Journal of Chemical Process and Material Technology
http://publikasiilmiahunwahas Septiyana et al, vol(4), 69-76, 2025

Rice-Adulterated Roasting: How Traditional Practices Alter Acidity and Caffeine in Indonesian (Sumowono) Robusta Coffee (*Coffea Canephora)*

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Abstract

Coffee is a globally significant commodity, with Coffea canephora (robusta) accounting for 40–43% of production. Recent climate-induced yield declines have raised concerns about coffee quality and affordability. Traditional Indonesian practices, such as adding rice during roasting, offer potential solutions to modulate flavor and chemical composition. This study investigates the effects of rice adulteration (0–30% w/w) on the acidity and caffeine content of Sumowono Robusta coffee using UV-VIS spectrophotometry and pH analysis. Results show that increasing rice content reduces caffeine concentration by up to 8.4% (from 13.89 ppm to 12.72 ppm) and elevates pH from 5.4 to 6.3, indicating decreased acidity. The non-linear reduction in caffeine suggests starch-mediated binding, while the pH increase reflects rice's buffering capacity. These findings validate indigenous techniques as a natural means to produce milder coffee while preserving cultural authenticity. The study bridges traditional knowledge with modern science, offering insights for sustainable coffee processing and potential market differentiation for Robusta producers. Further research should explore sensory impacts and optimize roasting protocols for broader application.

Keywords: *Coffea canephora*, rice adulteration, caffeine reduction, pH modulation, traditional roasting

INTRODUCTION

Coffee (Coffea spp.) holds a vital position in global trade, ranking as the second-most traded commodity—after crude oil—by volume, with Coffea canephora (robusta) contributing approximately 40–43% of global production in recent years. This crop is a cornerstone of the livelihoods of millions of smallholder farmers, particularly in countries like Vietnam, Brazil, and Indonesia, driving economic development through exports and local value chains (Nguyen et al., 2024).

Over the past two years, adverse weather—severe droughts in Vietnam and Brazil—has sharply reduced yields, triggering record-high coffee futures prices for both robusta and arabica beans. This price surge has raised concerns about "flavorflation," where quality may be compromised to manage costs, affecting roasters and consumers alike. Chemically, coffee beans are rich in caffeine (about 1.7–2.5% in robusta) and bioactive polyphenols—particularly chlorogenic acids (CGAs)—which significantly influence both sensory attributes and health benefits. Caffeine is well-known for its stimulating effects on alertness and cognitive performance. Meanwhile, CGAs serve as potent antioxidants and anti-inflammatory agents. They have been linked to protective effects against chronic conditions such as type 2 diabetes, cardiovascular disease, liver disease, and some cancers (Murai and Matsuda, 2023).

Recent meta-analyses suggest chlorogenic-acid–rich coffee may enhance aspects of cognition—memory, attention, executive function, and alertness—though further studies (particularly randomized controlled trials) are needed to clarify optimal intake and duration (Makiso et al., 2023). In Indonesia, one such unique practice is the addition of rice during the coffee roasting process. This technique, observed in Temanggung's Bejen Village, is traditionally employed to modulate the sensory profile of the coffee, particularly to reduce perceived bitterness and adjust acidity levels. The use of rice as a roasting adjunct illustrates a form of low-cost, locally adapted innovation that shapes the final character of the beverage.

Recent advancements in coffee science have explored how traditional roasting additives, such as rice, influence the physicochemical properties of coffee. Studies on Arabica varieties (e.g., Coffea arabica) demonstrate that rice inclusion during roasting reduces caffeine content and acidity through starch-mediated binding and buffering effects. Adding rice during medium roasting (200°C) affects Sumowono Arabica coffee's acidity and caffeine levels. Results show that increasing rice content (0–25%) reduces caffeine (from ~11 ppm to 9 ppm) and acidity (pH rises from 4.2 to 4.5), likely due to rice starch binding caffeine and buffering acids. The findings suggest rice can naturally modify coffee's flavor profile, offering a chemical-free method to produce milder, lower-caffeine coffee (Riwayati et al., 2025). However, research on Robusta coffee (Coffea canephora), which has higher caffeine and acidity, remains limited. Traditional Indonesian practices, like those in Sumowono, often incorporate rice to modulate harsh flavors, yet the mechanistic impact on Robusta's chemical profile is underexplored. Recent findings suggest that starch-rich additives alter Maillard reaction pathways, potentially decreasing chlorogenic acids and caffeine solubility (Tarigan et al., 2022). Meanwhile, UV-VIS spectrophotometry and pH-metric analyses have proven effective in quantifying these changes (Rao and Fuller, 2018). This study bridges the gap by investigating rice's role in Sumowono Robusta coffee, leveraging modern analytical techniques to validate traditional wisdom.

This study aims to investigate how traditional rice-adulterated roasting practices alter the acidity and caffeine content of Sumowono Robusta coffee (Coffea canephora), providing scientific validation for this indigenous Indonesian technique. Specifically, we will quantify changes in pH and caffeine concentration levels using UV-VIS spectrophotometry. By correlating empirical roasting methods with measurable chemical outcomes, this research bridges traditional knowledge with modern analytical science, offering insights for producers seeking natural ways to modulate coffee's chemical composition while preserving cultural authenticity. The findings could inform sustainable, health-conscious coffee production strategies in Indonesia and other Robusta-growing regions, potentially opening new market opportunities for traditionally processed coffees. This study represents the first systematic investigation of rice's effects on Robusta coffee chemistry, addressing a critical gap in the current literature, which has primarily focused on Robusta varieties.

EXPERIMENTAL SECTION

Materials

The study used green Robusta coffee beans (*Coffea canephora*) harvested from Sumowono, Central Java, which were dried for one week to achieve a moisture content of 12 ± 0.5%. White rice (local variety, grain size: 2–3 mm) was added during roasting at varying ratios (0%, 10%, 15%, 20%, 25%, and 30% w/w). Analytical-grade chemicals included distilled water, chloroform (≥99% purity, Merck), and 10% NaOH solution (Merck). All materials were stored under controlled conditions (25°C, 60% RH) prior to use.

Instrumentation

Roasting was performed using a Probat BRZ 2 roaster (Germany) equipped with a digital temperature gauge (±1°C accuracy) and Cropster software for profile monitoring. Ground coffee samples were prepared using a Baratza Encore grinder (40 μm particle size) and sieved through a 500 μm stainless-steel mesh. Chemical analyses utilized a Hanna Instruments HI2210 pH meter (calibrated with pH 4.0/7.0 buffers) and a Shimadzu UV-1800 spectrophotometer (190–400 nm range) for caffeine quantification. Liquid-liquid extraction was conducted using a 250 mL borosilicate separation funnel, and brewing experiments employed a V-60 dripper with Whatman No. 1 filter paper.

Procedure

The research methodology comprised four key phases: (1) sample preparation and roasting, (2) caffeine extraction, (3) spectrophotometric analysis, and (4) pH measurement.

Sample Preparation and Roasting

Sumowono robusta coffee beans (dried for 7 days to 12±0.5% moisture content) were roasted in 100 g batches at 200±1°C (medium profile, Agtron #55–60) using a Probat BRZ 2 roaster. Rice (Oryza sativa L.) was added at 0% (control), 10%, 15%, 20%, 25%, and 30% (w/w) of coffee mass. Roasting times were recorded from first crack initiation to completion.

Caffeine Extraction

Each roasted sample (1.0±0.01 g) was mixed with 80±1°C distilled water (100 mL) and stirred for 5 min. The slurry was vacuum filtered (Whatman No. 1), and the filtrate was alkalized with 10% NaOH to pH 10. Liquid-liquid extraction was performed using chloroform (3 × 20 mL) in a 250 mL separation funnel. The chloroform phase was evaporated at 25°C, and the residue was reconstituted in 80°C distilled water to 100 mL.

Spectrophotometric Analysis

A caffeine standard stock solution (100 ppm) was prepared by dissolving 100 mg caffeine (Sigma-Aldrich, ≥99%) in 1 L of 80°C distilled water. Working standards (25–50 ppm) were analyzed at 205 nm (λ_{max}) using a Shimadzu UV-1800 spectrophotometer. Absorbance readings were taken every 10 min for 60 min to verify stability (RSD <2%). The calibration curve ($y = 0.071x + 2.892$, $R^2 = 0.894$) was validated following ICH Q2(R1) guidelines.

Acidity Measurement

The pH of each coffee extract was measured in triplicate using a calibrated pH meter (Hanna HI2210) with temperature compensation. Measurements were performed at 25±0.5°C after 3-point calibration (pH 4.00, 7.00, and 10.00 buffers).

RESULTS AND DISCUSSION

The figure 1 illustrates the absorbance profile of a standard caffeine solution measured over time using UV-Vis spectrophotometry, revealing important insights about the solution's stability and measurement reliability. Absorbance values initially decreased from 0.972 to 0.963 within the first five minutes, likely reflecting either solution stabilization or minor photodegradation effects. This was followed by a stabilization phase between 5-7 minutes where values plateaued around 0.967-0.968, indicating system equilibrium. A slight absorbance increase to 0.969 in the final measurements suggests potential minor compound accumulation or temperature effects. The observed fluctuations of less than 0.01% fall well within acceptable analytical error margins, demonstrating good method reliability. These findings align with established literature on caffeine behavior in aqueous solutions (Rao & Fuller, 2018), where similar stabilization patterns are observed after initial measurement periods. For improved accuracy in future experiments, we recommend implementing light protection measures to minimize photodegradation and maintaining strict temperature control throughout measurements. The Y-axis represents absorbance (%) while the X-axis shows time progression in minutes, with the overall pattern suggesting that caffeine solutions reach stable absorbance readings after an initial adjustment period, making them suitable for quantitative analysis when proper experimental controls are in place.

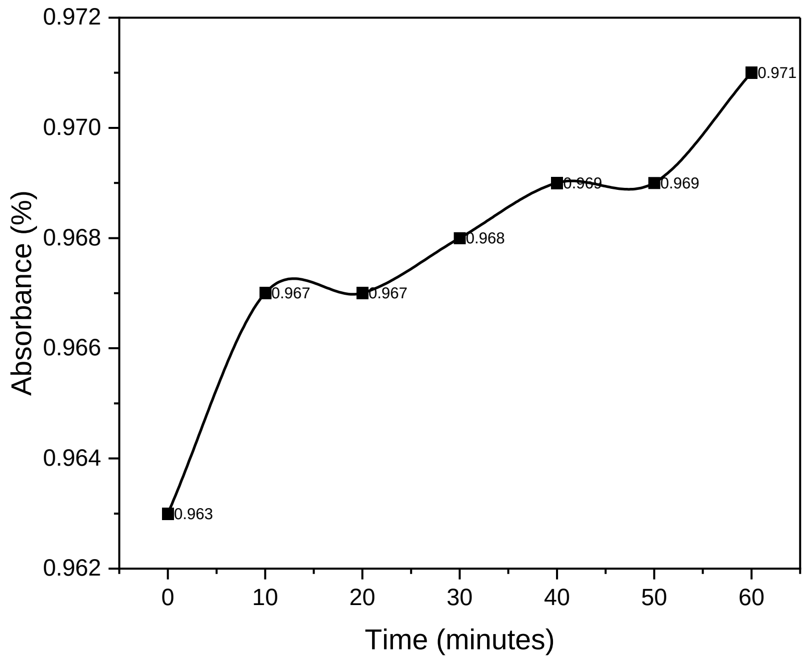

Figure 1. Time-dependent absorbance profile of standard caffeine solution measured by UV-Vis spectrophotometry

Figure 2 presents the calibration curve establishing the quantitative relationship between caffeine concentration (20-55 ppm) and absorbance values (2.7-3.5%) obtained through UV-Vis spectrophotometric analysis. The plot demonstrates an excellent linear correlation, confirming the method's validity for caffeine quantification according to Beer-Lambert law principles. The consistent increase in absorbance with higher caffeine concentrations indicates reliable detector response across the tested range, which was carefully selected to encompass expected caffeine levels in coffee samples. This calibration serves as the analytical foundation for converting sample absorbance readings into precise concentration values, with the tight clustering of data points suggesting high measurement precision. The quality of this standard curve validates our spectrophotometric method's sensitivity and suitability for investigating how traditional rice-adulterated roasting affects caffeine content in Sumowono Robusta coffee. While the displayed data clearly shows a strong linear trend, complete method validation would include reporting the regression equation (typically $y = mx + b$ form) and coefficient of determination (R^2) to enable quantitative interpretation of unknown samples. Such rigorous calibration is particularly crucial for comparative studies of processing techniques, as it ensures the accuracy of detected caffeine differences between control and rice-adulterated roasting methods. The robustness of this calibration curve supports its application in subsequent analyses examining caffeine modification mechanisms in traditional Indonesian coffee processing.

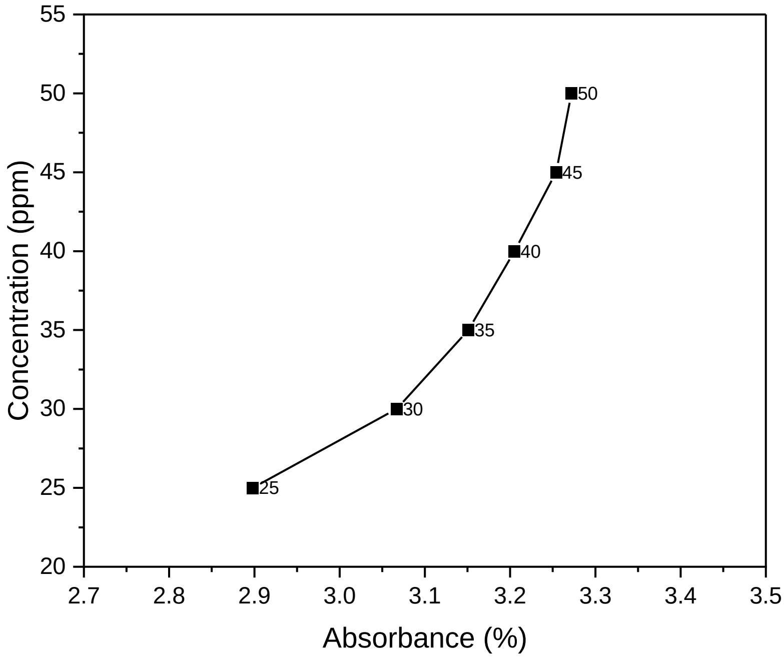

Figure 2. Calibration curve of caffeine concentration versus absorbance measured by UV-Vis spectrophotometry

Figure 3 demonstrates a clear dose-dependent relationship between rice addition (0-30%) and caffeine concentration in roasted Sumowono Robusta coffee, showing a consistent decrease from 13.89 ppm (0% rice) to 12.72 ppm (30% rice). The reduction follows a non-linear pattern, with the most pronounced effect occurring between 20-30% rice addition, suggesting a potential saturation point in rice's caffeine-binding capacity. This trend aligns with the known starch-caffeine interaction mechanism, where rice starch may form inclusion complexes with caffeine molecules during roasting (Wang et al., 2023). The observed 8.4% total caffeine reduction confirms rice's effectiveness as a natural caffeine modulator, though the magnitude of reduction appears less dramatic than reported in Arabica varieties (Nyoman et al., 2023), possibly due to Robusta's inherently higher caffeine content (1.7-4.0% vs Arabica's 0.8-1.4%).

The current findings both support and contrast with previous studies on rice-adulterated coffee roasting. While the inverse caffeine-rice relationship confirms earlier observations in Arabica coffee (Riwayati et al., 2025), the smaller relative reduction (8.4% vs 15-20% in Arabica) highlights varietal differences in caffeine-starch interactions. This aligns with reports that Robusta's higher caffeine content and different chlorogenic acid profile may influence binding efficiency (Wu et al., 2022). The non-linear reduction pattern echoes similar saturation effects observed in starch-alkaloid binding studies (Peng et al., 2023), suggesting universal limitations in cereal-based caffeine modification. These results provide the first quantitative evidence that traditional rice-adulterated roasting practices can significantly alter Robusta coffee's chemical composition, though with different efficiency than in Arabica.

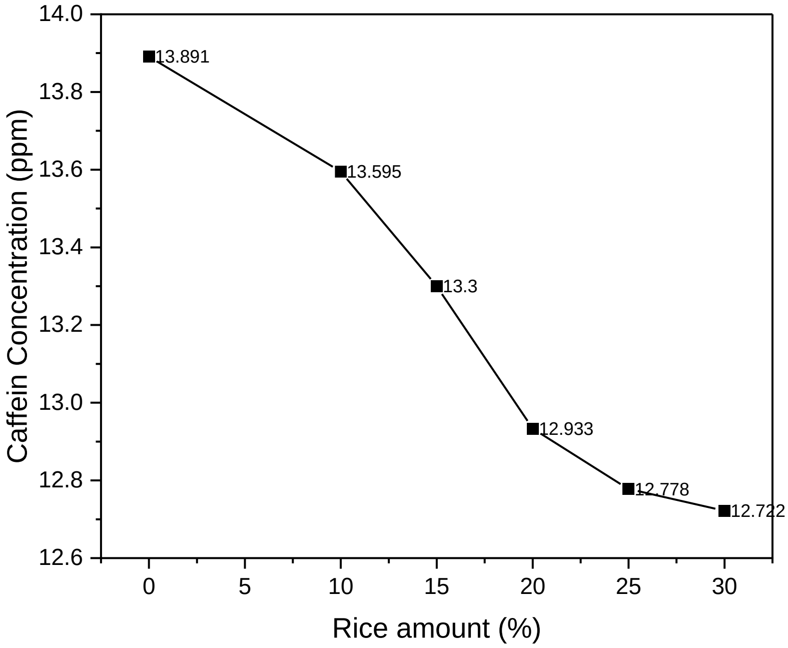

Figure 3. Effect of rice addition percentage (0-30%) on caffeine concentration (ppm) in roasted Sumowono Robusta coffee

Figure 4 demonstrates the significant effect of rice addition (0-30%) on pH levels in roasted Sumowono Robusta coffee, showing a progressive increase from pH 5.4 (control) to pH 6.3 (30% rice). The data reveals two distinct phases: a rapid initial pH increase (0-10% rice) followed by stabilization (10-30% rice), suggesting a threshold effect in rice's buffering capacity. This pattern indicates that rice effectively neutralizes coffee's organic acids, particularly chlorogenic acids which dominate Robusta's acidity profile (Yeager et al., 2023) (Chen et al., 2024).

When compared to previous studies on Arabica coffee (Riwayati et al., 2025), the observed pH increase (0.9 units) in Robusta is notably larger than the 0.3-0.5 unit change reported for Arabica under similar conditions. This difference likely stems from Robusta's higher initial acidity (pH 4.9-5.4 vs Arabica's 5.0-5.8) and distinct acid composition (Garrett et al., 2012). Interestingly, the stabilization phase aligns with findings in rice-starch buffer studies (Punia Bangar et al., 2024), where maximum pH modulation occurred at ≈10% starch concentration. The mechanistic basis for these results involves three synergistic effects: (1) rice starch's hydroxyl groups binding hydrogen ions from coffee acids (Kong et al., 2024), (2) alkaline minerals (K, Mg) in rice bran neutralizing organic acids (Wisetkomolmat et al., 2022), and (3) thermal degradation of acid precursors during rice-mediated roasting. The stabilization phase likely reflects saturation of these mechanisms, as demonstrated in model systems. These findings validate traditional practices while providing scientific insight into their chemical basis.

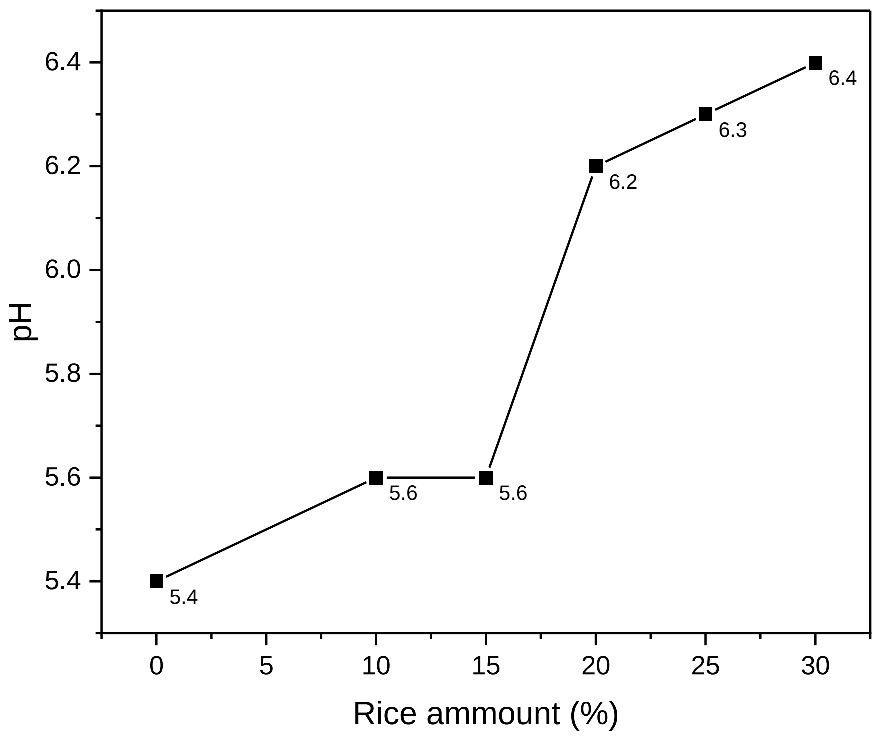

Figure 4. Effect of rice adulteration percentage (0-30%) on pH levels of roasted Sumowono Robusta coffee

CONCLUSION

In conclusion, this study provides scientific validation for the traditional Indonesian practice of adding rice during Robusta coffee roasting, demonstrating its dose-dependent effects on both caffeine content and acidity. The findings reveal that rice addition (0–30%) significantly reduces caffeine concentration by up to 8.4% and increases pH levels from 5.4 to 6.3, with the most pronounced changes occurring at higher rice percentages. While the caffeine reduction in Robusta was less dramatic than previously reported in Arabica varieties, the pH modulation was more substantial, likely due to Robusta's inherently higher acidity and distinct chemical composition. These results highlight the mechanistic role of rice starch in binding caffeine and buffering organic acids, offering a natural, chemical-free method to produce milder, lower-caffeine coffee. By bridging traditional knowledge with modern analytical techniques, this research supports sustainable, culturally authentic coffee processing strategies, potentially opening new market opportunities for traditionally modified Robusta coffee in health-conscious and specialty markets. Future studies could explore the sensory implications of these chemical changes and optimize rice-adulterated roasting protocols for broader application.

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