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Correlation Between Roasting Duration and Physicochemical Properties of Arabica Coffee (*Coffea arabica* L.) Beans: A Basis for Roasting Profile Standardization

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ABSTRACT

Roasting is a critical determinant of coffee quality, yet roast level is often assessed subjectively through sensory evaluation, limiting the standardization of roasting profiles. This study investigated the relationship between roasting duration and changes in the physicochemical properties of coffee beans as a preliminary step toward objective roasting control. Thirty samples of fully washed Solok Radjo Arabica coffee beans were roasted at a constant temperature of 195 °C using ten roasting durations ranging from 475 to 795 s, with three replications per treatment. Pearson correlation analysis revealed very strong linear relationships between roasting duration and four of the five measured physicochemical parameters. Coffee pH showed a very strong positive correlation (r = 0.985), increasing with longer roasting times due to the decomposition of organic acids. In contrast, titratable acidity (r = –0.983), color lightness (r = –0.959), and moisture content (r = –0.955) exhibited very strong negative correlations and decreased significantly as roasting time increased. Caffeine content showed the weakest correlation (r = –0.598) and fluctuated because of its high thermal stability. All correlations were statistically significant (p < 0.05). These findings demonstrate that physicochemical parameters can serve as objective indicators for roasting process control and roasting profile standardization, while providing a basis for future studies linking physicochemical changes with sensory quality.

1. INTRODUCTION

Coffee is one of the strategic agricultural commodities in the Indonesian economy, with total exports reaching 276,335.2 metric tons in 2023 (Badan Pusat Statistik, 2025). One of the key factors driving the strong international demand for Indonesian coffee, particularly in the specialty coffee market, is its distinctive taste, high quality, and wide varietal diversity across growing regions (Ashardiono & Trihartono, 2024).

The roasting process is a crucial factor in post-harvest coffee processing. Roasting conditions, including temperature and duration, are crucial factors in determining the quality and flavor of coffee, including color, aroma, storage time, and the resulting physicochemical properties such as pH, caffeine, water content, and titratable acidity (Kim *et al.,* 2024).

The chemical content of a food product is a crucial aspect in quality evaluation. Product quality evaluation is crucial for increasing product consumption and developing products for export. Each export destination or consumer country typically has its own quality criteria and standards, such as maximum permissible water content, total acidity, and caffeine (International Coffee Organization, 2018).

Most industry practices determine coffee roast levels by referring solely to descriptive roast labels (light, medium, and dark roast) based on roastery knowledge and subjective sensory evaluations of aroma, crack, and color. This results in inconsistent results and may not meet consumer expectations, as each roastery may have a different assessment of a roast profile (Giacalone *et al.,* 2019). This situation is crucial and creates challenges for standardizing roasting profiles, particularly in determining duration. To meet these varying quality standards, understanding the correlation or relationship between roasting duration and the physicochemical properties of coffee is crucial.

Most previous studies on coffee roasting have evaluated combined temperature–time binomials, in which both variables change simultaneously across roasting profiles, making it difficult to isolate the specific contribution of roasting duration alone (Freitas *et al.,* 2023). Consequently, although the general physicochemical response of coffee beans to roasting is well documented, quantitative correlation data describing how physicochemical properties change across a continuous range of roasting durations at a single, fixed temperature remain limited, particularly for Indonesian Arabica coffee, whose specialty-grade quality markers remain an active area of investigation (Amalia *et al.,* 2023). This study addresses this gap by evaluating ten roasting durations at a constant temperature of 195 °C, providing a duration-specific correlation dataset intended to support more precise control of roasting time as an independent process variable.

This research therefore examines the correlation between roasting duration and the physicochemical properties of coffee beans, using this relationship as a scientific basis for controlling and standardizing roasting duration in the coffee industry, providing physicochemical baseline information that can be integrated with future sensory (cupping) evaluation to support product quality optimization in the coffee industry.

2. MATERIALS AND METHODS

Coffee beans used come from Solok Radjo coffee in Solok Regency, and underwent a fully washed post-harvest treatment. The samples were then taken to the Dua Pintu Roastery in Padang City to undergo the roasting process at a temperature of 195 °C using a VNT roasting machine with varied roasting times. Ten roasting durations were conducted in this study, with three replications for each roasting time. This roasting temperature was held constant because it lies close to the 190 °C optimum reported for *Coffea arabica*, which balances the retention of desirable bioactive compounds with minimal formation of undesirable thermal contaminants such as acrylamide (Endeshaw & Belay, 2020), while remaining within the range typically required to reach medium-to-dark roast development (Getaneh *et al.,* 2020; Sunarharum *et al.,* 2022). Fixing the temperature at this level allowed roasting duration to be evaluated as an independent process variable, consistent with the objective of this study.

The roasting duration treatment was taken based on initial experiments to determine the profiles of light, medium, and dark roast. In these preliminary trials, roasting was performed at the same fixed temperature (195 °C) and monitored in real time by the roastery operator using the audible first-crack and second-crack milestones together with visual assessment of bean color, which are the criteria conventionally used to delineate roast levels in industry practice (Bempah *et al.,* 2025). Light roast was taken as the point shortly after first crack, medium roast as the point between first and second crack, and dark roast as the point shortly after second crack (Figure 1). Thus, the time obtained

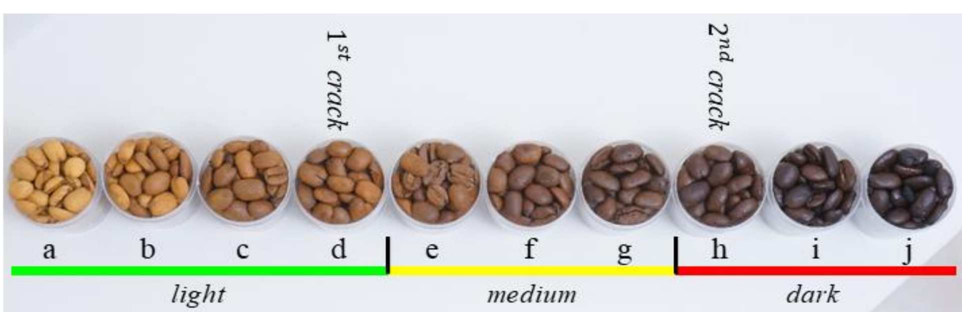

Figure 1. Change of coffee beans during roasting process at different times (in second): (a) 475 s, (b) 510 s, (c) 545 s, (d) 580 s, (e) 615 s, (f) 650 s, (g) 685 s, (h) 725 s, (i) 760 s, (j) 795 s

for light roast was 580 seconds, medium roast was 650 seconds, and dark roast was 760 seconds. Based on the initial duration obtained, it was then developed into 10 time duration treatments: 475, 510, 545, 580, 615, 650, 685, 725, 760, and 795 seconds. The roasting process was carried out in 3 batches, with the first, second, and third 10 kg roasting in stages. After that, roasted coffee beans were ground prior to physicochemical properties measurements. Each measurement was carried out in triplicate to improve the reliability and reproducibility of the data.

2.1. Water Content

Water content measurement is carried out using a gravimetric procedure, namely, the amount of water lost from the test material during the heating process at a temperature of 105 ° C is considered as the amount of water contained in the test material. First, weigh an empty cup, and add 5 g of material into the cup. The cup and the material are oven-dried for 3 to 4 hours. Observe the appearance of the test material; if it still contains water, continue heating, and if it looks dry, the cup can be cooled in a desiccator for 30 minutes and then weighed. After that, heat it back in the oven for 1 hour. This procedure is carried out continuously until a constant weight is obtained, with a difference in weight obtained of +0.2 g (Syukri, 2021). Mathematically, water content was calculated according to Equation (1).

$$WC = \frac{W_1\text{-}(W_2\text{-}W_0)}{W_2\text{-}W_0} \times 100\% \quad (1)$$

where WC is dry-based water content in %, W_0 is the weight of the empty cup, W_1 is the weight of the cup with the specimen, and W_2 is the constant weight of the contained cup.

2.2. Total Titratable Acid and pH

The pH value was measured using a pH meter. First, 5 g of the sample was placed in a beaker, 50 mL of distilled water was added, and then stirred thoroughly. The coffee solution was then filtered using filter paper, and the pH of the filtrate was measured using a pH meter, following an aproach with prior studies on pH changes in roasted coffe extracts (Kim *et al.,* 2024). The pH meter was calibrated using standard buffer solutions (pH 4.0 and 7.0) prior to each measurement session to ensure reading accuracy.

Total acidity is measured as TTA (total titratable acid) using the alkalimetry method, which involves titrating the acid content in food with a standard base (Syukri, 2021). The acids measured are generally organic acids (citric, malic, lactic, and tartaric). The first step in the measurement is to place 10 g of the sample in a 250 mL beaker, then add 150 mL of distilled water. After dissolving, transfer the solution to a 250 mL volumetric flask. The solution is filtered, and 10 mL of the filtrate is pipetted into a 50 mL Erlenmeyer flask. PP indicator is added (2–3 drops). Finally, titration is carried out with 0.1 N NaOH until a pink color forms in the solution. The TTA was calculated using Equation (2).

$$TTA = \frac{\text{vol NaOH} \times \text{N NaOH} \times \text{MP(25)} \times \text{MW}}{\text{specimen (mg)} \times \text{acid valence}} \times 100\% \quad (2)$$

where TTA is the total titratable acid in %, vol NaOH is the volume of NaOH solution in mL, N NaOH is the normality of NaOH solution, MP(25) is the multiplier factor at 25°C, and MW is the molecular weight in g/mol, and acid valence is the number of hydrogen atoms in acid molecules.

2.3. Caffeine Content

The first step in creating a caffeine standard value is to make a stock solution. Weigh 50 mg of caffeine and put it into a 50 mL volumetric flask. The caffeine is then dissolved in water until it reaches the limit mark to produce a standard caffeine solution (1 mg/mL). Make a standard curve by taking 2.5 mL of the caffeine standard solution from the stock solution, then dilute it using water in a 25 mL volumetric flask until it reaches the limit mark, which will produce a standard solution of 100 mg/L (100 ppm). The standard solution is taken in amounts of 0.05, 0.1, 0.15, 0.2, 0.25, and 0.3 mL, diluted with water to 5 mL. The dilution results produce standard solutions with concentrations of 1, 2, 3, 4, 5, and 6 mg/mL. Perform absorbance measurements with UV-Vis spectrophotometry at a wavelength of 273 nm. Create a standard curve using Microsoft Excel to produce the equation Y = ax + b.

After that, put 1 g of ground coffee beans into a beaker, add 150 mL of hot distilled water, and stir. Filter the solution into an Erlenmeyer flask. Then, 1.5 g of calcium carbonate ($CaCO_3$) and the coffee bean solution were put into a 150 mL separating funnel. Perform the extraction 4 times, each time adding 25 mL of chloroform. The bottom layer of each extraction process was taken and put into a rotary evaporator flask. The extract (chloroform phase) was evaporated with a rotary evaporator until the chloroform evaporated completely. The results of the caffeine extraction that had been free from the solvent were taken from the rotary evaporator flask by rinsing the flask with distilled water until it reached the 100 mL mark, then dissolved with distilled water until it reached the infinity line. Next, the absorbance was measured using a UV-Vis spectrophotometer at a wavelength of 273 nm. This process was repeated for each coffee bean sample as a whole. After obtaining the absorbance value from the sample, the value is then substituted into the standard curve that has been created as the Y axis. The caffeine content (KF) and total caffeine content (TKF) were respectively measured using Equation (3) and Equation (4) (Mulyani *et al.,* 2022).

$$\mathrm{KF} = \frac{[\text{concentration } (x) \times \text{volume}]}{\text{total weight of sample (g)}} \times 100\ \% \tag{3}$$

$$\text{Caffeine} = \frac{\mathrm{KF}}{\text{standard sample weight}} \tag{4}$$

where concentration (x) is the concentration of caffeine solution from the calibration curve in mg/mL, volume is the total sample volume (mL), and standard sample weight in 1000 mg.

2.4. Lightness

Color measurements are carried out using a colorimeter to obtain L, A, and B values. The L or lightness value is Chroma to indicate the intensity and brightness of the color. A is a value to describe the axis of the green-red color, green if the A value decreases, red if A increases. B is a value to describe the axis of the blue-yellow color, blue if the B value decreases, yellow if B increases (Mulyani *et al.,* 2022). However, in this study, the main focus is only on the lightness value because it is related to the level of brightness and darkness of the color of the material. The first stage of color measurement is to put the ground coffee sample into a petri dish, level the top of the material using a spoon or spatula. Once it is even, take a color reading using a colorimeter (Tripetch & Borompichaichartkul, 2019).

2.5. Data Processing

Data processing was performed using Microsoft Excel, which consisted of several stages. First, the physicochemical test data were input into Microsoft Excel. Next, the the Pearson product-moment correlation coefficient (r) was calculated using the CORREL function to examine the linear relationship between roasting duration and each physicochemical property, as well as among the physicochemical properties themselves. The statistical significance of each correlation coefficient was evaluated by comparing it against the critical r-value for $n = 30$ ($df = 28$) at a significance level of $\alpha = 0.05$ (r-critical = 0.361); correlations exceeding this threshold were considered statistically significant. The Pearson correlation (r) was measured using Equation (5) (Saccenti *et al.,* 2020).

$$r = \frac{\sum(x_i - \bar{x}) - (y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})}^2} \tag{5}$$

where x_i is the individual observed value of variable x, $\bar{x}$ is the mean value of variable x, y_i is the individual observed value of variable y, and $\bar{y}$ is the mean value of variable y.

Data correlation was divided into 5 levels: 0.8-1 very strong, 0.6-0.8 strong, 0.4-0.6 moderate, 0.2-0.4 weak, and 0-0.2 very weak or uncorrelated (Syukri, 2021). There are also two types of correlation: a positive correlation (+) indicates a correlation in the same direction, while a negative correlation (-) indicates a correlation in the opposite direction. After determining the correlation and trends in the physicochemical properties of the data, a graph was created to determine the coefficient of determination (R^2).

3. RESULTS AND DISCUSSION

3.1. Correlation of Physicochemical Properties of Coffee Beans with Roasting Duration

As can be seen in Table 1, there is a linear correlation between roasting duration and the physicochemical properties of the roasted coffee bean. Four of five variables of physicochemical properties showed high correlation with roasting duration, which are pH, lightness, WC, and TTA. The value of pH has a positive correlation, while the others have a negative correlation. The highest correlation was shown by pH with a correlation value of 0.985, followed by the correlation value of TTA of -0.983, lightness of -0.959, WC of -0.955, and finally caffeine with the lowest correlation of -0.598. The caffeine variable has the lowest correlation value due to the inconsistent pattern of its data. The same phenomenon was also reported by the previous study; caffeine value increased and decreased with different roasting conditions (Duke *et al.,* 2025). This weak and inconsistent correlation is closely linked to the inherently low caffeine content of Arabica coffee, unlike Robusta (*Coffea canephora*), which typically contains 9–33 mg/g caffeine, Arabica beans generally contain only about 5.5–10 mg/g (Freitas *et al.,* 2023). Because the absolute caffeine pool available for thermal loss is already small, minor variations in bean mass loss, extraction efficiency, or analytical measurement translate into proportionally larger fluctuations in the calculated caffeine value, which is consistent with the weak and non-monotonic correlation observed here, and with reports that the high thermal stability of caffeine can even produce an apparent relative increase in its concentration as other, more heat-labile compounds are lost during roasting (Mestanza *et al.,* 2023).

Table 1. Correlation of physicochemical properties of coffee beans with roasting duration

	Roasting duration (s)	**pH**	**Lightness**	**WC (%)**	**TTA (%)**	**Caffeine (%)**
Roasting duration (s)	1					
pH	0.985***	1				
Lightness	-0.959***	-0.920***	1			
WC (%)	-0.955***	-0.966***	0.947***	1		
TTA (%)	-0.983***	-0.987***	0.938***	0.964***	1	
TKF (%)	-0.598***	-0.654***	0.517**	0.641***	0.587***	1

Note: Values are Pearson product-moment correlation coefficients (r), n = 30 (10 roasting durations × 3 replications). All coefficients in the matrix exceeded the critical r-value for df = 28 at α = 0.05 (r-critical = 0.361; Statistical significance (*) $p < 0.05$, (**) $p < 0.01$, (***) $p < 0.001$.

3.2. Effect of Roasting Duration on Physicochemical Properties of Roasted Coffee Bean

As can be seen in Figure 2, the pH value increases with the length of roasting time. This relationship was well decribed by a linear regression model with has a high determination value (R^2 = 0.9705). This indicates that pH changes are closely associated with the heating stage. In the phase toward the first crack, the pH increase is relatively slow because the degradation of acid compounds is not yet optimal. However, after entering the first crack and second crack phases, the pH increases sharply due to the decomposition of organic acids, such as citric and malic acids, into volatile compounds. This increase in pH indicates that the coffee beans are losing their acidic character and becoming more neutral or slightly alkaline, which affects the final taste of the coffee to become less acidic and more bitter. A comparable upward pH trend with increasing roast degree has been reported by Kim *et al.,* (2024), who linked the rise in coffee extract pH to the progressive degradation of chlorogenic acids into caffeic acid during roasting, supporting the acid-decomposition mechanism proposed here.

The results of the total titratable acid (TTA) analysis revealed a strong negative correlation between TTA and roasting time, which fitted a linear regression model, with a value of R^2 is 0.9655 (Figure 2). TTA values decreased significantly with increasing temperature and heating time. In the initial phase (toward first crack), the decrease in acidity was still limited, but after first crack and second crack, the decrease became more pronounced due to the degradation of organic acid compounds and the formation of volatile gas compounds. This decline is primarily attributed to the thermal degradation of chlorogenic acids, one of the dominant organic acid fractions in green coffee beans, which breaks down into quinic acid and caffeic acid derivatives, as well as volatile compounds such as CO_2 and various furan derivatives, during prolonged heat exposure (Kim *et al.,* 2024). As chlorogenic acids are progressively degraded with increasing roasting duration, the pool of titratable organic acids available for neutralization decreases, directly lowering the measured TTA value. After the second crack, the rate of decline began to slow as most of the acid had broken down. This decrease in TTA indicates that a darker roasting process will produce coffee with lower acidity and a more bitter flavor with caramel or chocolate notes. This result is in line with Bempah *et al.,* (2024) which states that the overall acidity level in coffee beans decreases with increasing roasting duration. Conversely, the pH of coffee beans tends to increase (become less acidic) with increasing roasting duration or level.

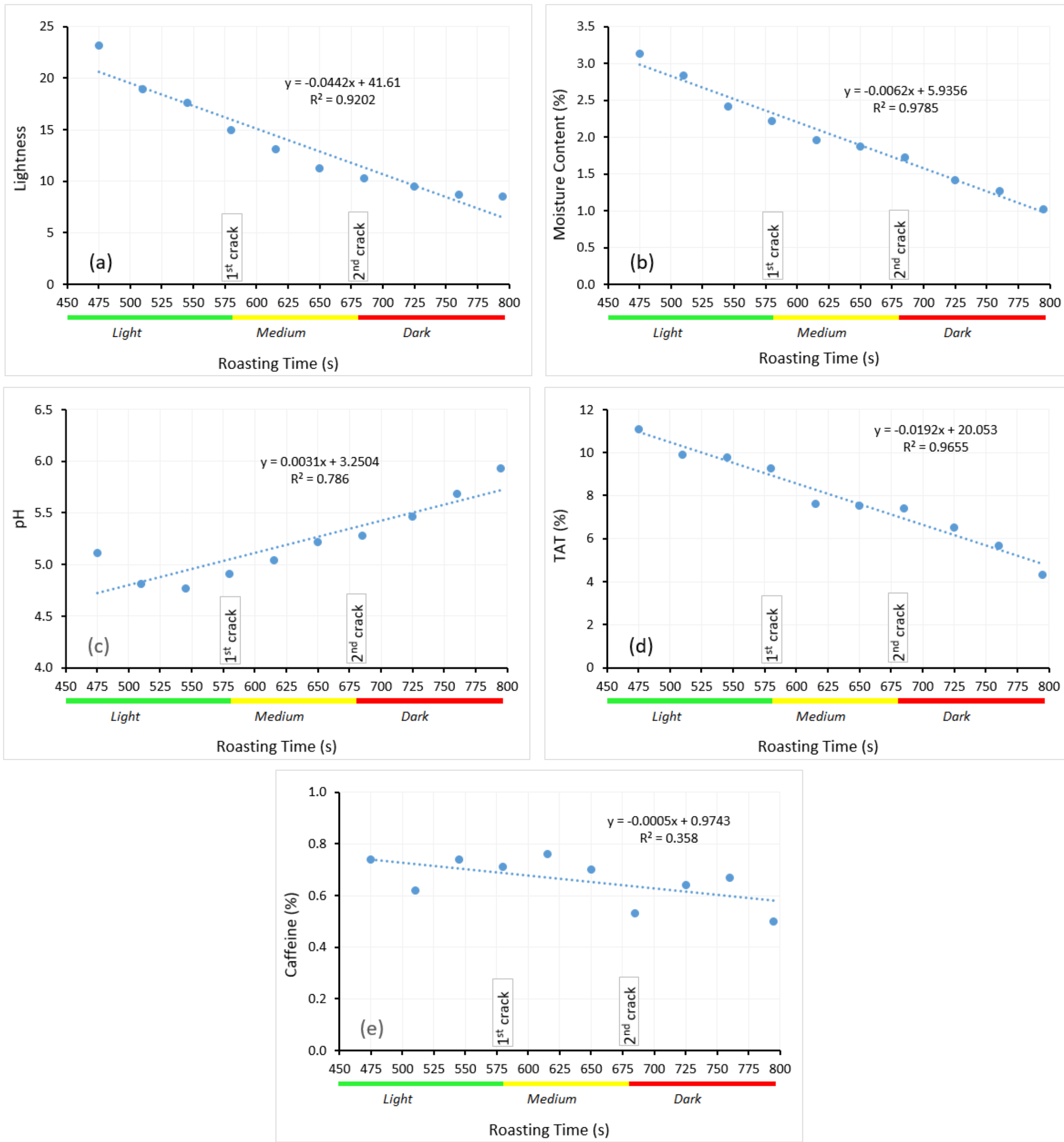

Figure 2. Effect of roasting time on the physicochemical characteristic of coffee beans: (a) Lightness, (b) Moisture content (%), (c) pH, (d) Titrable acidity (%), (d) Caffeine (%)

As shouwn in Figure 2, the lightness (*L*) value, an indicator of bean brightness, decreases steadily with increasing roasting duration and was well described by a linear regression model ($R^2 = 0.92$). This decrease indicates a change in the color of the coffee beans from light brown to dark brown, to almost black in the final stage of roasting. The sharpest decrease occurs between the first crack and second crack, where the Maillard reaction and caramelization take place intensively, producing melanoidin pigments that are responsible for the dark color of coffee beans. This color change is the main visual indicator for determining the level of ripeness of coffee beans, so the lightness (*L*) color parameter can be used as an objective reference in controlling the quality of the roasting process. This occurs due to the melanoidin compound formed during the Maillard reaction. Melanoidin is a high molecular weight compound that causes coffee beans to turn brown, which directly causes a decrease in the lightness (*L*) value or the level of brightness of coffee beans (Hu *et al.,* 2020). This pattern is consistent with Bempah *et al.,* (2025), who reported a reproducible Arabica color trajectory with L^* values of approximately 29.7 at first crack and 19.9 at second crack across different roasting profiles and origins; the sharp lightness decline observed between first and second crack in the present study follows this same trajectory, supporting the use of the lightness (*L*) parameter as an objective, transferable reference for monitoring roast development.

As shown in Figure 2, moisture content decreased sharply with increasing roasting duration, showing a strong negative correlation that was well described by a linear regression model (R^2 = 0.9781). Moisture content decreases sharply with increasing temperature, especially in the phase toward the first crack, where free water in the beans evaporates rapidly due to heating. After the first crack, water bound in the beans' cellular structure also begins to evaporate, causing the beans to become lighter and more brittle. In the post-second crack phase, moisture content reaches its lowest point (around 0.5–1%), indicating near-complete drying. This reduction in moisture content is crucial for achieving final product stability, as excessively high moisture content can lead to suboptimal aroma and accelerate the deterioration of coffee beans during storage. The longer the roasting time, the lower the water content of the coffee beans. This occurs due to the evaporation of water, caused by the transfer of heat from the roasting machine into the material (Syukri, 2021; Wahyuni *et al.,* 2020). A similarly strong, well-fitted decline in moisture content with roasting time was reported by Zhu *et al.,* (2022), who modeled coffee bean moisture loss as a first-order kinetic process with R^2 values consistently above 0.98; the very strong negative correlation obtained in the present study (R^2 = 0.9781) falls within this same range, indicating that moisture evaporation followed a comparable first-order-like kinetic pattern under the fixed-temperature, variable-duration conditions tested here.

The caffeine content analysis graph (Figure 2) shows a weak correlation with roasting duration, with an R^2 value of only 0.3572. Although a linear trendline was fitted to this relationship, its low R^2 value indicates that a linear model explains only a limited proportion of the variability in caffeine content, consistent with the fluctuating, non-monotonic pattern. This fluctuating pattern indicates that changes in caffeine content do not follow a linear trend like other parameters. Caffeine is a relatively heat-stable compound, so there is no significant change from the first crack to the second crack stage. A small decrease is only seen in the post-second crack phase, possibly due to partial sublimation of the caffeine or a decrease in bean mass that affects the calculation of relative content. Within the specific conditions examined in this study – a single Arabica cultivar roasted at a fixed temperature of 195 °C – caffeine content therefore appeared to be governed less by roasting duration than by bean-specific and mass-loss-related factors; this interpretation is limited to the variety, temperature, and duration range evaluated here and should not be generalized to other roasting conditions without further verification. Wahyuni *et al.,* (2020) reported that caffeine is a heat-stable compound, but its concentration in roasted coffee beans is influenced by the total mass loss of the beans during the process.

Beyond establishing statistically significant correlations, the novelty of this study lies in isolating roasting duration as an independent process variable at a single, fixed temperature (195 °C), whereas most previous investigations examined combined temperature time binomials that vary simultaneously and therefore cannot separate the specific contribution of duration alone (Freitas *et al.,* 2023). By deriving explicit linear regression equations linking roasting duration to pH, lightness, moisture content, titratable acidity, and caffeine content in Indonesian Solok Radjo Arabica beans a specialty-grade origin whose quality markers remain comparatively underexplored (Amalia *et al.,* 2023)—this study contributes a duration-specific, equation-based reference that researchers and roasters can use to estimate physicochemical states at a given roasting duration. This provides a quantitative foundation for developing objective, real-time roasting control and profile-standardization systems, moving beyond the descriptive, sensory-based roast classifications (light, medium, dark) that currently dominate industry practice (Giacalone *et al.,* 2019).

4. CONCLUSION

This study found that four of the five physicochemical variables tested showed a very strong correlation (in the range of 0.8 to 1) with roasting duration. The pH value variable showed the strongest positive correlation (0.985), which means the pH value tends to increase with the length of roasting time due to the decomposition of organic acids. In contrast, the total titratable acid (TTA) (-0.982), lightness (-0.959), and moisture content (-0.955) variables showed a very strong negative correlation, where the values decreased drastically with increasing roasting duration. The decrease in lightness value is an objective visual indicator to determine the level of ripeness of coffee beans due to the Maillard reaction and caramelization. Meanwhile, caffeine content showed the lowest correlation (-0.597) and fluctuated due to its high thermal stability. By identifying these strong correlations, this study provides preliminary physicochemical benchmarks that can support quality control and the standardization of roasting profiles. However, as this study did not include a sensory (cupping) evaluation, these physicochemical correlations alone cannot be used to determine the optimal roasting duration for coffee quality. Future research correlating these physicochemical parameters with standardized sensory evaluation is therefore recommended to establish a comprehensive relationship between roasting duration, physicochemical properties, and cup quality, enabling well-supported recommendations for roasting process optimization.

AUTHOR CONTRIBUTION

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
IE	✓	✓	✓	✓	✓	✓		✓	✓		✓			
FH	✓	✓		✓			✓	✓		✓		✓	✓	✓
REK	✓	✓					✓					✓	✓	

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION

During the preparation of this work, the authors used Grammarly in order to check and fix grammar mistakes. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

REFERENCES

Amalia, F., Irifune, T., Takegami, T., Yusianto, Sumirat, U., Putri, S.P., & Fukusaki, E. (2023). Identification of potential quality markers in Indonesia's Arabica specialty coffee using GC/MS-based metabolomics approach. *Metabolomics*, ***19***, 90. https://doi.org/10.1007/s11306-023-02051-5

Ashardiono, F., & Trihartono, A. (2024). Optimizing the potential of Indonesian coffee: a dual market approach. *Cogent Social Sciences*, ***10***(1), 2340206. https://doi.org/10.1080/23311886.2024.2340206

BPS (Badan Pusat Statistik). (2025). *Ekspor Kopi Menurut Negara Tujuan Utama*. https://www.bps.go.id/id/statistics-table/1/MTAxNCMx/ekspor-kopi-menurut-negara-tujuan-utama-2000-2024.html

Bempah, L.A., Styczynski, T., De Andrade, N., Fernandes, T., Hague, J.G., Ristenpart, W.D., & González, I.R.D. (2024). The effect of roast profiles on the dynamics of titratable acidity during coffee roasting. *Scientific Reports*, ***14***, 8237. https://doi.org/10.1038/s41598-024-57256-y

Bempah, L.A., Styczynski, T., Ristenpart, W.D., & Donis-González, I.R. (2025). A universal color curve for roasted arabica coffee. *Scientific Reports*, ***15***, 24192. https://doi.org/10.1038/s41598-025-06601-w

Duke, B.W., Mokonon, M.A., Mekonin, N.D., & Kuf, K.D. (2025). Effects of Roasting Degree and Grinding Size on Caffeine Content and Sensorial Quality of Coffee. *Journal of Food Quality*, ***2025***, 2405668. https://doi.org/10.1155/jfq/2405668

Endeshaw, H., & Belay, A. (2020). Optimization of the roasting conditions to lower acrylamide content and improve the nutrient composition and antioxidant properties of Coffea arabica. *PLoS ONE*, ***15***(8), e0237265. https://doi.org/10.1371/journal.pone.0237265

Freitas, V.V., Rodrigues Borges, L.L., Dias Castro, G.A., Henrique dos Santos, M., Teixeira Ribeiro Vidigal, M.C., Fernandes, S.A., & Stringheta, P.C. (2023). Impact of different roasting conditions on the chemical composition, antioxidant activities, and color of Coffea canephora and Coffea arabica L. samples. *Heliyon*, ***9***(9), e19580. https://doi.org/10.1016/j.heliyon.2023.e19580

Getaneh, E., Fanta, S.W., & Satheesh, N. (2020). Effect of Broken Coffee Beans Particle Size, Roasting Temperature, and Roasting Time on Quality of Coffee Beverage. *Journal of Food Quality*, ***2020***, 8871577. https://doi.org/10.1155/2020/8871577

Giacalone, D., Degn, T.K., Yang, N., Liu, C., Fisk, I., & Münchow, M. (2019). Common roasting defects in coffee: Aroma composition, sensory characterization and consumer perception. *Food Quality and Preference*, *71*, 463–474. https://doi.org/10.1016/j.foodqual.2018.03.009

Hu, G., Peng, X., Gao, Y., Huang, Y., Li, X., Su, H., & Qiu, M. (2020). Effect of roasting degree of coffee beans on sensory evaluation: Research from the perspective of major chemical ingredients. *Food Chemistry*, *331*, 127329. https://doi.org/https://doi.org/10.1016/j.foodchem.2020.127329

ICO (International Coffee Organization). (2018). *National quality standards 2018*. https://www.ico.org/documents/cy2017-18/icc-122-12e-national-quality-standards.pdf

Kim, Y.K., Lim, J., Kim, Y.J., & Kim, W. (2024). Alterations in pH of Coffee Bean Extract and Properties of Chlorogenic Acid Based on the Roasting Degree. *Foods*, *13*(1757), 1–9. https://doi.org/10.3390/foods13111757

Mestanza, M., Mori-Culqui, P.L., & Chavez, S.G. (2023). Changes of polyphenols and antioxidants of arabica coffee varieties during roasting. *Frontiers in Nutrition*, *10*, 1078701. https://doi.org/10.3389/fnut.2023.1078701

Mulyani, E., Fauziah, D.W., & Haque, A.F. (2022). Perbandingan Kadar Kafein pada Jenis Kopi Hasil Perkebunan Bengkulu dengan Metode Spektrofotometri Ultraviolet. *Indonesian Journal of Pharmaceutical Education*. *2*(2), 86–93. https://doi.org/10.37311/ijpe.v2i3.15492

Saccenti, E., Hendriks, M.H.W.B., & Smilde, A.K. (2020). Corruption of the Pearson correlation coefficient by measurement error and its estimation, bias, and correction under different error models. *Scientific Reports*, *10*, 438. https://doi.org/10.1038/s41598-019-57247-4

Sunarharum, W.B., Mahatmanto, T., Ali, Y., Prananto, Y.P., Efrat, N., Asih, N.E., & Mirillia, N.G. (2022). Sensory and physicochemical characteristics of two common roast defects in Robusta coffee. *International Journal on Advanced Science, Engineering and Information Technology* (*IJASEIT*), ***12***(1), 394-402. https://doi.org/10.18517/ijaseit.12.1.13805

Syukri, D. (2021). *Bagan Alir Analisis Proksimat Bahan Pangan (Volumetri dan Gravimetri)*. Andalas Universitas Press, Padang. ISBN: 978-623-7763-89-5.

Tripetch, P., & Borompichaichartkul, C. (2019). Effect of packaging materials and storage time on changes of colour, phenolic content, chlorogenic acid and antioxidant activity in arabica green coffee beans (*Coffea arabica* L. cv. Catimor). *Journal of Stored Products Research*, *84*, 101510. https://doi.org/10.1016/j.jspr.2019.101510

Wahyuni, N.L.E., Rispiandi, R., & Hariyadi, T. (2020). Effect of bean maturity and roasting temperature on chemical content of robusta coffee. *IOP Conference Series: Materials Science and Engineering*, *830*(2), 22019. https://doi.org/10.1088/1757-899X/830/2/022019

Zhu, M., Long, Y., Ma, Y., Huang, Y., Wan, Y., Yu, Q., Xie, J., & Chen, Y. (2022). Investigation of thermal contaminants in coffee beans induced by roasting: A kinetic modeling approach. *Food Chemistry*, *378*. https://doi.org/10.1016/j.foodchem.2022.132063