Analysis of Caffeine, Total Phenolic Content, and Antioxidant Activity in Liberica Coffee Beans Roasted by Semi-Automatic and Conventional Methods

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ABSTRACT (10 PT)

This study aims to evaluate the effect of roasting methods on the chemical and functional properties of Liberica coffee, focusing on caffeine content, total phenolic content (TPC), and antioxidant activity. Two roasting approaches were compared: semi-automatic roasting with controlled conditions, and traditional pan roasting with manual heat regulation. Caffeine levels were determined using UV-Vis spectrophotometry at 273 nm, while TPC was measured using the Folin–Ciocalteu method. Antioxidant activity was assessed via DPPH radical scavenging assay. The results revealed that semi-automatic roasting preserved more bioactive compounds, with higher caffeine content (1.86%) and TPC (56.84 mg GAE/g), compared to conventional roasting (1.34% and 41.27 mg GAE/g, respectively). Antioxidant activity was also significantly higher in semi-automatically roasted samples, with 72.3% inhibition and lower IC_{50} value (168.5 ppm). These findings indicate that semi-automatic roasting enhances both chemical quality and functional potential of Liberica coffee. The study supports the application of controlled roasting technologies in post-harvest processing to improve the health-related value and market competitiveness of Liberica coffee products.

Keyword: : Antioxidant activity, Caffeine content, Liberica coffee, Phenolic compounds, Roasting methods

1. INTRODUCTION

Coffee is one of the most widely consumed beverages globally, cherished for its distinctive aroma, flavor, and stimulating effects, primarily attributed to its caffeine content. Beyond its sensory appeal, coffee is also recognized as a significant source of bioactive compounds, particularly phenolic compounds, which contribute substantially to its antioxidant activity. These compounds play a crucial role in human health, offering protective effects against oxidative stress and various chronic diseases (Mubarak & Din, 2021). While Coffea arabica and Coffea canephora (Robusta) dominate the global coffee market, Coffea liberica (Liberica) represents a distinct species with unique characteristics, including a robust growth habit and a flavor profile that is gaining increasing interest, especially in Southeast Asian countries where it is traditionally cultivated (Salahuddin, 2024).

The transformation of green coffee beans into the aromatic product consumed worldwide is largely dependent on the roasting process. Roasting is a critical step that drives complex chemical reactions, leading to the formation of flavor precursors, color development, and changes in the concentration of various bioactive compounds. However, the specific roasting method employed can significantly influence the final chemical composition and, consequently, the quality and health-promoting properties of the coffee. Different roasting profiles, temperatures, and durations can lead to variations in caffeine degradation, phenolic compound formation or degradation, and overall antioxidant capacity (Bintoro et al., 2020). Despite its growing regional importance, there is a relative paucity of comprehensive research specifically investigating the impact of different roasting methods on the key chemical constituents and antioxidant potential of Liberica coffee beans (Insanu, 2021). This gap in knowledge limits the ability to optimize roasting processes for Liberica coffee to maximize its beneficial compounds and sensory attributes.

Previous studies have extensively explored the effects of roasting on Arabica and Robusta coffees, demonstrating that roasting intensity can alter caffeine levels, often decreasing them at higher temperatures or longer durations, while also influencing the profile and content of phenolic acids like chlorogenic acids, which are major contributors to antioxidant activity (Kopi & Jagat, 2022). However, the unique matrix and chemical precursors present in Liberica coffee beans may respond differently to roasting conditions compared to other species. The problem addressed by this research is the lack of specific data on how semi-automatic versus conventional roasting methods affect the crucial quality parameters—caffeine content, total phenolic content (TPC), and antioxidant activity—in Liberica coffee beans. Understanding these changes is vital for producers and consumers alike, enabling informed decisions regarding processing and consumption.

This study proposes to analyze and compare the caffeine content, total phenolic content, and antioxidant activity of Liberica coffee beans subjected to two distinct roasting methods: semi-automatic roasting and conventional roasting. By employing established analytical techniques, including spectrophotometric methods for TPC and antioxidant activity, and high-performance liquid chromatography (HPLC) for caffeine quantification, this research aims to provide a detailed chemical profile of Liberica coffee under different processing conditions (Salahuddin, 2024). The new value and innovation of this research lie in its specific focus on Coffea liberica, a less-studied but culturally and economically significant coffee species. By directly comparing the effects of semi-automatic and conventional roasting, this study will offer novel insights into how processing choices can optimize the nutritional and functional properties of Liberica coffee. The findings will contribute to a better understanding of Liberica coffee's potential health benefits and guide the development of optimal roasting protocols, ultimately enhancing the quality and market value of this unique coffee variety.

2. RESEARCH METHOD

2.1 Materials

Liberica coffee beans were sourced from the Tahura Sumber Unggul plantation in Mojokerto, East Java, Indonesia. All reagents used for analysis, including methanol, Folin-Ciocalteu reagent, sodium carbonate (Na_2CO_3), and DPPH (2,2-diphenyl-1-picrylhydrazyl), were of analytical grade and obtained from certified suppliers.

2.2 Sample Preparation

The green coffee beans were sorted to ensure uniformity, then divided into two equal groups. One group was roasted using a semi-automatic roasting machine set at approximately 200°C for 9 minutes. The second group was roasted conventionally in a frying pan over an open flame for 7.5 minutes. All roasted beans were allowed to cool to room temperature before being ground into fine powder using a standard laboratory grinder.

2.3 Extraction Method

For each sample, 5 grams of ground coffee were soaked in 50 mL of 70% ethanol and subjected to maceration for 24 hours at room temperature. The solution was then filtered using Whatman filter paper, and the resulting extract was stored in amber bottles at 4°C until analysis. This research was conducted using an experimental approach with a comparative design. The objective was to evaluate and compare the chemical and functional properties of Liberica coffee beans roasted by two different methods: semi-automatic and conventional pan roasting.

2.4 Research Design and Procedure

The research followed a structured experimental flow involving sample selection, roasting, grinding, extraction, and chemical analysis. Liberica coffee beans were obtained from Sumber Unggul, Mojokerto, and divided into two groups. One group was roasted using a semi-automatic roasting machine with controlled temperature and time (9 minutes, ~200°C), while the other was roasted using a conventional frying pan over a gas stove (manual heat control, 7.5 minutes). After roasting, the beans were ground uniformly, then extracted using 70% ethanol by maceration for 24 hours. The filtrates were stored in dark containers prior to chemical analysis.

2.5 Data Collection and Testing Methods

2.5.1 Caffeine Analysis

Conducted using UV-Vis spectrophotometry at a wavelength of 273 nm. A standard caffeine curve was prepared A standard caffeine calibration curve was constructed using six standard solutions ranging from 1 to 15 ppm. Each solution was measured for absorbance using a UV-Vis spectrophotometer at 273 nm, and the linear regression equation was generated ($R^2 > 0.99$). Coffee extracts were analyzed under the same conditions, and caffeine concentration was calculated using the standard curve. This method follows procedures validated in similar coffee studies (Of et al., 2024). Standard solutions with known concentrations ranging from 1 to 15 ppm were prepared, and their absorbance was measured to calculate the caffeine content in the coffee samples.

2.5.2 Total Phenolic Content (TPC):

TPC was quantified using the Folin–Ciocalteu reagent. A 0.5 mL aliquot of coffee extract was mixed with 2.5 mL of 10% Folin-Ciocalteu reagent and allowed to react for 5 minutes before adding 2.0 mL of 7.5% Na_2CO_3. The mixture was incubated for 30 minutes at room temperature in the dark and the absorbance was read at 765 nm. Gallic acid was used as the standard, and results were expressed in mg gallic acid equivalents per gram (mg GAE/g) of coffee Measured using the Folin–Ciocalteu method. Extracts (0.5 mL) were mixed with Folin reagent and Na2CO3, incubated for 30 minutes, and measured at 765 nm. Results were expressed as mg gallic acid equivalent per gram (mg GAE/g) (Liao et al., 2022).

2.5.3 Antioxidant Activity

The DPPH free radical scavenging method was applied to determine antioxidant activity. A 1 mL aliquot of extract was added to 3 mL of a 0.1 mM DPPH solution in methanol. The mixture was incubated in the dark for 30 minutes at room temperature, and the absorbance was measured at 517 nm. The percentage of inhibition was determined using the formula: $\%\ \text{inhibition} = [(A_0 - A_1)/A_0] \times 100$, where A_0 represents the absorbance of the control (blank) and A_1 is the absorbance measured for the sample. The IC_{50} value was determined by plotting the inhibition percentage against concentration and analyzing the regression curve (Pebriati et al., 2023). Evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. Samples were reacted with 0.1 mM DPPH solution, incubated in the dark for 30 minutes, and read at 517 nm. The percentage of inhibition and IC_{50} values were calculated based on standard protocols (Antioxidant & Coffee, 2022).

2.3 Data Analysis

The data obtained from laboratory analyses were tabulated and presented in descriptive statistical form. Mean values of caffeine content, TPC, and antioxidant activity (inhibition percentage and IC_{50}) were compared between roasting methods to assess their relative effectiveness in preserving functional compounds. This methodological approach allows for reproducible, scientifically sound comparisons, supported by standard analytical techniques widely used in coffee and food chemistry studies (Rahmawati & Gustiani, 2023).

3 RESULTS AND ANALYSIS (10 PT)

3.1 Extraction

Maceration of Liberika coffee samples was carried out to obtain ethanol extracts containing bioactive compounds. A total of 5 grams of ground coffee was placed in an Erlenmeyer flask, followed by the addition of 50 mL of 70% ethanol. The mixture was then stirred briefly and covered with aluminum foil to prevent evaporation. The samples were allowed to stand for 24 hours at room temperature with occasional shaking to enhance the diffusion of the compounds into the solvent. After the maceration period, the mixture was filtered using Whatman No. 1 filter paper, and the filtrate was collected as an ethanol extract. This extract was stored in an amber bottle at 4°C until further analysis.

The ethanol extract yield indicates the efficiency of compound dissolution during maceration. Table 1 shows that semi-automatic roasting resulted in a slightly higher extraction yield (23.5%) than conventional roasting (20.2%). Semi-automatic roasting can increase extraction yield due to 1) Increased Cell Wall Breakage. Consistent and even heat exposure in semi-automatic roasting can lead to more effective damage to the cell walls of plant materials. The cell wall is a major barrier that prevents the release of intracellular compounds. When the cell wall is damaged by heat, the solvent (in this case ethanol) can penetrate the cell more easily and dissolve more bioactive compounds (Chemat et al., 2012). Conventional roasting, with its possibly uneven heat distribution, may result in some parts of the plant material not undergoing optimal cell wall damage. 2) Increased Solubility of Compounds. The controlled and stable temperature during semi-automatic roasting may increase the solubility of certain compounds in ethanol solvents. Many phytochemical compounds show higher solubility at slightly higher temperatures. Consistent heat exposure ensures that all parts of the plant material reach adequate temperatures to maximize the solubility of target compound (Meng et al., 2024). Temperature fluctuations in conventional roasting can result in variations in compound solubility. 3) Enhanced Release of Volatile and Non-Volatile Compounds. The uniform heat of semi-automatic roasting can facilitate the release of volatile and non-volatile compounds from the plant material matrix. These compounds, which may be trapped in cell structures or complex matrices, can be released more efficiently when consistently exposed to heat. This process is similar to how heating can improve the extraction efficiency of essential oils or other aromatic compounds (Syahputra et al., 2024). 4) Prevention of Compound Degradation. While heat is important for release, excessive or uneven heat can lead to compound degradation. Semi-automated systems that provide better temperature control can minimize thermal degradation of heat-sensitive compounds, so that more compounds remain intact and can be extracted (Science et al., 2022).

Table 1. Extraction Yield of Liberica Coffee by Roasting Method

Roasting Method	Extraction Yield (%)
Semi Automatic- Roast	23,5 ± 0,8
Conventional Roast	20,2 ± 1,1

Controlled and uniform heating helps prevent thermal degradation and maintain the integrity of cellular structures, making it easier for solvents to access and extract bioactive constituents such as caffeine and phenolic compounds (Of et al., 2024). In contrast, conventional roasting with uneven temperature exposure may cause localized overheating, resulting in degradation or loss of extractable ingredients.

3.2 Caffeine

Caffeine content was higher in coffee roasted with the semi-automatic method (1.86%) compared to conventional roasting (1.34%). Table 2 provides the comparative results. The better preservation of caffeine in the semi-automatic method is attributed to uniform heat distribution and temperature control, reducing caffeine degradation (Voon et al., 2024). Caffeine is a heat-stable alkaloid but can degrade under excessive or uneven heating, particularly during longer exposure at higher temperatures typical of conventional roasting. Semi-automatic roasting minimizes this risk by applying consistent thermal input, which protects caffeine molecules from breakdown through pyrolysis or sublimation (Savi & Savi, 2024). In contrast, the fluctuating heat in traditional pan roasting may result in uneven roasting and localized overheating, promoting the partial degradation of caffeine content. According to (Poli et al., 2024), high roasting temperature can significantly reduce caffeine and chlorogenic acid content in coffee due to thermal decomposition. Furthermore, (Wibowo et al., 2021) noted that the intensity and duration of roasting are critical factors that influence the retention of caffeine and other antioxidant compounds in coffee beans.

Table 2. Caffeine Content of Liberica Coffee by Roasting Method

Roasting Method	Caffeine Content (%)
Semi- automatic Roast	1,86 ± 0,02
Conventional Roast	1,34 ± 0,03

In addition, research by (Baptestini & Melo, 2016) demonstrated that caffeine degradation becomes more pronounced during prolonged roasting at high temperatures due to thermal instability beyond certain thresholds. Similarly, (Pertanian & Payakumbuh, 2024) confirmed that inconsistent roasting temperatures significantly reduce the concentration of caffeine and other alkaloids in coffee, particularly when the beans are exposed to direct flame or uneven heat transfer. These findings support the observation that semi-automatic roasting helps to maintain caffeine content through its more precise and homogeneous thermal profile.

3.3 Total Phenolic Content (TPC)

TPC analysis indicated significantly higher phenolic retention in semi-automatically roasted samples (56.84 mg GAE/g) compared to conventional roasting (41.27 mg GAE/g), as shown in Table 3. This difference highlights the critical role of roasting technique in preserving phenolic compounds, which are known for their potent antioxidant properties. TPC (Total Phenolic Content) refers to the total concentration of phenolic compounds—organic molecules characterized by one or more hydroxyl groups attached to aromatic rings—in the coffee extract. These compounds contribute significantly to antioxidant activity and offer various health benefits.

Table 3. Total Phenolic Content (TPC) in Liberica Coffee

Roasting Method	TPC (mg GAE/g)
Semi-Auromatic Roast	56,84 ± 1,45
Conventional Roast	41,27 ± 1,17

The elevated TPC observed in coffee roasted using the semi-automatic method is likely due to the heat-sensitive nature of phenolic compounds. Phenolics are easily degraded under excessive or prolonged heat, leading to the breakdown of their molecular structure and a loss of antioxidant functionality (Chi et al., 2024). In conventional roasting, where heat application tends to be less consistent and less controlled, localized overheating or prolonged exposure can accelerate degradation and reduce the extractability of phenolic compounds. In contrast, semi-automatic roasting offers several technological advantages:

- Better Temperature Control: More precise thermal regulation minimizes phenolic degradation while still achieving the desired roast level.
- Optimized Heat Exposure: With accurate timing, semi-automatic systems limit unnecessary thermal stress, preserving thermolabile compounds like chlorogenic acids.
- Even Heat Distribution: The uniform application of heat across the beans prevents the formation of "hot spots" that could otherwise degrade phenolics unevenly.

Moreover, high-temperature roasting may also induce polymerization reactions that bind phenolic compounds to melanoidins, reducing their solubility and extractability (Laukaleja & Kruma, 2019). By avoiding these adverse conditions, semi-automatic roasting retains more of the naturally occurring phenolic compounds. These findings are consistent with the work of (Wu et al., 2022), who emphasized that roasting conditions significantly affect TPC levels in various coffee species. The evidence supports that optimized roasting profiles are essential for preserving the health-promoting bioactive compounds in coffee.

3.4 Antioxidant Activity

Antioxidant activity was assessed using the DPPH assay (2,2-diphenyl-1-picrylhydrazyl), a simple, fast, and reliable method commonly used to evaluate the radical scavenging ability of bioactive compounds in food and plant extracts. The principle of the method is based on the reduction of the deep violet DPPH radical to a yellow-colored diphenylpicrylhydrazine, as the antioxidant donates hydrogen or electrons to neutralize the free radical (Ngibad & Puji, 2020).

In this study, the degree of discoloration was measured spectrophotometrically and expressed as percentage inhibition (% inhibition) and IC_{50} (half-maximal inhibitory concentration (Awwad et al., 2021). A higher % inhibition and lower IC_{50} value indicate greater antioxidant potency. The results demonstrated that semi-automatic roasted coffee had superior antioxidant activity, with 72.3% inhibition and an IC_{50} of 168.5 ppm, whereas conventional roasting resulted in 55.8% inhibition and an IC_{50} of 239.7 ppm (Table 4). These values clearly indicate that semi-automatic roasting yields coffee with a stronger capacity to scavenge free radicals, requiring lower concentrations to achieve 50% inhibition.

Table 4. Antioxidant Activity of Liberica Coffee

Roasting Method	% Inhibition (DPPH)	IC_{50} (ppm)
Semi-automatic Roast	72,3 ± 1,2	168,5
Conventional Roast	55,8 ± 1,5	239,7

This enhanced antioxidant performance is strongly correlated with the higher total phenolic content (TPC) observed in semi-automatically roasted samples (56.84 mg GAE/g vs. 41.27 mg GAE/g in conventional roast). Compounds such as chlorogenic acids, which belong to the phenolic group, are widely recognized as key contributors to the antioxidant properties of coffee. The ability of these compounds to donate electrons or hydrogen atoms makes them effective in neutralizing free radicals such as DPPH (Rahmawati & Purnamasari, 2024).

Furthermore, the controlled heating profile of the semi-automatic method helps preserve thermolabile phenolics that would otherwise degrade under the inconsistent or excessive heat of conventional pan roasting (Morales-castro et al., 2024). When roasting is not well-regulated, phenolics are more likely to undergo oxidation or polymerization, reducing their antioxidant efficacy.

These findings affirm the positive correlation between phenolic content and antioxidant activity, as supported by (Agric & Article, 2019). The higher phenolic retention in the semi-automatic roast is the main reason behind its enhanced antioxidant potential. It demonstrates that improved roasting technology directly contributes to functional quality, making the coffee not only richer in flavor but also more beneficial to health.

4 CONCLUSION

This study successfully demonstrated that the roasting method significantly influences the chemical and functional properties of Liberica coffee. As hypothesized in the introduction, semi-automatic roasting—due to its consistent temperature control and uniform heat distribution—led to better preservation of key bioactive compounds compared to conventional pan roasting. Specifically, the semi-automatic method resulted in a higher extraction yield (23.5%), caffeine content (1.86%), and total phenolic content (56.84 mg GAE/g). These parameters were consistently superior to those of conventionally roasted samples, which had lower extract yield (20.2%), caffeine (1.34%), and phenolic content (41.27 mg GAE/g). Moreover, the antioxidant activity, as measured by DPPH assay, showed that the semi-automatic roast achieved a greater radical scavenging capacity (72.3% inhibition) and a lower IC_{50} value (168.5 ppm) than the conventional roast (55.8% inhibition; IC_{50} = 239.7 ppm). These results confirm the positive correlation between total phenolic content and antioxidant activity, and affirm that improved thermal control during roasting plays a crucial role in preserving the health-promoting compounds in Liberica coffee. Therefore, adopting semi-automatic roasting technology is recommended to optimize the nutritional quality, functional potential, and commercial value of Liberica coffee beans.

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