Gas Chromatography–Mass Spectrometry (GC-MS).

Yield

The yield of Robusta coffee bean essential oil was calculated by comparing the weight of the extracted coffee bean essential oil to the weight of the initial coffee bean sample [39, 40].

$$x = \frac{\text{Weight of extract (gr)}}{\text{Weight of initial sample (gr)}} \times 100\%$$

ajfand Since 2001 AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Information:

x = Yield (%)

W_1 = Weight of extract (g)

W_2 = Weight of initial sample (g)

Organoleptic Test

The organoleptic test was conducted to observe the physical characteristics of the extracted coffee bean essential oil [13]. This test included an assessment of color and aroma by a panel of evaluators. Before solvent evaporation, the essential oil was colorless [41]. After the evaporation process, the essential oil displayed various colors, including green, brown, yellow and red. The aroma of the essential oil was stimulating and unique to each solvent type and extraction condition.

Oil Component Analysis

The analysis of coffee bean essential oil components was conducted using Gas Chromatography–Mass Spectrometry (GC-MS). This analysis was performed at the Chemical Laboratory of the Makassar Plantation Products Industry Center.

RESULTS AND DISCUSSION

Effect of Solvent Type

Effect on the Yield of Coffee Bean Essential Oil

Based on the results of the extraction process using the Soxhlet method with varying solvent volumes, it can be observed in Figure 1 that when using 96% ethanol, the yield of the extracted coffee bean essential oil (extraction yield) increased with increasing solvent volume. The yields obtained at solvent volumes of 350 mL, 500 mL, 650 mL, 800 mL, and 950 mL were 3.11%, 6.26%, 7.00%, 10.65% and 9.31%, respectively. In contrast, when using n-hexane as the solvent, the yield of the extracted coffee bean essential oil, as shown in Figure 1, was lower. The yields at solvent volumes of 350 mL, 500 mL, 650 mL, 800 mL and 950 mL were 2.36%, 2.09%, 1.17%, 2.58% and 2.07%, respectively.

ajfand Since 2001
AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

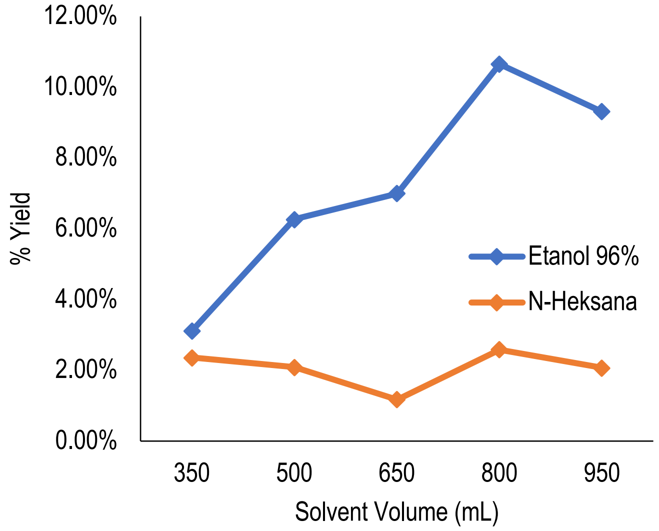

Figure 1: Relationship between Variation in Solvent Volume (mL) and Yield (%) of Coffee Bean Essential Oil

The choice of solvent is a critical factor in the extraction of essential oils from coffee beans, as it directly affects both the yield and the spectrum of chemical compounds recovered. A total of 96% ethanol and n-hexane were employed due to their differing polarities and established selectivity profiles. Ethanol, a semipolar solvent, is recognized for its versatility in dissolving a wide range of both polar and nonpolar compounds, including essential oils, alkaloids, and flavonoids, making it a favored choice in food, pharmaceutical, and cosmetic industries. Its miscibility with water allows it to penetrate plant matrices effectively, facilitating the extraction of a broader spectrum of bioactive compounds. Conversely, n-hexane, a nonpolar solvent, excels in the selective extraction of nonpolar compounds, particularly lipophilic and aromatic constituents, due to its chemical stability and volatility, qualities that make it ideal for industrial-scale extraction of oils and fragrances [42]. Some studies conducted in various countries underscores both the promise and the limitations of solvent selection in essential oil extraction from coffee and other botanicals [17]. For instance, studies in Brazil and Colombia, two leading coffee-producing nations, have demonstrated that ethanol extracts tend to capture a broader range of phenolic compounds and antioxidants but may co-extract unwanted polar impurities, potentially compromising oil purity or sensory attributes [16, 26, 43]. However, hexane yields higher concentrations of volatile aroma compounds and triglycerides in Indonesian and Vietnamese extracts are excluding polar bioactive compounds. This limitation restricts the functional properties of the extracts, as the absence of polar bioactives such as antioxidants, phenolics, and other health-promoting molecules and also reduces their potential benefits.

Previous research also often relied on a single extraction solvent or did not systematically compare the efficiency and selectivity of solvents with different polarities, which restricts the generalizability of their findings and leaves open questions regarding optimal solvent systems for comprehensive essential oil recovery. Furthermore, many earlier studies lacked rigorous compositional analysis or failed to consider the environmental impact of solvent use, an increasingly important factor in green chemistry and sustainable processing. The comparative approach uses ethanol and n-hexane, thereby enabling a more nuanced evaluation of solvent selectivity and extraction yield. By analyzing the resulting extracts for both yield and chemical profile, this study aimed to provide clearer guidance on solvent choice for coffee essential oil extraction, balancing extraction efficiency, compound diversity, and practical considerations such as solvent safety and environmental impact. These improvements not only enhance the academic rigor of the work by situating it within the broader context of global research but also offer actionable insights for industry and future studies seeking to optimize extraction methodologies for maximal recovery and functionality of coffee-derived essential oils.

The extracted coffee bean essential oil was higher when 96% ethanol was used as the solvent compared to n-hexane, under identical extraction conditions of a 3-hour duration and 40 g of coffee bean powder. This observed difference in yield can be attributed to the chemical transformations that occur during the roasting process, which activates and generates a diverse array of compounds within the coffee beans. Specifically, the pyrolysis of carbohydrates such as hemicellulose, cellulose, and lignin during roasting leads to the formation of a variety of simpler and often more polar compounds, including furans, phenols, reducing sugars, and carbonyl compounds [29]. These newly formed polar substances, such as phenolic and carbonyl groups, are more readily soluble in semipolar solvents like ethanol. Ethanol's higher selectivity and broader solubility range allow it to effectively extract both polar and some nonpolar constituents, resulting in a greater overall yield of essential oil. In contrast, n-hexane, being a nonpolar solvent, is less efficient at dissolving the more polar compounds that are prevalent in roasted coffee beans, thus yielding a lower extract amount [45]. Therefore, the enhanced yield observed with ethanol is a direct consequence of its ability to better match the polarity of the compounds formed during roasting, highlighting its suitability as a solvent for comprehensive extraction of coffee bean essential oils.

Ethanol, as a volatile solvent with semipolar properties, is particularly effective in the extraction of a broad spectrum of compounds from plant matrices, including coffee beans. Its unique molecular structure allows it to dissolve both polar and nonpolar components, making it a highly versatile solvent in natural product extraction processes [46]. The principle "like dissolves like" governs how well a solvent can extract certain compounds. This means that the polarity of the solvent should be very similar to the polarity of the target components in order to maximize solubility and extraction efficiency [47]. In the context of coffee bean essential oil extraction, the roasting process plays a crucial role in altering the chemical makeup of the beans, generating a variety of polar substances such as phenolics, carbonyls, and reducing sugars. This theoretical basis is corroborated by the experimental results presented in Figure 1, which show a noticeably higher yield of essential oil when ethanol is used as the extraction solvent compared to n-hexane under the same conditions.

N-hexane, in contrast, is a nonpolar solvent that excels in extracting nonpolar compounds, primarily targeting lipids and volatile aromatic constituents present in coffee beans. While n-hexane is efficient for isolating certain oil fractions, its extraction capability is inherently limited to nonpolar molecules, resulting in lower overall yields, especially after the roasting process, which favors the formation of more polar compounds. The comparative results from this study illustrate that the semipolar nature of ethanol gives it a distinct advantage in extracting the more abundant polar compounds formed during roasting, thereby significantly increasing the yield of essential oil. Thus, the choice of ethanol not only ensures a more comprehensive extraction of bioactive and flavor compounds but also demonstrates the critical importance of matching solvent polarity to the chemical characteristics of the target components in optimizing extraction processes for coffee bean essential oils.

Effect on the Color and Aroma of Essential Oil

After the extraction of coffee bean essential oil using 96% ethanol and n-hexane, an organoleptic evaluation was systematically conducted to unravel the nuanced impact of solvent choice on the oil’s color and aroma, two parameters essential for both product quality and consumer acceptance. Employing a panel of 15 trained evaluators, the study ensured a controlled and statistically robust sensory assessment, minimizing subjective variability. Analytical depth is provided by considering the molecular interactions underlying the observed results: Ethanol, with its semipolar profile, facilitates the extraction of a diverse array of compounds, including polar Maillard reaction products, phenolic derivatives, and caramelized sugars, all of which are known contributors to the rich amber color and layered aroma typical of high-quality coffee extracts. The evaluators consistently reported that ethanol-extracted oils exhibited a more intense golden-brown hue and a complex aroma profile, marked by roasted, caramel, and subtly fruity notes attributes likely linked to the solvent's ability to dissolve both polar and nonpolar volatile compounds generated during roasting.

Color

The results of the color evaluation by the trained panel, as summarized in Table 1, reveal a clear and analytically significant difference in the color of coffee bean essential oil extracts depending on the solvent used. When n-hexane was used, the color scores ranged from 1.73 to 3.20, corresponding visually to shades from yellow to brown. This variability is attributable to the limited solubility of n-hexane, a nonpolar solvent, which primarily extracts lipid-based compounds and only a small fraction of pigmented molecules, thus resulting in lighter-colored oils. In contrast, the assessment for the extracts obtained with 96% ethanol was remarkably consistent, with evaluators uniformly assigning the maximum score of 5.00, denoting a black-colored oil [48]. This striking difference is mechanistically rooted in the fundamental chemistry of both the roasting process and solvent extraction.

During the roasting of coffee beans, a set of complex thermal reactions occur, most notably the Maillard reaction, a non-enzymatic browning process that involves reducing sugars and amino acids, producing high-molecular-weight melanoidin polymers responsible for the characteristic brown to black color of roasted coffee [48]. Simultaneously, pyrolysis of structural polysaccharides such as cellulose, hemicellulose, and lignin generates additional pigmented byproducts, some of which are intensely black. The molecular structure of these pigments, including melanoidins, is typically rich in polar and semipolar functional groups, making them readily soluble in polar or semipolar solvents like ethanol but only sparingly soluble in nonpolar solvents like n-hexane.

Ethanol's semipolar nature allows it to break hydrogen bonds and dissolve a wide range of colored compounds, from low-molecular-weight caramelization products to high-molecular-weight melanoidins and even some pigments that come from chlorogenic acid. It demonstrates that ethanol efficiently extracts not just volatile or lipidic fractions but also the full suite of roast-generated pigments, imparting the observed intense black color to the oil [49]. The mechanism here is governed by solvent-solute polarity compatibility: ethanol's ability to engage in both hydrogen bonding and van der Waals interactions allows for the dissolution of a broader spectrum of both hydrophilic and hydrophobic colored species. In contrast, n-hexane, lacking such polarity and hydrogen-bonding capacity, selectively extracts only nonpolar color compounds, which are less abundant in roasted coffee, resulting in oils of a lighter hue [50]. These findings underscore how solvent polarity and the chemistry of coffee roasting interact synergistically to determine the final appearance

ajfand Since 2001 AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

and likely the chemical composition of coffee bean essential oil extracts, with implications for both their aesthetic and functional qualities in various applications.

Aroma

The panel of evaluators' assessments of the aroma of the extracted coffee bean essential oils, as presented in Table 2, reveal a clear distinction between the sensory effects of the two solvents utilized in this study. The scores for the n-hexane extracts, ranging from 1.40 to 2.00, indicate that the coffee aroma was perceived as weak by the evaluators. This subdued aroma profile can be mechanistically explained by both the chemical nature of n-hexane and possible solvent residue effects. N-hexane, as a nonpolar solvent, preferentially extracts nonpolar, hydrophobic compounds such as certain lipids and waxes, but is less effective at solubilizing the polar and semipolar volatile aromatic compounds responsible for coffee's distinctive fragrance, such as ketones, furans, and pyrazines [51]. Hence, the key aroma-active molecules remain unextracted or are present only in low concentrations in the n-hexane derived oil. Furthermore, any residual n-hexane that is not completely removed during post-extraction processing can impart a faint hydrocarbon note to the oil, which can mask or suppress the natural coffee aroma and contribute to the panel's weaker aroma ratings. Hydrocarbon residues not only dampen the pleasant aroma but can also interfere with the perception of subtle volatile compounds due to olfactory adaptation or antagonism effects.

The essential oil extracted with 96% ethanol received significantly higher aroma scores, ranging from 2.93 to 3.73, corresponding to the aroma being perceived as slightly strong to strong. Ethanol's semipolar character allows it to dissolve a much broader spectrum of volatile and semi-volatile compounds, including those produced or intensified during the roasting process. Roasting induces a cascade of chemical transformations: the Maillard reaction and caramelization processes give rise to complex mixtures of aromatic molecules, notably ketones (which add buttery, creamy notes), furans (which contribute sweet, caramel-like aromas), and pyrazines (which are associated with nutty, roasted, and earthy tones). Ethanol can effectively solubilize these compounds due to its ability to engage in hydrogen bonding and dipole-dipole interactions, ensuring their recovery in the extract and intensifying the oil's aroma profile [52].

Mechanistically, the extraction and retention of these volatile aroma compounds are highly dependent on solvent polarity and the resulting solubility parameters. Ethanol not only extracts but also helps stabilize these volatile molecules, reducing their loss during processing. This is a critical advantage over n-hexane, which is less compatible with the majority of polar and semipolar aroma compounds created during roasting [30]. It is also important to note that the absence of noticeable solvent

Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

odor in ethanol extracts, due to the relatively rapid evaporation and lower olfactory impact of ethanol compared to n-hexane, further enhances the authentic coffee aroma perceived by the panel. The panel's aroma assessments provide sensory evidence of the underlying extraction mechanisms: ethanol's semipolarity and volatility facilitate the recovery and preservation of the complex bouquet of roasted coffee aromas, while n-hexane's nonpolarity and potential for residual odor limit both the extraction and the sensory intensity of key aromatic compounds. This analytical perspective clarifies the reasons behind the observed differences and reinforces the importance of solvent choice in optimizing the flavor of coffee bean as an essential oil products.

Comparison of GC-MS Results

Based on the results of the extraction process, using 96% ethanol solvent produced the highest yield at a solvent volume of 800 mL, which was 10.65%. Meanwhile, using n-hexane solvent, the highest yield was produced at a solvent volume of 800 mL, which was 2.58%. The extracts with the highest yields from each solvent were then analyzed using Gas Chromatography–Mass Spectrometry (GC-MS) to analyze the chemical components present in the extracted coffee bean essential oil for each solvent.

Essential Oil Components Using 96% Ethanol Solvent

In this study, the essential oil components of coffee beans extracted using 96% ethanol solvent were analyzed. The results of the Gas Chromatography–Mass Spectrometry (GC-MS) analysis are shown in Figure 2 below.

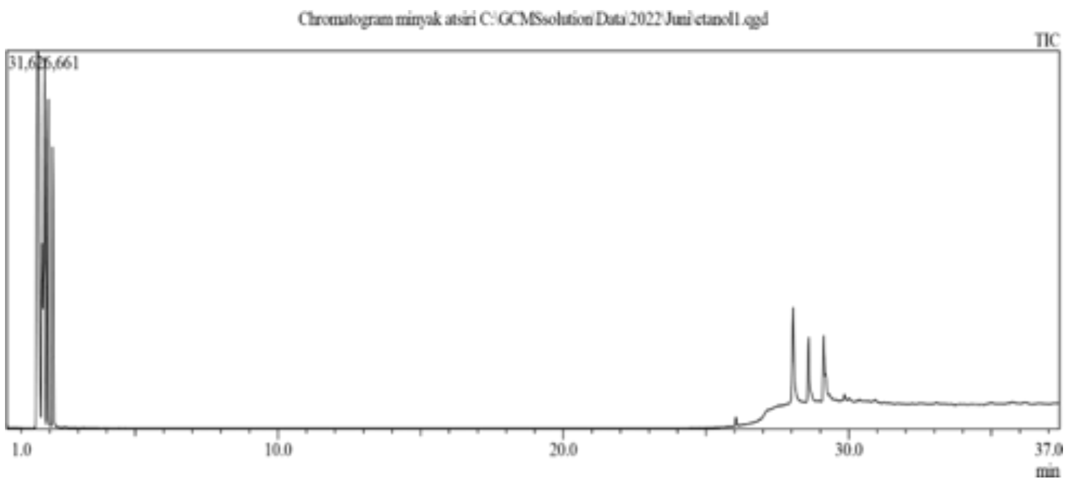

Figure 2: GC Chromatogram of Coffee Bean Essential Oil Extracted with Ethanol Solvent

The results of the analysis showed that when using ethanol as a solvent, the main components of the extracted coffee bean essential oil were identified as follows: Pentadecanoic acid (CAS: Pentadecylic acid), Octadecanoic acid, 2-propenyl ester (CAS: Allyl stearate), 9,12-Octadecadienoic acid (Z,Z)- (CAS: Linoleic acid), Tetradecanoic acid (CAS: Myristic acid), 1-Nonadecene (CAS), Hexadecanoic acid (CAS: Palmitic acid), 9-Octadecenoic acid (Z)- (CAS: Oleic acid), 1-Hexacosene (CAS), 1,2-Benzenedicarboxylic acid, ditridecyl ester, and 9,12-Octadecadienoic acid (Z,Z)-, trimethylsilyl ester. The respective peak area percentages of these compounds were 5.18%, 1.25%, 2.91%, 1.73%, 2.60%, 0.67%, 2.23%, 2.31%, 1.14% and 1.02%. The total area of the identified components in the extracted coffee bean essential oil using 96% ethanol solvent was 21.04%. The major components were primarily fatty acids, which are widely used in the manufacture of soaps, cosmetics, flavors, perfumes and antioxidants [48].

Essential Oil Components Using N-hexane Solvent

The essential oil components of coffee beans extracted using n-hexane solvent were analyzed. Figure 3 below displays the results of the Gas Chromatography–Mass Spectrometry (GC-MS) analysis.

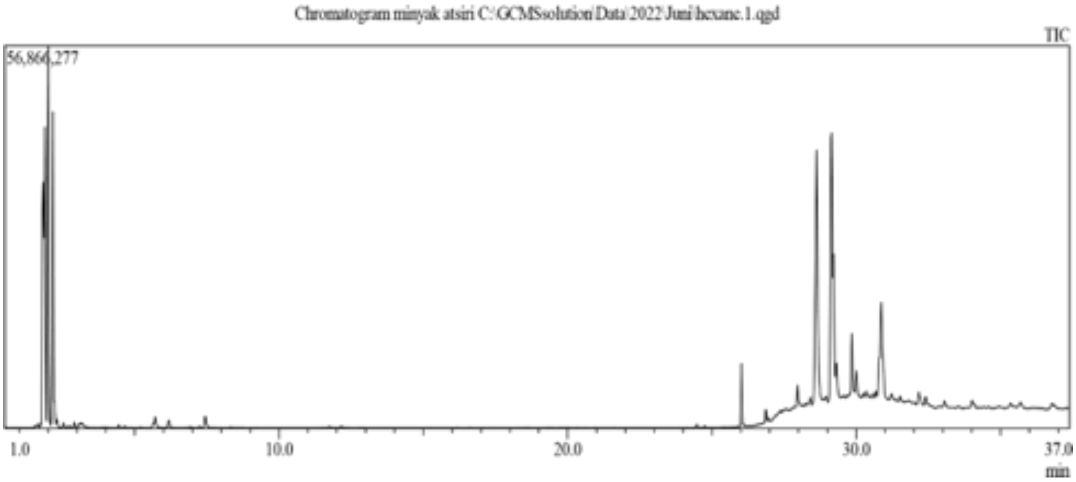

Figure 3: GC Chromatogram of Coffee Bean Essential Oil Extracted with N-hexane Solvent

Using n-hexane as a solvent, the main components with the highest concentrations in the extracted coffee bean essential oil were identified as follows: 2-Propanone (CAS: Acetone), 2-Pentanol, 2-methyl- (CAS: 2-Methyl-2-pentanol), Benzene, methyl- (CAS: Toluene), and Butanal, 2-ethyl- (CAS: 2-Ethylbutanal). The respective peak areas of these compounds were 0.11%, 0.11%, 0.12%, and 0.23%. Based on the Gas Chromatography–Mass Spectrometry (GC-MS) results, the total area of the components in the extracted coffee bean essential oil using n-hexane solvent was

ajfand Since 2001 AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

0.95%. The major components identified are widely used as flavoring agents, perfumes or fragrances, and antioxidants [17].

Table 3 shows that the choice of solvent plays a crucial role in determining the quality attributes of coffee bean essential oil, particularly its color and aroma. Based on organoleptic assessments, ethanol (96%) and n-hexane exhibit distinct effects on these sensory properties. Ethanol consistently produced higher color scores across all tested solvent volumes, maintaining the maximum score of 5.00. This indicates that ethanol is highly effective in extracting or preserving the color compounds inherent in coffee beans. Ethanol's polarity allows it to dissolve a broader range of compounds, including pigments and polyphenols, which contribute to the oil's vibrant appearance. In contrast, n-hexane, a non-polar solvent, yielded lower and more variable color scores (ranging from 1.73 to 3.20). This suggests that n-hexane is less efficient at extracting color-rich compounds, resulting in a paler oil. A similar trend was observed in the aroma scores. Ethanol-extracted oils exhibited consistently higher aroma scores (2.93–3.73), reflecting a richer and more characteristic coffee scent. Ethanol's ability to dissolve both volatile and semi-volatile aroma compounds enhances the sensory quality of the oil. Conversely, n-hexane extracts resulted in lower aroma scores (1.40–2.00), indicating a less intense and less complex aromatic profile. This is likely due to n-hexane's limited capacity to extract the diverse array of aroma compounds present in coffee beans. Overall, ethanol 96% is superior to n-hexane in extracting both the color and aroma of coffee bean oil, making it a preferable solvent for applications requiring high sensory quality.

CONCLUSION AND RECOMMENDATIONS FOR DEVEOPMENT

The findings demonstrated that ethanol, a semi-polar solvent, significantly outperformed the non-polar solvent n-hexane in terms of extraction yield and quality of the essential oil obtained. Ethanol produced a higher yield and resulted in oils with superior sensory characteristics, such as richer color and stronger aroma. These differences are attributed to the ability of ethanol to dissolve a broader range of compounds, particularly those that are more polar, which are commonly formed during the roasting process of coffee beans. Moreover, the GC-MS analysis further confirmed that the essential oils extracted with ethanol contained a more diverse and complex composition of volatile compounds compared to those extracted with n-hexane. This calls attention to the possible application of ethanol-extracted coffee bean essential oils in various industries, including cosmetics, food and beverages, and aromatherapy. It also underlines the importance of not only maximizing extraction yield but also enhancing the functional and commercial value of the extracted products through the careful selection of solvents.

Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

The selection of extraction solvent must be evaluated holistically, as it directly impacts product safety, sustainability and economic feasibility. Ethanol is generally regarded as safe (GRAS) for food and cosmetic applications, with relatively low toxicity and rapid biodegradability. In contrast, n-hexane is classified as a neurotoxic and environmentally hazardous solvent, posing health risks through inhalation or residue in the final product and requiring strict regulatory controls. Volatility also poses practical challenges: both solvents are highly volatile, but hexane's higher vapor pressure increases the risk of workplace exposure and environmental release, thus necessitating rigorous ventilation and recovery systems. Economically, ethanol is more readily available, can be produced from renewable resources, and may be recycled within the process, while n-hexane, being a petroleum derivative, is subject to price fluctuations and supply chain concerns. Ethanol, being less toxic and easier to evaporate or distill, poses fewer risks in this regard, but its strong solvating power can co-extract unwanted polar impurities, which may require further purification steps, such as distillation or chromatography, to achieve the desired essential oil purity. This study emphasizes that optimizing coffee essential oil extraction requires a balance between technical efficiency, product safety, economic feasibility, and environmental sustainability. It also points out the need for future research into green extraction methods, advanced purification techniques, and regulatory harmonization to support the sustainable development and global competitiveness of Indonesia's coffee-based essential oil industry.

Practical Implications

This study offers several practical implications, particularly for industries that are engaged in the production and commercialization of essential oils. First and foremost, the results demonstrate that solvent selection has a direct and substantial impact on both the extraction efficiency and the chemical quality of essential oils. This suggests that industries should carefully evaluate their choice of solvents considering the polarity of the target compounds and the desired quality attributes of the final product, such as aroma intensity, color and functional properties. Most appropriate solvent, producers can maximize yields while also enhancing the commercial appeal of their essential oils. This study highlights the potential of coffee beans, an abundant agricultural commodity in Indonesia, as a promising source of high-value essential oils. The findings suggest that with appropriate solvent selection and process optimization, coffee-based essential oils can be developed as an innovative product for various sectors, including perfumery, cosmetics, food flavoring, and aromatherapy. This could provide a significant opportunity for coffee producers and agro-industrial entrepreneurs in Indonesia to diversify their product portfolios and improve their competitiveness in the global market.

This study also demonstrates the value of integrating scientific research with industrial practices. Companies involved in essential oil production are encouraged to collaborate with research institutions to explore new extraction technologies, optimize processing parameters, and ensure compliance with safety and environmental regulations. Such collaboration could lead to the development of standardized, high-quality essential oils derived from coffee, which would encourage product innovation and international trade. Lastly, the insights gained from this study could be valuable for policymakers and agricultural extension agencies aiming to enhance the economic value of local agricultural products. By promoting research-based innovations and supporting the development of value-added products such as coffee-based essential oils, governments can contribute to sustainable rural development, increase farmers' incomes, and strengthen the national agro-industrial sector.

This study extends directly to Indonesian coffee farmers, offering tangible opportunities to increase both the value and marketability of their crops. One immediate strategy is the formation of farmer cooperatives or partnerships with local agro-industries and universities to establish small-scale essential oil extraction units in coffee-producing regions. These units can utilize affordable, food-grade ethanol that is readily available in Indonesia, allowing farmers to process post-harvest or lower-grade beans, which would otherwise have limited market value into premium essential oils for sale to the cosmetics, food and aromatherapy sectors. Farmers can also be trained, through government extension services or university outreach programs, on best practices for post-harvest handling, roasting, and extraction, ensuring that the quality of the raw material and the resulting oil meets industry standards. Additionally, farmers can collaborate with researchers to develop environmentally friendly extraction methods, improve product traceability, and obtain organic or fair-trade certifications, further enhancing the export value of their essential oils.

Limitations and Future Study Directions

Although this study presents valuable findings, it is important to acknowledge several limitations. First, this research focused solely on the use of two types of solvents, ethanol and n-hexane, with a specific extraction method, namely Soxhlet extraction. These solvents are polar and non-polar, but they do not cover the whole range of solvents that can be used to extract essential oils. For example, supercritical CO_2, ionic liquids, and deep eutectic solvents may be more efficient, selective, and environmentally friendly. Furthermore, the study was conducted under controlled laboratory conditions, which may not fully reflect the complexities and operational challenges encountered in industrial-scale extraction processes. Furthermore, this study exclusively examined coffee beans from a single geographical origin. Given the significant variation in chemical composition of coffee beans due to factors such as cultivar, soil conditions, climate and post-harvest handling, future studies should incorporate a more diverse set of coffee bean samples from different regions and growing conditions. Such efforts would improve the generalizability of the findings and provide a more comprehensive understanding of the potential of coffee-based essential oils.

ACKNOWLEDGEMENTS

Many thanks go to the participation of Universitas Muslim Indonesia, Makassar, Sulawesi Selatan, Indonesia.

Author Contributions

Conceptualization AA and ZNA, Methodology Mm and NH, Validation AA and NH, Data curation MM and ZNA, Writing the original draft preparation AA and MM, and Supervision AA and MH. All authors have read and agreed to the published version of the manuscript.

Since 2001 ajfand AFRICAN JOURNAL OF FOOD, AGRICULTURE, NUTRITION AND DEVELOPMENT
SCHOLARLY, PEER REVIEWED
Volume 26 No. 2
February 2026
PUBLISHED BY AFRICAN SCHOLARLY SCIENCE COMMUNICATIONS TRUST
ISSN 1684 5374

Table 1: Organoleptic Test Results of Coffee bean oil Color

No.	Solvent Volume	Color	
		Ethanol 96%	N-hexane
1.	350 mL	5.00	2.47
2.	500 mL	5.00	3.20
3.	650 mL	5.00	3.20
4.	800 mL	5.00	1.73
5.	950 mL	5.00	2.80

Table 2: Organoleptic Test Results of Coffee bean oil Aroma

No.	Solvent Volume	Color	
		Ethanol 96%	N-hexane
1.	350 mL	2.93	2.00
2.	500 mL	3.13	1.40
3.	650 mL	3.13	1.60
4.	800 mL	3.73	1.80
5.	950 mL	3.13	1.93

Table 3: Organoleptic Test Results of Coffee bean oil Aroma

No.	Solvent	Effect on Color	Effect on Aroma
1.	Ethanol 96%	Maintains strong, rich color	Provides richer, stronger aroma
2.	n-Hexane	Weaker, less intense color	Weaker, less complex aroma

https://doi.org/10.18697/ajfand.149.26200

REFERENCES

1. **Gunawan H, Setyawati T, Atmoko T, Subarudi S, Kwatrina RT, Yeny I, Yuwati TW, Effendy R, Abdullah L, Mukhlisi M, Lastini T, Arini DID, Sari UK, Sitepu BS, Pattiselanno F and W Kuswanda** A review of forest fragmentation in Indonesia under the DPSIR framework for biodiversity conservation strategies. *Global Ecology and Conservation*. 2024; **51**: e02918. https://doi.org/10.1016/j.gecco.2024.e02918

2. **Andayani SA, Ismail AY, Permana NS, Nainggolan MF and SA Sembiring** Price predictions on red chili (Capsicum annuum) commodities in Indonesia. *Afr. J. Food Agric. Nutr. Dev*. 2025; **25(5)**: 26600-26628. https://doi.org/10.18697/ajfand.142.24495

3. **Mukaila YO, Pfukwa TM and OA Fawole** Essential oils from South African indigenous plants: Extraction techniques, phytochemistry, biological activities and applications. *South African Journal of Botany*. 2025; **180**: 774-794. https://doi.org/10.1016/j.sajb.2025.04.004

4. **Isoto RE, Bashaasha B and I Nakamatte** Impact of nutritional status of smallholder farm households on agricultural productivity: panel data evidence from Uganda. *Afr. J. Food Agric. Nutr. Dev*. 2025; **25(5)**: 26846-26865. https://doi.org/10.18697/ajfand.142.25535

5. **Ministry of Trade of The Republic of Indonesia.** Patchouli Oil. *Export News* September 2015; Directorate General of National Export Development, Indonesia. https://ditjenpen.kemendag.go.id/storage/publikasi/240-5291455002421.pdf *Accessed on July 2025.*

6. **Butnariu M and I Sarac** Essential Oils from Plants. *Journal of Biotechnology and Biomedical Science*. 2018; **3(5)**: 35–43. https://doi.org/10.14302/issn.2576

7. **Kant R and A Kumar** Review on essential oil extraction from aromatic and medicinal plants: Techniques, performance and economic analysis. *Sustainable Chemistry and Pharmacy*. 2022; **30**: 100829. https://doi.org/https://doi.org/10.1016/j.scp.2022.100829

8. **Jugreet BS, Suroowan S, Rengasamy RRK and MF Mahomoodally** Chemistry, bioactivities, mode of action and industrial applications of essential oils. *Trends in Food Science & Technology*. 2020; **101**: 89–105. https://doi.org/https://doi.org/10.1016/j.tifs.2020.04.025

9. **Sharmeen JB, Mahomoodally FM, Zengin G and F Maggi** Essential oils as natural sources of fragrance compounds for cosmetics and cosmeceuticals. *Molecules*. 2021; **26(3)**: 666. https://doi.org/10.3390/molecules26030666

10. **Gaikwad RK**, **Mondal IH, Dash KK, Shaikh AM and B Kovács** Effectiveness of sustainable oil extraction techniques: A comprehensive review. *Journal of Agriculture and Food Research*. 2025; **19:** 101546. https://doi.org/10.1016/j.jafr.2024.101546

11. **Nabi MH, Md. Monir A, Md. Suhel M, Sumon I and Z Wahidu** Essential oils: Advances in extraction techniques, chemical composition, bioactivities, and emerging applications. *Food Chemistry Advances.* 2025; **8**: 101048. https://doi.org/10.1016/j.focha.2025.101048

12. **Arisena GMK, Darmawan DP, Dewi NLMIM, Sahatmana GW, Paskahadi KA, Salombe GA, Gunawan IWNF, Jayanti PD, Mufa RMD and PH Sudipa** Risk mitigation model for layer farming agribusiness in penebel district, Tabanan regency. *J. Anim. Health Prod.* 2025; **13(3)**: 676-681. https://dx.doi.org/10.17582/journal.jahp/2025/13.3.676.681

13. **Konfo TRC, Djouhou FMC, Koudoro YA, Dahouenon-Ahoussi E, Avlessi F, Sohounhloue CKD and J Simal-Gandara** Essential oils as natural antioxidants for the control of food preservation. *Food Chemistry Advances.* 2023; **2**: 100312. https://doi.org/10.1016/j.focha.2023.100312

14. **Shi J, Xu J, Liu X., Goda AA, Salem SH, Deabes MM, Ibrahim MIM, Naguib K and SR Mohamed** Evaluation of some artificial food preservatives and natural plant extracts as antimicrobial agents for safety. *Discov Food.* 2024; **4**, 89. https://doi.org/10.1007/s44187-024-00162-z

15. **Ayllón-Gutiérrez R, Díaz-Rubio L, Montaño-Soto M, Haro-Vázquez MdP and I Córdova-Guerrero** Applications of Plant Essential Oils in Pest Control and Their Encapsulation for Controlled Release: A Review. Agriculture. 2024; **14(10)**: 1766. https://doi.org/10.3390/agriculture14101766

16. **Shiekh RAE, Atwa AM, Elgindy AM, Mustafa AM, Senna MM, Alkabbani MA and KM Ibrahim** Therapeutic applications of eucalyptus essential oils. *Inflammopharmacology*. 2025; **33**: 163–182. https://doi.org/10.1007/s10787-024-01588-8

17. **Bordiga M, Disca V, Manfredi M, Barberis E, Carrà F, Navarini L, Lonzarich V and M Arlorio**. Fingerprinting of Green Arabica Coffee Volatile Organic Compounds (VOCs): HS-GC-IMS Versus GC × GC-MS. *International Journal of Food Science.* 2025. https://doi.org/10.1155/ijfo/1302823

18. **Genovese A, Caporaso N and A Baiano** the Impact of Brewing Methods on the Quality of a Cup of Coffee. *Beverages*. 2025; **11(5)**: 125. https://doi.org/10.3390/beverages11050125

19. **Marwani E, Syamsudin TS, Awaliyah S, Maulani RR, Hidayat A, Husyari UD and S Widiyanto** Volatile Metabolite Profiles of Robusta Green Bean Coffee From Different Geographical Origins in West Java and Their Correlation With Temperature, Rainfall, and Altitudes Using SPME GC-MS–Based Metabolomics. *International Journal of Food Science*. 2024; 1-16. https://doi.org/10.1155/2024/6908059

20. **Freitas VV, Borges LLR, Vidigal MCTR, dos Santos MH and PC Stringheta** Coffee: A comprehensive overview of origin, market, and the quality process. *Trends in Food Science and Technology*. 2024; **146**: 104411. https://doi.org/https://doi.org/10.1016/j.tifs.2024.104411

21. **Jaworska M and W Majchrzak** The Coffee Market in Global Terms: Production and Trade Considerations. *Journal of Agribusiness and Rural Development*. 2025; **76(2)**: 177–186. https://doi.org/10.17306/j.jard.2025.00015r1

22. **Ochago R** How Innovation Platforms Govern the Experiential Learning Process of Coffee Farmers in Uganda. *Afr. J. Food Agric. Nutr. Dev*. 2025; **24(12)**: 25179—25204. https://doi.org/10.18697/ajfand.137.24640

23. **Suryana AT, Saleh Y, Dewi TG and HSP Rahayu** Global competitiveness of coffee products: A comparative study of Indonesia and Vietnam. *Coffee Science*. 2024; **19**: 1-11. https://doi.org/10.25186/.v19i.2237

24. **Irjayanti M, Azis AM, Susilawati S and AR Sobari** Transformative innovations igniting coffee supply chain process efficiency. *Journal of Innovation and Entrepreneurship*. 2025; **14(1)**: 44. https://doi.org/10.1186/s13731-025-00486-9

25. **Aytar EC and B Aydın** Investigation of Chemical Composition, Antioxidant Properties, and Molecular Docking in Different Roasting Stages of Coffee Beans. *Food and Bioprocess Technology*. 2025; **18(2)**: 1464–1482. https://doi.org/10.1007/s11947-024-03539-1

26. **Ribeiro RC, Mota MFS, Silva RMV, Silva DC, Novaes FJM, da Veiga VFJ, Bizzo HR, Teixeira RSS and CM Rezende** Coffee Oil Extraction Methods: A Review. *Foods.* 2024, **13(16)**: 2601. https://doi.org/10.3390/foods13162601

27. **Tsitlakidou P, Tasopoulos N, Chatzopoulou P and I Mourtzinos** Current status, technology, regulation and future perspectives of essential oils usage in the food and drink industry. *Journa l of the Science of Food and Agriculture*. 2023; **103(14)**: 6727–6751. https://doi.org/10.1002/jsfa.12695

28. **Hassid A, Salla M, Krayem M, Khaled S, Hassan HF and S El Khatib** A review on the versatile applications of plant-based essential oils in food flavoring, culinary uses and health benefits. *Discover Food*. 2025; **5(130)**: 1-17. https://doi.org/10.1007/s44187-025-00417-3

29. **Zhou W, Li J, Wang X, Liu L, Li Y, Song R, Zhang M and X Li** Research Progress on Extraction, Separation, and Purification Methods of Plant Essential Oils. *Separations*. 2023; **10(12)**: 1–17. https://doi.org/10.3390/separations10120596

30. **Lee JE, Jayakody JTM, Kim JI, Jeong JW, Choi KM, Kim TS, Seo C, Azimi I, Hyun J and B Ryu** The Influence of Solvent Choice on the Extraction of Bioactive Compounds from Asteraceae: A Comparative Review. *Foods*. 2024; **13(19)**: 3151. https://doi.org/10.3390/foods13193151

31. **Usman M, Cheng S, Boonyubol S and JS Cross** Evaluating Green Solvents for Bio-Oil Extraction: Advancements, Challenges, and Future Perspectives. *Energies*. 2023; **16(15)**: 5852. https://doi.org/10.3390/en16155852

32. **Debastiani R, da Silva LP, Touguinha GC, dos Santos CEI, Amaral L and JF Dias** Elemental Analysis of Coffee with Ion Beam Analytical Techniques. *Foods*. 2025; **14(4)**: 585. https://doi.org/10.3390/foods14040585

33. **Santander M, Chica V, Correa HAM, Rodríguez J, Villagran E, Vaillant F and S Escobar** Unravelling Cocoa Drying Technology: A Comprehensive Review of the Influence on Flavor Formation and Quality. *Foods*. 2025; **14(5)**: 721. https://doi.org/10.3390/foods14050721

34. **Bakhshabadi H, Ganje M, Gharekhani M, Mohammadi-Moghaddam T, Aulestia C and A Morshedi** A Review of New Methods for Extracting Oil from Plants to Enhance the Efficiency and Physicochemical Properties of the Extracted Oils. *Processes*. 2025; **13(4):** 1124. https://doi.org/10.3390/pr13041124

35. **Kim YK, Lim JM, Kim YJ and W Kim** Alterations in pH of Coffee Bean Extract and Properties of Chlorogenic Acid Based on the Roasting Degree. *Foods*. 2024; **13(11)**: 1757. https://doi.org/10.3390/foods13111757

36. **Ray A, Dubey KK, Marathe SJ and R Singhal** Supercritical fluid extraction of bioactives from fruit waste and its therapeutic potential. *Food Bioscience*. 2023; **52**: 102418. https://doi.org/https://doi.org/10.1016/j.fbio.2023.102418

37. **Yusran Y, Erniwati E, Maksum H, Khumaidi A and RHB Setiarto** Effect of Cooking on the Proximate Composition and Minerals content of Wild Eible Macro Funfi from Lore Lindu National Park, Central Sulawesi, Indonesia. *Afr. J. Food Agric. Nutr. Dev*. 2022; **22(5)**: 20523-20541. https://doi.org/10.18697/ajfand.110.21660

38. **Torres-Rodriguez A, Darvishzadeh R, Skidmore AK, Fränzel-Luiten E, Knaken B and B Schuur** High-throughput Soxhlet extraction method applied for analysis of leaf lignocellulose and non-structural substances. *MethodsX*. 2024; **12**: 102644. https://doi.org/10.1016/j.mex.2024.102644

39. **Dong E, Chen Q, Wei C, Hu R, Long Y, Zong Y and Z Chu** Comparison of the effect of extraction methods on the quality of green coffee oil from Arabica coffee beans: Lipid yield, fatty acid composition, bioactive components, and antioxidant activity. *Untrasonics Sonochemistry*. 2021; **74**: 105578. https://doi.org/10.1016/j.ultsonch.2021.105578

40. **Jia Z, Wan L, Huang Z and W Zhang** Quality Evaluation of Hainan Robusta Coffee Bean Oil Produced by Ultrasound Coupled with Coconut Oil Extraction. *Foods*. 2023; **12(11)**: 2235. https://doi.org/10.3390/foods12112235

41. **Pandey VK, Srivastava S, Ashish A, Dash KK, Singh R, Dar AH, Singh T, Farooqui A, Shaikh AM and B Kovacs** Bioactive properties of clove (Syzygium aromaticum) essential oil nanoemulsion: A comprehensive review. Heliyon. 2024; **10(1)**: e22437. https://doi.org/10.1016/j.heliyon.2023.e22437

42. **Ashaari NS, Mohamad NE, Afzinizam AH, Rahim MHA, Lai KS and JO Abdullah** Chemical composition of hexane-extracted plectranthus amboinicus leaf essential oil: Maximizing contents on harvested plant materials. *Applied Sciences*. 2021; **11(22)**: 1–14. https://doi.org/10.3390/app112210838

43. **Krinski IM, Leite VR, Moura LM and VC Mariani** Critical Extraction Parameters for Maximizing Oil Yield from Spent Coffee Grounds. *Energies*. 2025; **18(6)**: 1–17. https://doi.org/10.3390/en18061346

44. **Lee JE, Jayakody JTM, Kim JI, Jeong JW, Choi KM, Kim TS, Seo C, Azimi I, Hyun JM and BM Ryu** The Influence of Solvent Choice on the Extraction of Bioactive Compounds from Asteraceae: A Comparative Review. *Foods*. 2024; **13(19)**: 1–21. https://doi.org/10.3390/foods13193151

45. **Cao X, Wu H, Viejo CG, Dunshea FR and HAR Suleria** Effects of postharvest processing on aroma formation in roasted coffee – a review. *International Journal of Food Science & Technology*. 2023; **58(3)**: 1007–1027. https://doi.org/https://doi.org/10.1111/ijfs.16261

46. **Akinmoladun AC, Falaiye OE, Ojo OB, Adeoti A, Amoo ZA and MT Olaleye** Effect of extraction technique, solvent polarity, and plant matrix on the antioxidant properties of Chrysophyllum albidum G. Don (African Star Apple). *Bulletin of the National Research Centre*. 2022; **46(1)**: 1-17. https://doi.org/10.1186/s42269-022-00718-y

47. **Zhang QW, Lin LG and WC Ye** Techniques for extraction and isolation of natural products: a comprehensive review. *Chin Med*. 2018; **13(20)**: 1-19. https://doi.org/10.1186/s13020-018-0177-x

48. **Otsogile K, Seifu E and G Bultosa** Physicochemical properties and sensory quality of Motlopi (Boscia albitrunca) coffee prepared using different temperature-time combinations. *Heliyon*. 2022; **8(10)**: e10829. https://doi.org/10.1016/j.heliyon.2022.e10829

49. **Cravotto C, Fabiano-Tixier AS, Claux O, Abert-Vian M, Tabasso S, Cravotto G and F Chemat** Towards Substitution of Hexane as Extraction Solvent of Food Products and Ingredients with No Regrets. *Foods*. 2022; **11(21)**: 3412. https://doi.org/10.3390/foods11213412

50. **Almaguer C, Kollmannsberger H, Gasti M and T Becker** Characterization of the aroma profile of quinoa (Chenopodium quinoa Willd.) and assessment of the impact of malting on the odor-active volatile composition. *Journal of the Science of Food and Agriculture.* 2022; **1035(5)**: 2283-2294. https://doi.org/10.1002/jsfa.12418

51. **Jeong EJ, Lee SH, Kim BT, Lee G, Yun SS, Lim HS and YS Kim** An analysis method for determining residual hexane in health functional food products using static headspace gas chromatography. *Food Science and Biotechnology*. 2017; **26(2)**: 363–368. https://doi.org/10.1007/s10068-017-0049-7

52. **Dias LD, Carbinatto FM, Almeida IS, Blanco KC, Marquele-Oliveira F, Munari CC and VS Bagnato** Eco-Friendly Extraction of Green Coffee Oil for Industrial Applications: Its Antioxidant, Cytotoxic, Clonogenic, and Wound Healing Properties. *Fermentation*. 2023; **9(4)**: 370. https://doi.org/10.3390/fermentation9040370