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# Comparison of Oven and Microwave Drying on Extraction of Spent Coffee Grounds Oil

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ABSTRACT

Spent coffee grounds (SCG) are frequently disposed of in landfills, which creates significant environmental concerns. Scientists are investigating methods to repurpose SCG, recognizing its potential for various beneficial applications. This study compared oven and microwave drying methods for extracting oil from spent coffee grounds (SCG), focusing on yield and quality of oil. The findings demonstrated that oven drying resulted in a slightly lower moisture content and a significantly higher oil yield (10.01%) compared to microwave drying (8.9%). Additionally, oil from oven-dried SCG exhibited superior quality, with lower acid and peroxide values, indicating less oxidative degradation during the drying process. The structural analysis further supported these results, showing that oven drying better preserved the SCG's cellular structure, which may contribute to the higher retention of oil-bearing compounds. In contrast, microwave drying, while faster, caused more structural damage and led to lower oil yield and reduced quality due to its rapid heating mechanism. This research contributes to the growing body of knowledge on sustainable SCG utilization by highlighting the advantages of oven drying for optimizing oil extraction. The findings are particularly relevant for industries that prioritize oil quality and yield, such as cosmetics and pharmaceuticals.

***Keywords:*** Microwave drying, Oil extraction, Oven drying, Spent coffee grounds

## Introduction

Coffee ranks among the most popular beverages worldwide, with an estimated consumption of 10 million tons of green coffee beans during the 2019–2020 period.[1] The rising of coffee consumption has led to the generation of significant quantities of waste, particularly spent coffee grounds (SCG), which are by-products of the brewing process. SCG are often discarded into landfills, posing serious environmental challenges. Researchers are exploring ways to repurpose SCG due to its valuable content, including fatty acids, polyphenols, and antioxidants, which could have industrial applications in the food, pharmaceutical, and cosmetic sectors.[2] Waste generated from coffee processing is broadly classified into two categories: pre-roasting waste (such as coffee husks and pulp) and post-roasting residues, which include coffee silverskin and SCG.[3] These residues contain a range of valuable organic compounds, including amino acids, lignin, cellulose, and bioactive substances like caffeine, tannins, flavonoids, and phenolics.[4,5] Such compounds present numerous opportunities for valorization, including biofuel production, antioxidant extraction, and the development of activated carbon and absorbents.[6] Despite these promising uses, SCG are primarily disposed of in environmentally harmful ways, such as incineration or landfill disposal, contributing to greenhouse gas emissions and air quality degradation.[2]

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Therefore, finding efficient methods to recover valuable compounds from SCG and prevent their environmental impact has become a pressing issue.A significant challenge in SCG management is its high moisture content, which can reach up to 80%.[7] This high moisture level makes SCG prone to microbial degradation, reducing its storage stability and the quality of its bioactive compounds. The degradation of these compounds not only diminishes the potential for industrial applications but also limits SCG's shelf life.[8] Drying is a widely recognized method to address this issue, as it effectively removes water from materials, extending their storage life by preventing microbial growth and chemical degradation.[9] In the context of SCG, drying is essential to reduce moisture levels below 12%, the threshold required to inhibit microbial activity during storage and transport.[10] The drying process also plays a critical role in preserving the phytochemical properties of SCG, making it a fundamental pre-treatment step for any subsequent utilization.[11]

Given the importance of drying for moisture reduction, several methods have been developed and studied, including oven drying and microwave drying. Oven drying, a conventional method, involves heating the material's surface, and the heat gradually penetrates deeper into the material. While effective, oven drying can be time-consuming and energy-intensive. On the other hand, microwave drying employs electromagnetic waves that penetrate the material, causing water molecules to oscillate rapidly. This agitation generates heat internally, accelerating the evaporation process.[12] This method offers time efficiency but may result in uneven drying and degradation of sensitive bioactive compounds due to localized overheating. These variations in the drying process can impact the quality and yield of oil extracted, with previous studies suggesting that different drying techniques lead to varying levels of oil retention and preservation of bioactive components.[1] Several studies have explored methods to optimize oil extraction, emphasizing the importance of drying as a crucial preparatory step. Chimsook and Assawarachan,[13] found that conventional drying methods such as oven drying produce higher quality of avocado oil with better retention of bioactive compounds

compared to microwave drying. Similarly, studies on coffee silverskin, another by-product of coffee production, show that oven drying results in higher oil yields and lower oxidative degradation, as indicated by lower peroxide values.[14] These findings highlight the importance of choosing the drying method, as it significantly influences the extracted oil quality and its suitability for various industrial applications.

Despite the promising applications of SCG oil, there is a clear lack of research regarding the comparative effects of oven and microwave drying specifically on SCG oil extraction. While studies like those by Miladi et al.,[3] have examined the general effects of drying on oil yield, few have focused specifically on the structural changes, moisture reduction efficiency, and preservation of bioactive compounds in SCG. Furthermore, studies have not thoroughly explored how these two drying techniques affect the physicochemical properties of the extracted oil, such as its saponification, peroxide, and acid values, which are crucial indicators of oil quality and stability. This study aims to address these gaps by systematically comparing the effects of oven drying and microwave drying on SCG oil extraction. By investigating the drying methods' impact on the physicochemical properties of SCG oil, this research seeks to provide new insights that could guide the selection of optimal processing methods for SCG in industrial applications. The scope of the study includes an analysis of drying kinetics, oil yield and quality parameters, contributing to the broader field of sustainable waste management and resource recovery from coffee by-products.

## Materials and Methods

*Sample preparation*

SCG samples used in this study were sourced from coffee shop around Banda Aceh, Aceh, Indonesia. Before proceeding with the experimental analysis, the SCG was dried using two methods: oven drying and microwave drying. The drying process aimed to reduce the SCG's moisture content to ensure optimal oil extraction and preservation of bioactive compounds. The solvent used for oil extraction was analytical-grade hexane, sourced from Merck, Germany.

*Experimental procedure*

The experimental workflow followed a systematic process divided into two main phases: SCG drying and oil extraction.

*SCG drying*

The SCG drying process was conducted using two distinct methods, i.e. oven and microwave drying. In the first process, the SCG samples were dried at 40°C using a digital laboratory drying oven (Prio, 800 W, 30 L capacity). Approximately 3 grams of SCG were placed on aluminum trays and dried until a constant weight was achieved. The drying process was monitored by weighing the samples every minute to ensure accurate tracking of moisture content. This process was repeated three times to ensure consistency and reliability. In the microwave drying process, SCG samples were dried at medium power using a microwave (Kris, 700 W, 20 L capacity). Samples were placed on ceramic plates, and the drying process was similarly monitored by weighing the samples. This procedure was also repeated three times for consistency. The initial moisture content ($M_i$) of the SCG was determined by drying a 3 g sample in an oven at 105°C for 24 hours. The initial moisture content was calculated using Eq. (1).

$$M_i = \frac{w_i - w_f}{w_i} \quad (1)$$

where $w_i$ represent the initial weight (g) and $w_f$ represent the final weight (g) of the sample. The moisture content at time $t$ ($M_t$) in the SCG was calculated using Eq. (2).

$$M_i = \frac{w_i - w_t}{w_i} \quad (2)$$

where $w_t$ is the weight SCG at time $t$ (g). All parameters were measured on a wet basis.

*SCG oil extraction*

Following the optimal drying process for each method, oil was extracted from the SCG using the Soxhlet extraction method with hexane as the solvent. A ratio of SCG to solvent of 1:15 (g/mL) was maintained. The extraction was carried out at 50°C for one hour. After extraction, the solvent was removed using a rotary evaporator (Eyela N-1000) under vacuum conditions at 55°C for 40 minutes. The extracted oil was stored in a sealed container for further analysis. The experimental results were reported in terms of SCG yield determined by Eq. (3).

$$Y = \frac{W_o}{W_d}\ x\ 100\% \quad (3)$$

where $Y$ is the oil yield (%), $w_o$ is the weight of extracted oil (g), and $w_d$ is the dry weight of SCG (g).

*Proximate analysis*

A proximate analysis was conducted to assess SCG composition in terms of carbohydrate, protein, ash, fiber, moisture, and fat content. Carbohydrates, protein, ash, fiber, and moisture content measured according to Indonesian National Standard No. 01-2891-1992. Fat content determined using the Soxhlet extraction method as per the Association of Official Analytical Chemists (AOAC) official method 945.16.

*Physicochemical analysis*

The physicochemical characteristics of the extracted oil were evaluated using protocols outlined in the official methods established by the AOCS, including AOCS Cc 10c-95 for density, AOCS Ca 5a-40 for free fatty acids (FFA), AOCS Cd 8–53 for peroxide value, and AOCS Cd 3–25 for saponification value.

*Morphological changes analysis*

The structural changes in the SCG after drying were examined using a scanning electron microscope (SEM, model Carl Zeiss-Bruker EVO MA10). The SEM analysis provided insights into the morphological changes caused by the drying process.

*Functional groups analysis*

Fourier-transform infrared (FTIR) spectrometer (Shimadzu Prestige 6400) was utilized to assess the functional groups present in the SCG oil, allowing for the identification of key bioactive compounds.

*Gas chromatography-mass spectrometry (GC-MS) analysis*

The fatty acid composition of the SCG oil was analyzed by transforming the oil samples into fatty acid methyl esters (FAME) using a derivatization process. The FAME samples were then subjected to GC-MS (Shimadzu Model QP 2010 Plus) to identify and quantify the major fatty acid components present in the SCG oil.

## Results and Discussion

*SCG drying*

The results of SCG proximate analysis were presented in Table 1. The proximate analysis indicated that both drying methods successfully reduced SCG moisture content, with oven drying achieving 7.86% and microwave drying 7.93%. These values are still lower than the minimum required moisture content for dried SCG, which is 12%.[10] However, the microwave-dried SCG had a slightly higher moisture content compared to the oven-dried groups. This is due to the relatively lower temperature used in microwave drying. The slightly higher moisture in microwave-dried SCG may have impacted its oil yield, which was lower than the oven-dried samples. In addition, the oven-dried SCG had slightly higher protein, total carbohydrate, and ash contents than the microwave-dried samples. This could be caused by the higher moisture content in the microwave-dried SCG, which may degrade some of the compounds within.[1] Oven-dried SCG also exhibited slightly better retention of protein and carbohydrates, which could be due to the lower drying temperatures in microwave drying.

**Figure 1** shows the moisture content variation over time during the drying process. The effectiveness of drying is influenced by various factors, including drying method, temperature, humidity, and wind, all of which can impact the quality and amount of the dried product.[15] The drying of SCG using both oven and microwave methods resulted in a significant reduction in moisture content. The initial moisture content of SCG was measured at 56.70% for oven drying and 56.24% for microwave drying.

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**Table 1:** Proximate analysis of dried SCG

| Parameters | Content (%) | |
|---|---|---|
| | Oven drying | Microwave drying |
| Fat | 14.14 ± 0.71 | 14.56 ± 0.62 |
| Carbohydrates | 64.27 ± 2.20 | 64.23 ± 3.02 |
| Protein | 12.35 ± 0.58 | 11.99 ± 0.61 |
| Moisture | 7.70 ± 0.38 | 7.81 ± 0.32 |
| Ash | 1.54 ± 0.08 | 1.41 ± 0.04 |

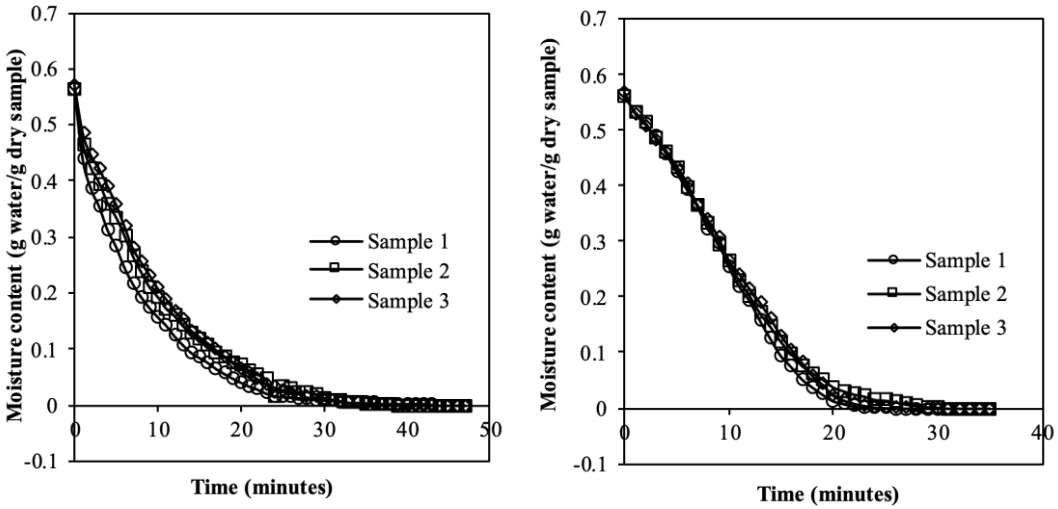


**Figure 1:** Comparison of SCG moisture ratio using different methods: (A) oven drying; and (B) microwave drying, in the form of drying time versus dry basis moisture content

As the drying time increases, the moisture content steadily decreases. Typical drying curves exhibit three distinct phases: an initial phase where the sample is heated until it reaches thermal equilibrium with the drying air, a phase of maximum and constant drying rate during which the surface of the material remains wet as the internal moisture transfer matches the surface evaporation rate, and a final phase characterized by a decreasing drying rate as the surface dries and internal moisture migration slows down.[16] The mass transfer process ends when the product surface's water vapor pressure equals that of the drying air.[17] After a certain period, the moisture content ceased to decrease despite extended drying time, as the residual water in the material had reached its minimum level.[18] After the drying process, the moisture content was reduced to below 8% indicating both methods are effective in reducing moisture levels, which is essential for preventing microbial growth and maintaining the quality of SCG during storage.

Despite the slight difference in moisture content between the two methods, microwave drying achieved faster moisture reduction, as indicated by the drying curves (Fig. 1). This is due to the nature of microwave drying, where electromagnetic waves cause rapid internal heating, facilitating quicker evaporation of moisture. However, the slightly higher final moisture content in microwave-dried samples suggests that it may be less effective than oven drying in removing residual moisture. This could be attributed to the lower temperature used in microwave drying, which might not completely remove bound water from SCG. In microwave drying, moisture reduction occurred at a faster rate compared to oven drying, reducing the overall drying time. Despite the speed advantage, oven drying's ability to maintain a slightly lower moisture content suggests it may be more suitable for long-term preservation of SCG.

*SCG oil extraction*

The drying method significantly influenced the amount of oil extracted from SCG. The oil yield from oven-dried SCG was 10.01%, while the yield from microwave-dried SCG was lower, at 8.9% (Fig. 2). This difference in yield can be attributed to the more uniform heat distribution in oven drying, which preserves the oil-bearing compounds more effectively than microwave drying. The extraction of oil from spent coffee grounds (SCG) is influenced by multiple variables, including the choice of solvent and the temperature conditions employed during the process.[19] Microwave drying, due to its rapid heating mechanism, may cause localized overheating, which could degrade some of the lipids, leading to a reduced oil yield. Moreover, the slightly higher moisture content in microwave-dried SCG may have contributed to the lower oil yield.[1] High moisture content in SCG can affect the efficiency of oil extraction by disrupting the solvent's penetration and reducing the solvent's ability to dissolve the oil. These results align with previous studies, which suggest that lower moisture levels result in higher oil yields and better preservation of bioactive compounds.[3,10]

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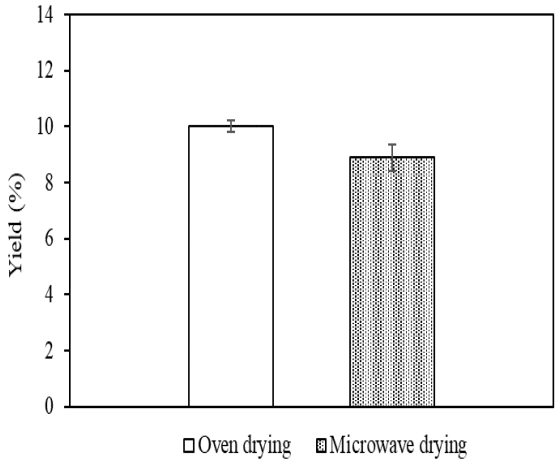


**Figure 2:** Effect of drying method on SCG oil yield

**Table 2** displayed the physicochemical parameters of SCG oil in relation to its quality. The acid value is an important quality indicator related to the level of oil degradation by hydrolysis, resulting in the release of free fatty acids.[14] The acid value of SCG oil obtained in the oven and microwave drying were 6.73 mg KOH/g and 7.29 mg KOH/g, respectively, indicating minimal hydrolysis of fatty acids. In a previous study by Böger et al.,[20] the acid value of arabica coffee oil was 7.3 mg KOH/g. The peroxide value serves as an indicator of the oxidative condition of oil, reflecting the concentration of primary oxidation products such as peroxides and hydroperoxides.[21] The peroxide value of SCG oil in the oven and microwave drying were determined as 6 mEq $O_2$/kg and 8 mEq $O_2$/kg respectively, suggesting that microwave drying may induce more oxidative degradation during the drying process.[20] This was higher than that reported by Bijla et al.,[21]

**Table 2:** Physicochemical properties of SCG oil

| Parameters | Oven drying | Microwave drying |
|---|---|---|
| Density (g/mL) | 0.89 ± 0.02 | 0.91 ± 0.01 |
| Acid value (mg KOH/g) | 6.73 ± 0.30 | 7.29 ± 0.32 |
| Peroxide value (mEq $O_2$/kg) | 6.00 ± 0.28 | 8.00 ± 0.36 |
| Saponification value (mg KOH/g) | 182.32 ± 6.08 | 176.71 ± 7.28 |

up to 5.21 mEq $O_2$/kg. However, it was still lower than the maximum. The peroxide value is still lower than the maximum value (15 mEq $O_2$/kg) indicating that SCG oil is resistant to oxidation and can be stored for a longer period of time.[14,20] The saponification value indicates the average length of fatty acid chains in a fat or oil. Shorter fatty acids result in higher saponification values due to their greater number of molecules per unit weight.[21]

The saponification values for SCG oil using the oven and microwave drying were 182.325 and 176.715 respectively, which are still within the general range for vegetable oils, typically between 180 and 200 mg KOH/g. The relatively low saponification levels result in the oil maintaining its viscosity and resistance to freezing, making it well-suited for use in oil processing applications.[14] The morphological structure changes of the SCG shown in Fig. 3.

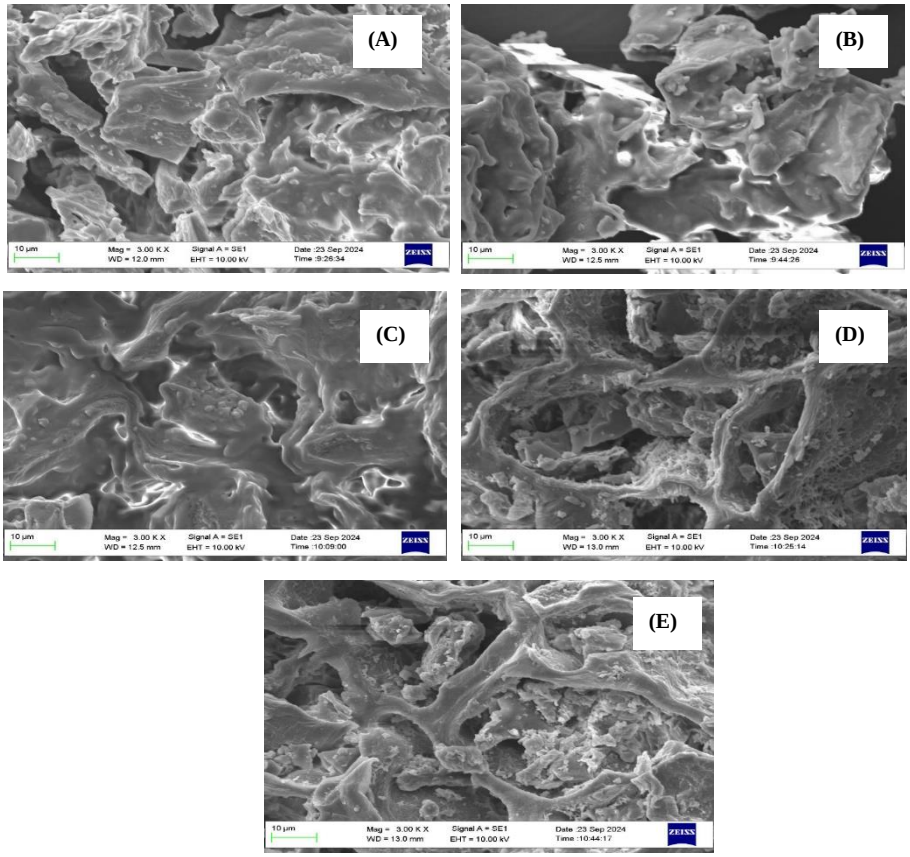


**Figure 3:** Scanning electron micrographs: (A) wet SCG; (B) dried SCG using oven drying; (C) dried SCG using microwave drying; (D) after extraction using oven drying; and (E) after extraction using microwave drying.

Figure 3A reveals that the SCG's external structure was intact prior to dried, with a smooth cellular structure. The SEM images revealed significant differences between the two drying methods. Oven-dried SCG (Figure 3B) seemed to collapse (pore size decreased), resulting in a more compact and denser structure.[14] Whereas, microwave-dried SCG (Figure 3C) had a more porous structure likely due to the rapid evaporation of moisture in microwave drying. After extraction, the SCG showed substantial changes in surface shape (Figures 3D and 3E). The external structure of the SCG was damaged, and the surface became rough, with many irregular pores and irregular large holes.

This alteration in surface morphology indicates the successful extraction of SCG oil that was previously contained in SCG. The stirring motion may promote more collisions between SCG particles and increase solvent penetration, resulting in increased surface roughness and porosity.[2]

Figure 4 depicts the FTIR spectrum used to analyze the main functional groups found in the SCG oil. FTIR results indicated similar chemical compositions between the oils extracted from both drying methods, confirming that the functional groups of key bioactive compounds were preserved in both methods. Although slight variations were observed in the intensity of these peaks, potentially reflecting differences in oil composition between the two drying methods.[2] The 715 and 714 $cm^{-1}$ regions observed the bending of cis C=C. Peak 1157 and 1159 $cm^{-1}$ exhibited the vibration of –C–O ester groups. Meanwhile, peak 1458 and 1460 $cm^{-1}$ contained the bending vibration of C–H of $CH_2$ and $CH_3$ aliphatic group.[5,22] At the peak 1741 and 1743 $cm^{-1}$ showed stretching vibration of ester carbonyl functional groups of triglycerides (O–C=O) and stretching vibration of lipid and fatty acid ester groups (C=O), respectively.[5,22] The 2920 and 2926 $cm^{-1}$ region contained asymmetric and symmetric stretching vibration of C–H bonds which showed the fatty acid component of lipids.[2,23]

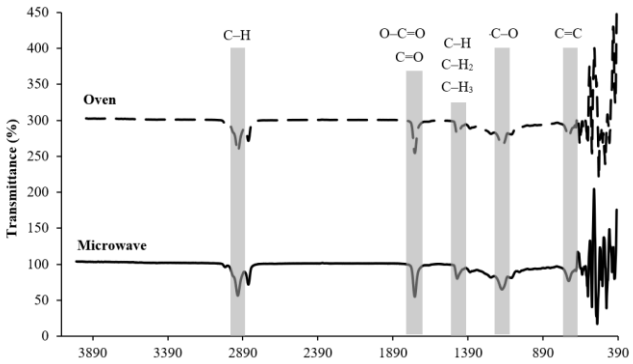


**Figure 4**: FTIR spectrum of SCG oil

Fatty acids are the primary components present in vegetable oils. They play a crucial role in determining the stability, nutritional value, and cosmetic properties of these oils, significantly influencing the commercial potential of coffee as a commodity.[21,22] **Table 3** displays the fatty acid composition of the SCG oil from oven drying and microwave drying. The primary fatty acid components found in all samples are linoleic acid and palmitic acid, followed by oleic acid and decanoic acid. A prior study reported that coffee oil mostly contains linoleic acid (40–46%), palmitic acid (32–51%), oleic acid (0–9%), and stearic acid (7–8%).[22,24]

GC-MS analysis of the fatty acid composition revealed that both drying methods resulted in similar fatty acid profiles, with linoleic acid and palmitic acid being the most abundant fatty acids. However, minor variations were observed in the percentages of these fatty acids between the two drying methods (Table 3). Oven-dried SCG oil contained slightly higher amounts of palmitic acid (34.39%) and linoleic acid (45.89%), compared to microwave-dried SCG oil, which had 34.34% palmitic acid and 46.09% linoleic acid. These variations may be attributed to the differences in the drying processes, with microwave drying causing more disruption to the fatty acid composition due to the rapid temperature changes.

*Comparison with previous studies*

The findings of this study align with those observed in earlier research on drying methods and their effects on oil extraction efficiency and quality. Studies have shown that oven drying tends to produce higher yields and better preservation of bioactive compounds in plant materials. For example, Chimsook and Assawarachan,[13] discovered that oven drying resulted in higher oil yields and better antioxidant retention, aligning with the findings of this research. The elevated peroxide values found in microwave-dried oils in this study are consistent with previous research, which suggests that microwave drying accelerates lipid oxidation. Similarly, Luka et al.,[25] recently observed that hot air oven drying preserved more bioactive components in cabbage compared to microwave drying. Karabacak,[26] also noted that while microwave drying reduces drying time and maintains nutritional value and bioactive compound digestibility, it negatively impacts sensory qualities.

**Table 3:** Fatty acid composition of SCG oil

| Fatty acid component | Composition (%) | |
|---|---|---|
| | Oven drying | Microwave drying |
| Decanoic acid (C10:0) | 4.626 ± 0.20 | 4.635 ± 0.08 |
| Myristic acid (C14:0) | 0.068 ± 0.00 | 0.067 ± 0.00 |
| Palmitic acid (C16:0) | 34.387 ± 1.62 | 34.344 ± 1.02 |
| Stearic acid (C18:0) | 3.687 ± 0.18 | 3.443 ± 0.02 |
| Oleic acid (C18:1) | 10.399 ± 0.42 | 10.610 ± 0.34 |
| Linoleic acid (C18:2) | 45.891 ± 2.02 | 46.094 ± 1.42 |
| Linolenic acid (C18:3) | 0.696 ± 0.01 | 0.710 ± 0.03 |
| Arachidic (C20:0) | 0.246 ± 0.01 | 0.097 ± 0.00 |

## Conclusion

This study examines the effects of oven and microwave drying on the extraction of oil from spent coffee grounds (SCG), a valuable byproduct in industrial applications. The goal was to compare both methods in terms of oil yield, quality, and structural preservation of SCG. SCG was dried using oven drying at 40°C and microwave drying at medium power, followed by oil extraction with hexane. The oil's physicochemical properties were analyzed, and structural changes was assessed using SEM. The results indicated that oven drying achieved a slightly lower final moisture content (7.86%) compared to microwave drying (7.93%), although microwave drying reduced moisture faster. The oil yield from oven-dried SCG was higher (10.01%) than that from microwave-dried SCG (8.9%). Furthermore, oven-dried SCG oil exhibited better quality, with lower acid and peroxide values, indicating less oxidative degradation. Structural analysis revealed that oven drying preserved the cellular structure of SCG more effectively, contributing to better retention of oil-bearing compounds. In conclusion, while microwave drying is faster, oven drying is more effective in preserving the quality of SCG oil and achieving higher yields. These findings suggest that oven drying may be a more suitable method for industrial-scale SCG oil extraction, where maximizing oil yield and maintaining quality are crucial.

## Conflict of Interest

The authors declare no conflict of interest.

## Authors' Declaration

The authors hereby declare that the work presented in this article are original and that any liability for claims relating to the content of this article will be borne by them.

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