

# Roasting optimization of robusta coffee beans and their effect on the antioxidant related compound

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**Abstract.** Coffee is known for its flavor and antioxidant effects. Roasting may change the characteristics of caffeic, chlorogenic, ferulic, and sinapic acids. While temperature and time are key factors affecting coffee's aroma, flavor, and taste, airflow during roasting also significantly impacts bean quality and antioxidant content. This study examined the effects of roasting parameters like temperature, time, and airflow on Robusta coffee beans' physicochemical qualities (phenols, tannins, flavonoids, and chlorogenic acid) and antioxidant activity. The best roasting parameters refer to the combination of temperature, time, and airflow that produces the most favorable qualities in the coffee beans, such as optimal flavor, aroma, and antioxidant content. Beans were roasted at 190°C, 210°C, and 230°C for 11, 14, and 17 minutes, with airflow settings of 1/4, 2/4, and 3/4. Response Surface Methodology (RSM) and Design Expert software optimized roasting conditions for optimal antioxidant content. The best roasting settings for antioxidant activity and physicochemical content were 190°C, 11 minutes, and 3/4 damper opening. These findings emphasize the importance of correctly managing temperature, time, and air movement during coffee roasting to maximize its health benefits. This approach helps produce functional beverages with better antioxidant capabilities for sensory pleasure and health advantages.

## 1. Introduction

Coffee is a highly popular beverage globally [1-2], originating from the coffee forests of Ethiopia and having a significant historical background. The stimulating benefits of coffee berries were initially uncovered by local monks residing in monasteries, who assumed the role as the primary custodians of this distinctive beverage. Coffee cultivation and trading commenced on the Arabian Peninsula around the 15th century and subsequently expanded throughout the Middle East. In the 17th century, explorers brought coffee to Europe. Since then, it has become increasingly popular and is now one of the most widely consumed beverages worldwide. It is also the second most traded commodity after petroleum, emphasizing its cultural and economic significance [3-4]. Coffee is an important export commodity for Indonesia and plays a major role in the country's economic activity. Along with gas and oil, coffee gives Indonesia a significant amount of foreign exchange and meets the needs of a sizable domestic market. The Indonesian Central Statistics Agency reported that the coffee plantations in Indonesia covered an estimated area of 1.246 thousand hectares in 2022. These farms yielded roughly 774.96 thousand tons of coffee, of which 56% (437.56 thousand tons) was exported. Indonesian coffee has successfully penetrated global markets, with the United States, India, Egypt,

Germany and Malaysia becoming the primary importers [5].

The widespread popularity of coffee can be attributed not only to its taste and cultural significance but also to its myriads of health advantages. Coffee is renowned for its invigorating and arousing effects, ability to promote fat metabolism, and potential to enhance athletic prowess and defend against ailments such as diabetes. The main reason for these advantages is the bioactive substances included in coffee, which are known for their powerful antioxidant properties. Coffee contributes substantially to the daily consumption of antioxidants and other sources such as fruits and vegetables [3,6-7]. The antioxidant properties in coffee are mainly due to the presence of polyphenols and melanoidins. Compounds such as chlorogenic acid, ferulic acid, caffeic acid, and *n*-coumaric acid are key contributors to these properties. During the roasting process, additional compounds, including phenylalanines and heterocyclic compounds, are formed, further enhancing the antioxidant capacity of coffee [8-9].

Previous studies have shown that roasting conditions, particularly temperature and time, play a crucial role in shaping the sensory and health attributes of coffee [3,7,10]. For instance, Catão et al. [11] highlighted that roasting temperatures between 160°C and 200°C significantly influence the degradation of chlorogenic acids and the formation of new flavor

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compounds. Lower temperatures tend to preserve more antioxidants, while higher temperatures above 230°C cause excessive degradation. Time is another key factor; Hidayat et al. [12] found that roasting durations 3 minutes after first cracked has the optimal antioxidant retention, with prolonged roasting reducing these beneficial compounds. These findings provide the foundation for determining the roasting parameters in the present research, focusing on maximizing both antioxidant content and flavor quality.

The roasting process is crucial in determining coffee's ultimate antioxidant levels and flavor characteristics. The process entails subjecting coffee beans to elevated temperatures, resulting in intricate chemical reactions such as the Maillard reaction, caramelization, and pyrolysis. These interactions enhance the formation of coffee's complex taste and scent and substantially affect its antioxidant capabilities. As the temperature and length of roasting rise, the levels of certain antioxidants may drop because of thermal degradation, while other antioxidant molecules may be formed or increased due to the Maillard reaction. Therefore, it is necessary to find a middle ground to maximize coffee's taste and nutritional advantages [4,13-14].

Airflow during roasting is another crucial factor influencing the antioxidant content of coffee beans. The airflow impacts the dispersion of heat and the speed at which moisture is extracted from the beans. Optimal air circulation is crucial for maintaining a consistent roasting process, preventing excessive heat that may cause the deterioration of valuable chemicals. In addition, the airflow might impact the speed of chemical processes within the beans, therefore influencing the creation of antioxidant chemicals. Regulating the airflow in the roaster is beneficial for controlling the temperature conditions, which in turn impacts the coffee beans' resistance to oxidation and the preservation or creation of antioxidants [11,15].

Response Surface Methodology (RSM) is used to optimize the roasting conditions. A chemometric approach, known as RSM, is commonly employed in the field of food production and analysis to enhance and streamline procedures. The process entails the modeling and optimization of parameters that impact several operations, with the primary objective of minimizing energy consumption and extraction expenses. Response Surface Methodology (RSM) produces prediction equations that establish a correlation between consumer reactions and the variables under investigation. This enables researchers to estimate the anticipated outcomes for combinations of elements that were not directly examined. This methodology enables the efficient design of experiments, allowing for the development of a large number of samples for evaluation in a short period of time. It also enhances the efficiency of laboratory-level tests [16-17].

The objective of this study is to quantify the physicochemical composition (phenol, tannin, flavonoids, chlorogenic acid) and assess the antioxidant activity of Robusta coffee beans under various roasting circumstances, with a specific focus on variables like temperature, duration, and air circulation. The research

aims to develop a method for making a functional beverage termed 'kopi purwaceng' with improved antioxidant capabilities by studying the impact of these parameters on the antioxidant content. This could potentially open new avenues for developing coffee drinks that prioritize health and offer both sensory enjoyment and potential health advantages.

## 2. Materials and Methods

### 2.1. Materials and tools

Coffee cherries of *Coffea robusta* were manually harvested from Gunung Kelir's, Semarang, Central Java, Indonesia. The farmer's group dried the cherries using direct sunlight, known as natural processing. The defective green beans were sorted to reduce the noise potential in the generated data.

The roasting machine used William Edison's (Indonesia) W600i series with a 1kg drum capacity. The heat resource from gas (LPG) and electricity of 25W/220V. The roasting drum was made from stainless steel, while the outside drum was doubled jacket with heat resistant layer. The cooling system was specially made for W600i with a turbo fan and electricity of 125W/220V that is made from steel and stainless.

### 2.2. Coffee roasting

The coffee was roasted using three parameters containing three variables in each parameter. The parameters were temperature (190, 210, and 230°C), time (11, 14, and 17 minutes), and airflow (damper opening at 1/4, 2/4, dan 3/4).

### 2.3. Research design and statistical analysis

Response Surface Methodology – Box-Behnken design using Design Expert 7.1.5. software was used to investigate the relationship between three parameters (as mentioned above) as independent variables and to obtain the data on the optimum condition. In this design, the optimum conditions corresponded to the highest phenol, tannin, flavonoid, chlorogenic acid, and antioxidant activity.

### 2.4. Phenol content

Phenol content was measured according to Kieu Tran et al. [18]. Ground coffee (5 g) was dissolved in 100 mL distilled water and centrifuged until a clear solution was obtained. The stock solution (1 mL) was taken in a test tube and dissolved with 0.5 mL follicle denis (follicle 1:1) and 1 mL saturated Na<sub>2</sub>CO<sub>3</sub>. Then test tube was kept in a dark place for 10 minutes. Finally, the stock solution was dissolved with distilled water until 10 mL, vortexed, and the absorbance was measured using 730 nm (spectrophotometer UV-Visible SP-300). A standard curve was made using phenol (0.114 mg/ml).

### 2.5. Tannin content

Tannin content was measured using [19]. The stock solution (1 mL) was taken in a test tube and dissolved with 0.5 mL follicle denis (follicle 1:1) and 1 mL saturated Na<sub>2</sub>CO<sub>3</sub>. Then test tube was kept in a dark place for 10 minutes. Finally, the stock solution was dissolved with distilled water until 10 mL, vortexed, and the absorbance was measured using 730 nm (spectrophotometer UV-Visible SP-300). A standard curve was made using pure tannin acid (0.109 mg/ml).

### 2.6. Flavonoid content

The flavonoid content was measured using [18]. Ground coffee (5 g) was dissolved in 100 mL ethanol and centrifuged until a clear solution was obtained. The stock solution (1 mL) was taken in a test tube and dissolved with 3 mL of 5% AlCl<sub>3</sub>. Finally, the stock solution was dissolved with distilled water until 10 mL, vortexed, and the absorbance was measured using 420 nm (spectrophotometer UV-Visible SP-300). A standard curve was made using Quercetin (0.15 mg/ml).

### 2.7. Chlorogenic acid content

Quantitative analysis of chlorogenic acid content was performed using the HPLC system (Shimadzu LC 20 AD, Japan) with C<sub>18</sub> column ODS. The solution test was prepared by dissolving coffee bean extract into methanol. Then, the solution test was homogenized for 30 minutes and filtered using a paper filter. The chlorogenic acid content in coffee is calculated based on the measured concentration (correlation with the standard curve) and then converted into % with the following formula.

$$\text{Chlorogenic Acid (\%)} = \frac{\text{measured concentration} \times \text{extract volume} \times \text{dilution factor}}{\text{sample weight} \times 10000} \times 100\%$$

### 2.8. Antioxidant activity (IC50)

The antioxidant activity was measured with the DPPH method conducted by [20] in [3]. Ground coffee was dissolved into methanol with a concentration of 100 ppm, 200 ppm, 300 ppm, 400 ppm, and 500 ppm. The stock solution (1 mL) was taken in a test tube and dissolved with 1 mL 2,2-dyphenyl-1-picrylhydrazyl (DPPH) 200 μM. Then test tube was kept in a dark place for 30 minutes. Finally, the stock solution was dissolved with distilled water until 5 mL, and the absorbance was using 517 nm (spectrophotometer UV-visible SP-300). A standard solution was made using 1 mL 2,2-diphenyl-1-picrylhydrazyl (DPPH) 200 μM and 4 mL methanol.

## 3. Results and Discussion

The phenol, tannin, flavonoid, chlorogenic acid content, and antioxidant activity of Robusta coffee beans are presented in Table 1. The data reveals distinct variations in the content of these compounds across the different roasting samples. Notably, sample D exhibited the

lowest levels of phenol, tannin, and chlorogenic acid, whereas sample H had the lowest flavonoid concentration. In contrast, sample L showed the highest levels of phenol, tannin, and chlorogenic acid, while I sample had the highest flavonoid content.

Antioxidant activity, assessed by measuring the inhibition percentage and determining the IC50 value, further underscores these variations. The IC50 number indicates the amount of the sample needed to neutralize 50% of the DPPH radicals. A lower IC50 value signifies greater antioxidant activity. The results clearly confirmed a reverse correlation between IC50 and antioxidant activity. Sample C had the greatest IC50 value, indicating the lowest antioxidant activity. Inversely, sample I had the lowest IC50 value, indicating the highest antioxidant activity. The IC50 values were determined by correlating the proportion of radical scavenging activity with sample concentration [12,21].

The reduction in chlorogenic acid content with increased roasting intensity is consistent with its known thermal instability. Higher IC50 values associated with more extensively roasted samples indicate a clear correlation between the decline in antioxidant activity and the decrease in chlorogenic acid. A decrease in antioxidant capacity and phenolic content with higher roasting intensity, establishing the link between chlorogenic acid content and antioxidant activity [8,21-22].

The total phenol concentration consistently decreased as the duration of roasting increased, indicating a gradual decline in these important antioxidants. Conversely, the quantity of flavonoids did not exhibit a consistent pattern of augmentation or reduction with prolonged roasting. The absence of consistency implies that flavonoids may exhibit a higher heat resistance than other phenolic compounds. Flavonoids may be less affected by changes in roasting conditions, suggesting that they have the ability to tolerate the heat damage caused by roasting operations [7,17].

**Table 1.** Response surface methodology design for phenol, tannin, flavonoid, chlorogenic acid content, and antioxidant activity.

Sample	Fenol (%)	Tannin (%)	Flavonoid (%)	Chlorogenic (%)	DPPH IC50 (ppm)
A	4.92	5.18	2.50	1.95	349.59
B	4.97	5.23	2.50	1.36	375.24
C	4.91	5.17	2.45	1.14	397.55
D	4.08	4.30	2.33	0.07	393.25
E	4.76	5.01	2.48	0.84	346.85
F	4.99	5.26	2.48	1.76	340.49
G	4.58	4.82	2.23	1.26	363.97
H	4.16	4.38	2.21	0.53	370.33
I	4.85	5.10	2.52	0.63	241.09
J	4.62	4.86	2.40	0.60	351.87
K	4.27	4.49	2.27	0.19	388.05
L	5.04	5.30	2.42	2.25	284.32

M 4.70 4.94 2.32 1.32 274.81

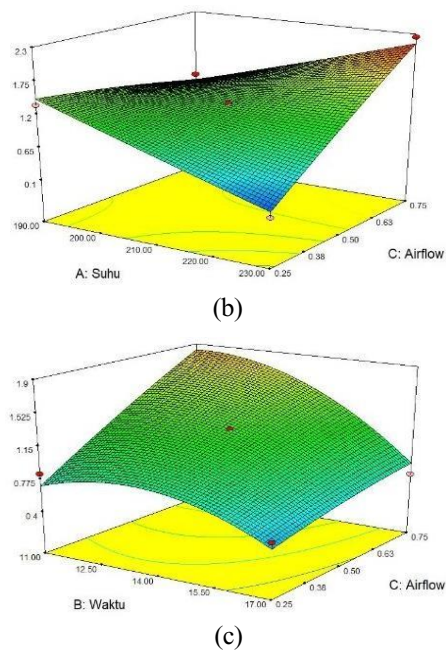
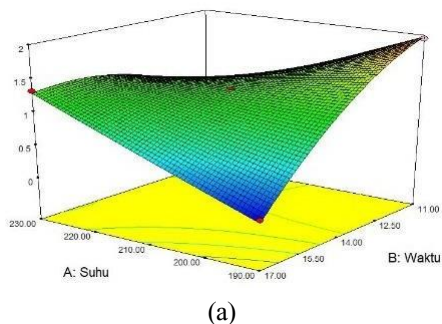
Table 2 shows the results of the analysis of variance (ANOVA) conducted on the data for phenol, tannin, flavonoid, chlorogenic acid content, and antioxidant activity. The ANOVA analysis revealed that there were no statistically significant changes in the response of phenol, tannin, and flavonoids to the roasting settings. The lack of significance in this case is likely due to the minimal variability in the test findings of these substances among various samples, rendering the differences statistically insignificant.

Conversely, the roasting methods significantly affected the ANOVA results for chlorogenic acid and antioxidant activity. The significant effect highlights the sensitivity of chlorogenic acid to heat treatment and its crucial function in defining the coffee's antioxidant capability. The significant differences among the samples emphasize the significance of chlorogenic acid as a key component in the antioxidant composition of roasted coffee [10].

**Table 2.** Analysis of variance for phenol, tannin, flavonoid, chlorogenic acid content, and antioxidant activity.

Compound	P-Value	Std. Dev.	R-Squared	Significancy
Phenol	0.15	0.19	0.92	not significant
Tannin	0.15	0.20	0.92	not significant
Flavonoid	0.09	0.05	0.94	not significant
Chlorogenic	0.02	0.18	0.98	significant
Antioxidant	0.02	14.42	0.98	significant

The results from Table 2 highlight that although the levels of phenol, tannin, and flavonoid remain generally consistent under various roasting conditions, the amount of chlorogenic acid and antioxidant activity is greatly influenced by the roasting process. These findings indicate that precise management of roasting variables is crucial for retaining the advantageous phenolic components in coffee, including chlorogenic acid, which notably impacts the coffee's antioxidant capabilities.

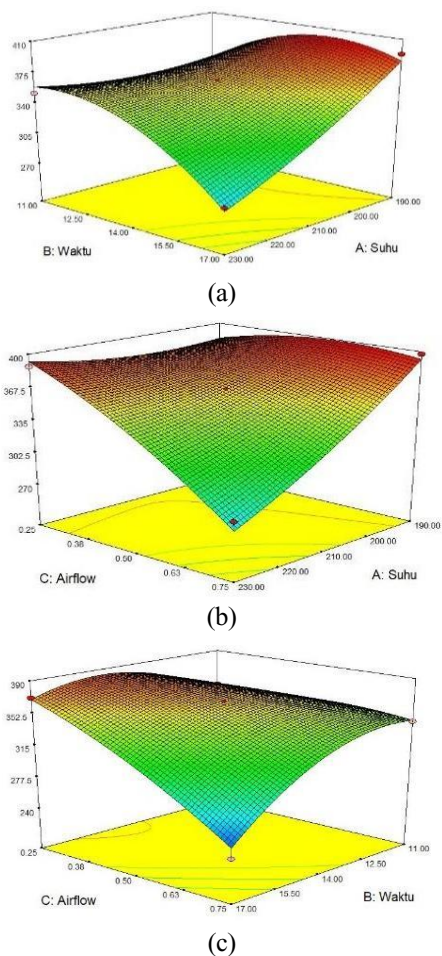


**Fig. 1.** Response surface for (a) temperature vs. time, (b) temperature vs. airflow, and (c) time vs. airflow in chlorogenic acid contents.

Response surface methodology for "temperature vs. time," "temperature vs. airflow," and "time vs. airflow" in the chlorogenic acid content of coffee beans that have been roasted can be seen in Figure 1. The chlorogenic acid content for temperature and time decreased when the roasting temperature increased from 190°C to 210°C and roasting time increased from 11 minutes to 13 minutes, however, the chlorogenic acid content increased again when the roasting temperature increased from 210°C to 230°C and roasting time increased from 13 minutes to 17 minutes so it will make a curve like the "V" letter. Conversely, chlorogenic acid content increased when the roasting temperature increased from 190°C to 210°C and the roasting time decreased from 17 minutes to 13 minutes. Still, the chlorogenic acid content decreased when the roasting temperature increased from 210°C to 230°C and time roasting decreased from 13 minutes to 11 minutes to form a curve like The same condition as the chlorogenic acid content for temperature vs. airflow, the chlorogenic acid content decreasing when the roasting temperature increased from 190°C to 210°C and the damper opening expanded from 0.25 to 0.5, but the chlorogenic acid content increasing again when the roasting temperature increased from 210°C to 230°C and the damper opening expanded from 0.5 to 0.75 to form a curve like a letter "V". The reverse is also the same, chlorogenic acid content increased when the roasting temperature increased from 190°C to 210°C and the damper opening was limited from 0.75 to 0.5, but the chlorogenic acid content decreased when the roasting temperature increased from 210°C to 230°C and the damper opening limited from 0.5 to 0.25 so that it forms a curve like a letter "A".

Unlike the chlorogenic acid content for time vs. airflow, the chlorogenic acid content increased when the roasting time increased from 11 minutes to 14 minutes

and the damper opening expanded from 0.25 to 0.5, but the chlorogenic acid content decreased when the roasting time increased from 14 minutes to 17 minutes, and the damper opening expanded from 0.5 to 0.75 to form a curve like the letter "A". Conversely, the chlorogenic acid content decreased when the roasting time increased from 11 minutes to 14 minutes and the damper opening was limited from 0.75 to 0.5, but the chlorogenic acid content increased when the roasting time increased from 14 minutes to 17 minutes and the damper opening limited from 0.5 to 0.25 so that it forms a curve like a letter "V".



**Fig. 2.** Response surface for (a) temperature vs. time, (b) temperature vs. airflow, and (c) time vs. airflow in antioxidant activity contents.

Response surface methodology for "temperature vs. time," "temperature vs. airflow," and "time vs. airflow" in the DPPH content of coffee beans that have been roasted is shown in Figure 2. The DPPH content for temperature and time increased when the temperature roasting increased from 190°C to 210°C and the roasting time increased from 11 minutes to 13 minutes, but the DPPH content decreased when the roasting temperature increased from 210°C to 230°C and roasting time increased from 13 minutes to 17 minutes thus forming a curve like the "A" letter. Still, the DPPH content will consistently decrease when the roasting temperature increases from 190°C to 230°C and the roasting time decreases from 17 minutes to 11 minutes.

The DPPH content for temperature vs. airflow consistently decreased when the roasting temperature

increased from 190°C to 230°C, and the damper opening expanded from 0.25 to 0.75. However, if the damper opening sequence was reversed, the DPPH content decreased when the roasting temperature increased from 190°C to 210°C and the damper opening was limited from 0.75 to 0.5 and then increasing again when the roasting temperature increased from 210°C to 230°C and the opening the damper shrank from 0.5 to 0.25 so it forms a curve like a letter "V."

Different from the graph of DPPH content for time vs. airflow, DPPH content increased when roasting time increased from 11 minutes to 14 minutes, and damper opening expanded from 0.25 to 0.5, but DPPH content decreased when roasting time increased from 14 minutes to 17 minutes, and the opening of the damper expanded from 0.5 to 0.75 to form a curve like a letter "A". However, the DPPH content consistently increased when the roasting time increased from 11 minutes to 17 minutes, and the damper opening shrank from 0.75 to 0.25.

Many chemical compound changes occurred during the roasting process, including the Maillard reaction and degradation of polyphenols. Bobková et al. [3] stated that antioxidant activity increased in coffee with roasting light and a medium profile. This is not suitable for this research. These results showed that DPPH content with random patterns. These could happen because of the influence of the additional function of airflow in the roasting machine. Airflow function to remove smoke from the roasting drum to prevent the coffee beans from becoming underdeveloped or baked. In some roasting machines, alternating fans emit smoke and then return the hot air to the roasting drum, but it was not the roasting machine used in this research. The roasting machine used in this research can adjust how much the damper is opened but cannot return hot air to the roasting drum. The greater the damper opened, the more smoke and hot air coming out of the roasting drum can reduce the risk of underdeveloped coffee beans. But the more the damper is opened, the colder air enters the roasting drum, thereby increasing the risk of baking on the coffee beans. A damper opening arrangement is very necessary because each coffee bean has a different reaction to heat due to the roasting process.

#### 4. Conclusion

The effect of airflow during the roasting process has a substantial influence on antioxidant activity and chlorogenic acid levels. Still, it does not significantly affect phenol, tannin, and flavonoid levels. The presence of a damper in the roasting machine, which controls the flow of air, should be considered during the roasting process. This is because it is one of the factors that might impact the antioxidant activity and chlorogenic acid levels in roasted beans. The anticipated increase in antioxidant activity and chlorogenic acid levels will likely enhance the value of functional beverages made from these beans as a primary ingredient. The use of response surface methods revealed that the optimal conditions for achieving maximum phenol content, tannin content, flavonoid

content, chlorogenic acid content, and antioxidant activity were found at a temperature of 190°C, a duration of 11 minutes, and a damper opening of 0.75.

This work was supported by Grant No. 2577/UN1.DITLIT/DIT-LIT/LT/2019. The Directorate of Research and Community Service, Directorate General of Research and Development Ministry of Research, Technology and Higher Education was therefore highly acknowledged.

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