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Effect of roasting temperature and time on volatile compounds and sensory properties of coffee

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ABSTRACT

Coffee is one of the most widely traded beverages worldwide, and the roasting process plays a crucial role in its final quality in terms of aroma, flavor, and consumer acceptance. This study aimed to evaluate the effects of roasting temperature and time on the aroma and flavor profile of coffee. Coffee beans were roasted at three temperature levels (220°C, 240°C, and 260°C) for 12, 14, and 17 minutes, respectively. Volatile compounds were identified and analyzed using SPME-GC-MS. A five-point hedonic sensory test was also conducted to evaluate sensory attributes. Results showed that increasing roasting temperature and time led to an increase in some compounds, such as 2,5-diethyl-3-methylpyrazine, and a decrease in desirable compounds such as linalool and β-damascenone. Sensory evaluation indicated that higher roasting temperatures increased sour aroma, bitterness, and burnt flavor, while overall consumer acceptance decreased. Therefore, selecting optimal roasting conditions is critical for producing high-quality coffee with favorable sensory properties.

1- INTRODUCTION

Coffee is one of the most important and widely consumed beverages in the world and is produced in more than 70 countries in tropical regions, particularly in Latin America, Africa, and Southeast Asia. Due to its extensive role in economics, culture, and lifestyle, coffee is recognized as the second most important global commodity and export product after oil [1]. Global coffee consumption has increased significantly in recent decades, and it is projected that by 2030, annual consumption will grow at a compound growth rate of approximately 2.5%, driven by the expansion of emerging markets, increased consumer awareness of quality, and the growing culture of specialty coffee consumption [2,3].

Coffee processing includes stages such as harvesting, fermentation, drying, grinding, roasting, and brewing; however, roasting is considered the most sensitive and influential stage in developing the sensory and physicochemical characteristics of coffee. During roasting, green coffee beans are exposed to specific temperature and time conditions, leading to numerous chemical reactions such as the Maillard reaction, sugar degradation, lipid oxidation, and the formation of aromatic compounds [4,5]. This process results in the production of more than 800 volatile and non-volatile compounds that contribute to the aroma, flavor, color, and texture of the final coffee product [6].

The most important compounds formed during roasting include pyrazines (responsible for earthy and roasted notes), furans (caramel-like and bread-like flavors), phenols (smoky and pungent notes), thiols (characteristic coffee aroma), and aldehydes (sweet and fruity notes). The relative presence or absence of these compounds determines the final quality of the product [7,8]. The intensity and duration of roasting directly affect the concentration of these compounds. High-temperature and long-duration roasting, while improving desirable color and body, may generate burnt and bitter flavors, whereas lighter roasting can preserve delicate aromatic compounds such as linalool, beta-damascenone, and pleasant esters [9].

Sensory evaluation is one of the key components in determining coffee quality. Sensory tests such as hedonic and descriptive analysis are capable of detecting subtle differences in aroma perception, taste, bitterness, acidity, mouthfeel, and overall consumer acceptance [10]. Therefore, combining analytical data (GC-MS) with sensory data provides a comprehensive view of final coffee quality.

Given the intense competition in the specialty coffee industry, a better understanding of the effects of process parameters such as roasting temperature and time on volatile compound profiles and sensory characteristics and consumer acceptance has become increasingly important. The present study was designed to comprehensively investigate the effect of different temperature and time conditions on the profile of volatile compounds affecting aroma and flavor, as well as hedonic evaluation of processed coffee beans. The results of this study can provide a basis for optimizing the roasting process in the coffee industry and producing products with higher quality and consumer acceptance [11].

2-Materials and Methods

2.1. Materials

Two kilograms of imported green coffee beans from Brazil with an average moisture content of 1.6% were obtained from Bidastar Coffee Company. Broken or heterogeneous beans were removed, and only intact beans with similar size and shape were used for the study.

2.2. Roasting

For roasting each 50 g batch of green coffee beans, a hot-air home roaster was used. The beans were roasted at three different temperatures:

- Light: 220°C for 12 min
- Medium: 240°C for 14 min
- Dark: 260°C for 17 min

The control sample consisted of unroasted green beans with no heat treatment applied [12].

2.3. SPME-GC-MS Analysis

Coffee beans were analyzed immediately after roasting. Sample preparation was performed in three replicates. Beans were ground to level 3, and 7 mL of coffee solution was transferred into a 20 mL vial [13].

Aroma compounds were extracted using solid-phase microextraction (SPME) at 40°C for 10 min. Injection was performed at 240°C in splitless mode with a 240 s injection time. Separation was carried out using a ZB-Wax column (60 m × 0.25 mm × 0.25 µm, Phenomenex, Germany) on an 8000-series gas chromatograph coupled with a quadrupole mass spectrometer. Electron ionization was performed at 70 eV, and selected ion monitoring (SIM) mode was used. All measurements were performed in triplicate.

2.4. Sensory Evaluation

Sensory evaluation was conducted by 10 trained experts in food science. Assessments were performed using a 5-point hedonic scale. Panelists evaluated color, aroma, taste, texture, and mouthfeel. A score of 1 indicated the lowest intensity and 5 the highest intensity of the attribute. In addition, specific sensory attributes including citric acid aroma, burnt taste, acidic taste, bitterness, and astringency were also evaluated, where 1 indicated low intensity and 5 indicated high intensity [14].

2.5. Statistical Analysis

Data were reported as mean ± standard deviation. Analysis of variance (ANOVA) and mean comparison using Duncan's test were performed at a significance level of $P < 0.05$. Statistical analysis was conducted using SPSS version 24.

3- Results

3.1. Volatile Compounds

In this study, the identified volatile compounds included 2-Furanmethanethiol, 2,3-Butanedione, β-Damascenone, 2,5-Diethyl-3-methylpyrazine, 2-Methoxy-4-vinylphenol, Linalool, Guaiacol, 3-Methylbutyric acid, Methional, and 3-Mercapto-3-methylbutyl formate. Several other compounds were also detected, but their concentrations were unstable. According to Duncan's multiple range test ($P < 0.05$) (Table 4-1 and Figure 4-1), significant differences were observed among the control and roasted samples at different temperatures. 2-Furanmethanethiol increased with rising temperature from 220°C to 260°C. 2,3-Butanedione showed the highest level in the control sample, decreased with increasing temperature, and slightly increased again at 260°C. β-Damascenone showed no significant differences among roasted treatments, but all treatments showed a decrease compared to the control. 2,5-Diethyl-3-methylpyrazine showed the highest level at 240°C. Linalool and Guaiacol showed a decreasing trend with increasing temperature, with no significant differences among treatments. Other compounds such as 3-Methylbutyric acid, Methional, and 3-Mercapto-3-methylbutyl formate also showed notable changes depending on temperature, indicating the effect of roasting temperature and time on aroma compounds

Table 4-1. Concentrations of volatile compounds in control and roasted coffee beans (Mean ± SD)

Compound	Treatment	Concentration (Mean ± SD)	P value
2-Furanmethanethiol	Control	0.0130 ± 0.0010 a	0.0001
	Roasted 220°C	0.0192 ± 0.0001 b	
	Roasted 240°C	0.0272 ± 0.0001 c	
	Roasted 260°C	0.0365 ± 0.002 d	
2,3-Butanedione	Control	0.2325 ± 0.010 d	0.0001
	Roasted 220°C	0.0132 ± 0.000 a	

	Roasted 240°C	0.1128 ± 0.003 b	
	Roasted 260°C	0.2095 ± 0.007 c	
β-Damascenone	Control	0.2275 ± 0.010 a	0.0001
	Roasted 220°C	0.0190 ± 0.000 a	
	Roasted 240°C	0.0161 ± 0.000 a	
	Roasted 260°C	0.0153 ± 0.000 b	
2,5-Diethyl-3-methylpyrazine	Control	1.1750 ± 0.035 a	0.015
	Roasted 220°C	1.8265 ± 0.239 b	
	Roasted 240°C	2.5025 ± 0.371 c	
	Roasted 260°C	2.1815 ± 0.012 bc	
2-Methoxy-4-vinylphenol	Control	0.2050 ± 0.014 a	0.0001
	Roasted 220°C	0.3050 ± 0.001 b	
	Roasted 240°C	0.4460 ± 0.001 c	
	Roasted 260°C	0.6145 ± 0.000 d	
Linalool	Control	0.1020 ± 0.117 a	0.499
	Roasted 220°C	0.0250 ± 0.000 a	
	Roasted 240°C	0.0228 ± 0.000 a	
	Roasted 260°C	0.0172 ± 0.000 a	
Guaiacol	Control	0.1110 ± 0.000 a	0.160
	Roasted 220°C	0.1071 ± 0.000 a	
	Roasted 240°C	0.1315 ± 0.000 a	
	Roasted 260°C	0.1295 ± 0.020 a	
3-Methylbutyric acid	Control	0.4455 ± 0.017 a	0.0001
	Roasted 220°C	0.5665 ± 0.000 b	
	Roasted 240°C	0.7766 ± 0.000 d	
	Roasted 260°C	0.6542 ± 0.001 c	
Methional	Control	0.0713 ± 0.001 a	0.0001
	Roasted 220°C	0.0985 ± 0.000 b	
	Roasted 240°C	0.1441 ± 0.001 c	
	Roasted 260°C	0.1515 ± 0.003 d	
3-Mercapto-3-methylbutyl formate	Control	0.0650 ± 0.015 a	0.001
	Roasted 220°C	0.1255 ± 0.000 b	
	Roasted 240°C	0.1285 ± 0.002 b	
	Roasted 260°C	0.1900 ± 0.014 c	

Values are expressed as mean ± standard deviation of three replicates. Different superscript letters within each column indicate significant differences at P < 0.05 according to Duncan's multiple range test.

3.2. Sensory Evaluation Results

Based on Duncan's test (P < 0.05), specific sensory attributes including Citric Acid Aroma, Burnt Taste, Acidic Taste, Bitterness, and Astringency showed significant differences among the different treatment groups (Table 4-2). The highest intensity of citric acid aroma was observed in the 260°C treatment, while the lowest value was recorded in the control sample. Burnt taste reached its highest level at 260°C, whereas the 220°C treatment and the control sample showed similar values. Bitterness increased with rising roasting temperature, with the highest level observed at 260°C.

Overall sensory parameters, including aroma, flavor, color, texture, and overall acceptance, were also significantly influenced by roasting temperature (Table 4-3). The highest aroma score was recorded in the 220°C treatment, which also achieved the highest overall consumer acceptance among all samples.

Table 4-2. Sensory evaluation of specific aroma and flavor parameters (Mean ± SD)

Treatment	Citric Acid Aroma	Burnt Taste	Acidic Taste	Bitterness	Astringency
Roasted 220°C	2.33 ± 0.577 (b)	2.00 ± 1.000 (a)	1.33 ± 0.577 (a)	2.67 ± 1.154 (b)	2.00 ± 1.000 (a)
Roasted 240°C	2.67 ± 1.154 (b)	3.33 ± 0.577 (b)	3.67 ± 0.577 (b)	3.33 ± 0.577 (b)	2.00 ± 0.000 (a)
Roasted 260°C	4.33 ± 0.577 (c)	5.00 ± 0.000 (c)	2.33 ± 0.577 (ab)	5.00 ± 0.000 (c)	1.33 ± 0.577 (a)
Control	1.00 ± 0.000 (a)	1.33 ± 0.577 (a)	1.67 ± 1.154 (a)	1.00 ± 0.000 (a)	4.33 ± 0.577 (b)
P value	0.003	0.001	0.024	<0.0001	0.002

Sensory evaluation was performed by 10 trained panelists using a 5-point hedonic scale (1 = very low intensity, 5 = very high intensity). Different letters indicate significant differences at P < 0.05.

Table 4-3. Sensory evaluation of general attributes (Mean ± SD)

Treatment	Aroma	Flavor	Color	Texture	Overall Acceptance
Roasted 220°C	4.67 ± 0.577 (c)	4.00 ± 1.000 (b)	4.33 ± 0.577 (b)	4.33 ± 0.577 (a)	4.67 ± 0.577 (b)
Roasted 240°C	2.67 ± 0.577 (b)	2.33 ± 0.577 (a)	4.00 ± 0.001 (b)	4.00 ± 0.001 (a)	2.33 ± 0.577 (a)
Roasted 260°C	1.33 ± 0.577 (a)	1.00 ± 0.001 (a)	1.67 ± 1.154 (a)	3.67 ± 0.577 (a)	1.33 ± 0.577 (a)
Control	3.33 ± 0.577 (b)	4.00 ± 1.000 (b)	2.67 ± 1.154 (ab)	4.00 ± 0.577 (a)	2.67 ± 1.527 (a)
P value	0.001	0.003	0.019	0.363	0.012

Sensory evaluation was performed by 10 trained panelists using a 5-point hedonic scale (1 = very low intensity, 5 = very high intensity). Different letters indicate significant differences at P < 0.05.

4-Discussion and Conclusion

In this study, the identified volatile compounds included 2-Furanmethanethiol and 2,3-Butanedione. The highest concentration was observed for 2,5-Diethyl-3-methylpyrazine, which significantly increased with rising roasting temperature, whereas 2-Furanmethanethiol showed the lowest concentration but exhibited an increasing trend with temperature. Mild and floral aroma compounds such as β-Damascenone and Linalool were present at appreciable levels only in the control sample and decreased with increasing roasting temperature, indicating their high thermal sensitivity. These findings are consistent with previous studies [7,9], which emphasize the importance of controlling roasting temperature and time to preserve desirable aromatic compounds.

Sensory evaluation results demonstrated that increasing roasting temperature led to higher intensities of attributes such as Citric Acid Aroma, Burnt Taste, and Bitterness, which were associated with a decrease in overall acceptance. In other words, although certain volatile compounds increased at higher temperatures, excessive roasting intensity reduced positive sensory attributes such as balanced aroma, desirable flavor, and overall consumer acceptance.

Based on the results, roasting at temperatures above 240°C (time ≥ 14 min) resulted in a decline in sensory quality and reduced consumer acceptance. In contrast, roasting at 220°C for 12 minutes, and if necessary up to 240°C for 14 minutes, provided optimal conditions for preserving aromatic compounds and desirable sensory characteristics. Additionally, the quality of green beans and their interaction with the roasting process play a decisive role in final flavor characteristics. Bean moisture content and internal temperature significantly influence aroma-forming reactions. The highest aroma development typically occurs during the mid-stages of the drying phase; therefore, medium-temperature roasting is essential to achieve desirable aroma profiles. High-temperature roasting can lead to the degradation of sensitive compounds and unfavorably alter the aroma profile of the product and should therefore be avoided.

In conclusion, this study demonstrated that selecting optimal roasting conditions (moderate temperature and appropriate time) plays a critical role in producing high-quality coffee with higher consumer acceptance and can serve as a basis for process optimization in the coffee industry.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Authors' Contributions

All authors contributed substantially to the conception and design of the study. They participated in data collection, experimental work, data analysis, interpretation of the results, manuscript preparation, critical revision of the manuscript, and approved the final version for publication.

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اثر دما و زمان برشته‌کاری بر پروفایل ترکیبات فرار و ویژگی‌های حسی قهوه

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چکیده

قهوه یکی از مهم‌ترین نوشیدنی‌های تجاری در بازار جهانی است و فرآیند برشته‌سازی نقش کلیدی در کیفیت نهایی آن از نظر عطر، طعم و پذیرش مصرف‌کننده دارد. هدف این مطالعه بررسی اثر دما و زمان برشته‌سازی بر پروفایل ترکیبات مؤثر بر عطر و طعم قهوه بود. دانه‌های قهوه در سه سطح دمایی ۲۲۰، ۲٤۰ و ۲٦۰ درجه سلسیوس به مدت ۱۲، ۱٤ و ۱۷ دقیقه برشته شدند. ترکیبات فرار با استفاده از روش SPME-GC-MS شناسایی و آنالیز شدند. همچنین آزمون حسی هدونیک پنج‌نقطه‌ای برای ارزیابی ویژگی‌های حسی انجام شد. نتایج نشان داد که افزایش دما و زمان برشته‌سازی موجب افزایش برخی ترکیبات مانند ۲،۵-دی‌اتیل-۳-متیل‌پیرازین و کاهش ترکیبات مطلوب مانند لینالول و بتا-داماسنون شد. ارزیابی حسی نشان داد که دماهای بالاتر با افزایش بوی اسیدی، تلخی و طعم سوختگی همراه بوده و پذیرش کلی مصرف‌کننده کاهش یافت. بنابراین، انتخاب شرایط بهینه برشته‌سازی نقش مهمی در تولید قهوه با کیفیت و مقبولیت بالا دارد.