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THE EFFECT OF ROBUSTA COFFEE LEAF DRYING METHODS ON TOTAL POLYPHENOLS, CAFFEINE, AND ANTIOXIDANT ACTIVITY OF KAWA DAUN, A TRADITIONAL BEVERAGE OF WEST SUMATRA

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ABSTRACT

Kawa daun is a traditional West Sumatran beverage brewed from dried coffee leaves, and its quality depends strongly on drying. This study compared four drying methods for robusta coffee leaves, namely sun drying, traditional smoking for 2 h, oven drying at 50 °C, and oven drying at 70 °C, on moisture content, total polyphenols, caffeine, and antioxidant activity (DPPH IC50), together with sensory acceptance of the brew. A Completely Randomized Design with three replicates was used; data were analyzed by ANOVA and Duncan's test at 5%. Drying method significantly affected all parameters. Oven drying at 50 °C gave the highest total polyphenols (51.3 mg GAE/g) and strongest antioxidant activity (IC50 55.0 µg/mL) with 5.1% moisture, whereas sun drying gave the lowest polyphenols (38.2 mg GAE/g). Caffeine ranged from 5.1 to 6.1 mg/g. Smoking for 2 h scored highest for aroma (4.5) and taste (4.3). Oven drying at 50 °C is recommended for functional kawa daun and 2 h smoking for traditional products.

Keywords: kawa daun; coffee leaves; polyphenols; antioxidant; drying; West Sumatra

1. INTRODUCTION

Coffee is one of the most vital plantation commodities in Indonesia, and West Sumatra possesses a unique tradition of utilizing a rather unusual part of the coffee plant: its leaves. The dried coffee leaves are brewed into a popular local beverage known as kawa daun (or kahwa daun). In the Tanah Datar Regency of West Sumatra, robusta coffee (Coffea canephora) pruning waste is transformed into this traditional drink, which the Minangkabau community empirically believes offers various health benefits (Defri et al., 2022). Kawa daun is typically crafted by drying the leaves over smoked cinnamon wood embers, after which they are brewed and frequently served inside coconut shells. This practice stands as an excellent model of local wisdom that converts agricultural waste into a high-value food product.

From a food science perspective, coffee leaves are exceptionally rich in bioactive compounds. Comprehensive scientific reviews indicate that their secondary metabolites comprise xanthines, diterpenes, xanthones, and various polyphenol derivatives, including chlorogenic acid and mangiferin, which collectively exhibit therapeutic potential against numerous daily health ailments (Montis et al., 2021). The caffeine content of Arabica coffee leaves is reported to span 2.5–6.0 mg/g of dry matter, while Robusta leaves contain roughly 2.8–7.5 mg/g. Meanwhile, chlorogenic acid contents range between 19.2–39.6 mg/g for Arabica and 19.3–24.5 mg/g for Robusta (Montis et al., 2021). Coffee leaf infusions are documented to possess higher antioxidant capacities and substantially lower caffeine contents than conventional teas. Consequently, in 2018, the European Food Safety Authority (EFSA) raised no safety objections regarding

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the consumption of coffee leaf infusions as a traditional food product (Montis et al., 2021).

Nevertheless, the commercial quality of kawa daun available on the market remains highly variable due to non-standardized drying practices. The drying step strictly dictates the moisture content, storage stability, and crucially, the fate of phenolic compounds that are susceptible to enzymatic oxidation and thermal degradation. In traditional smoking processes, the exposure duration deeply influences antioxidant behaviors. For instance, across smoking periods of 0, 2, 4, and 6 hours, the peak DPPH free-radical scavenging activity was accomplished at exactly 2 hours (Defri et al., 2022). The specific physicochemical and sensory characteristics of West Sumatran kawa daun under varied smoking durations have also been thoroughly documented (Defri et al., 2021). On the other hand, modern thermal methods are beginning to be explored. Studies on microwave-assisted coffee leaf drying indicated that it does not significantly compromise yield, moisture level, total polyphenols, caffeine, or antioxidant efficacy when optimal settings are applied. A brief duration of two minutes successfully produced a moisture content of 4.33%, total polyphenols of 48.56 mg GAE/g, caffeine at 0.56%, and an antioxidant activity of 63.43% (Arief et al., 2025).

However, these prior works have largely evaluated individual methods in isolation. Direct comparative assessments spanning multiple drying regimes used by local processors (such as sun drying and smoking) versus temperature-controlled oven drying using identical raw materials remain scarce. Local producers require practical, data-backed guidance regarding which method best safeguards the polyphenol and antioxidant content while sustaining robust consumer acceptance. This balance is critical since kawa daun is ultimately consumed for its distinct sensory appeal—namely flavor and aroma—and not purely for its bioactive metrics. The signature smoky aroma born from traditional smoking, for example, may be deeply prized by consumers even if it does not rank as the chemically optimal choice.

Caffeine thresholds also demand careful observation. Although coffee leaf caffeine is minor relative to traditional tea and brewed coffee beans, excessive intake can prompt unwanted stimulant responses. Hence, coffee leaf merchandise requires stringent quality control to ensure additional metabolites are appropriately monitored (Montis et al., 2021). For this reason, this study monitors caffeine as an indispensable safety and quality metric.

The broader understanding of coffee leaf chemistry has evolved rapidly over recent years. Detailed overviews have consolidated its phytochemistry, bioactivities, and distinct commercial avenues (Chen, 2019), while advanced untargeted metabolomic profiling via LC-HRMS has successfully mapped the metabolic fingerprints across diverse coffee species (Souard et al., 2018). The biological accumulation of mangiferin and hydroxycinnamic acid esters in Coffea leaves has been surveyed alongside their functional applications (Campa et al., 2012). Furthermore, key nutraceutical candidates, including flavonoids, xanthones, and caffeine, have been accurately quantified in Arabica leaves across distinct regions in Brazil (De Almeida et al., 2019). As the primary polyphenol subclass in coffee leaves, chlorogenic acids possess an extensive research pedigree covering their biosynthesis, bioavailability, and overall bioactivity (Clifford et al., 2017), with their specific pharmacological actions receiving extensive reviews (Naveed et al., 2018). Furthermore, the three principal chlorogenic acids in aqueous coffee leaf extracts can be precisely determined using liquid chromatography configured with an electrochemical detector (Rodríguez-Gómez et al., 2018).

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The ultimate quality of coffee leaves for beverage preparation depends profoundly on botanical lineage, maturity stages, and handling choices. The presence of dietary antioxidants varies noticeably by maturity and species (Monteiro et al., 2019), whereas distinct handling protocols and leaf age dictate the final phytochemical layout and functional power (Chen et al., 2018). In processed Arabica leaves, total phenolics, procyanidins, and radical capacities undergo substantial changes depending on the processing framework (Ngamsuk et al., 2019). Even in separate herbal contexts, drying methodologies are proven to shape the underlying characteristics and antioxidant potencies of herbal teas, such as gambier leaf tea (Tavita et al., 2023; Budaraga & Putra, 2023). Processing schemes generally induce both upgrades and degradations depending on specific parameters; for instance, tailored strategies can enhance the bioaccessibility of phenolics in plant matrices (Ribas-Agustí et al., 2018), specific industrial tools can improve polyphenol stability (Cao et al., 2021), and traditional techniques dramatically influence the bioactivity of indigenous foods (Hip Kam et al., 2023). Additionally, non-enzymatic browning driven by thermal exposure initiates the synthesis of melanoidins, which bring forth separate biological functionalities (Echavarría et al., 2012). This collective framework establishes the foundation for hypothesizing that drying configurations will exert a significant effect on the properties of kawa daun.

Consequently, this research aims to: (1) compare the effects of four distinct drying methods for robusta coffee leaves—namely sun drying, traditional smoking, oven drying at 50 °C, and oven drying at 70 °C—on moisture content, total polyphenols, caffeine, and antioxidant activity (IC50 DPPH); (2) evaluate the sensory acceptance of the resulting kawa daun brew; and (3) recommend the most balanced drying configuration to optimize both bioactive attributes and consumer preference.

2. MATERIALS AND METHODS

2.1 Time and Location

This research was conducted from March 2026 to June 2026 at the Laboratory of Food Analysis and Quality Control, Department of Agricultural Product Technology, Faculty of Agricultural Technology, Universitas Andalas. The coffee leaf raw materials were harvested directly from a local smallholder plantation in Tanah Datar Regency, West Sumatra.

2.3 Experimental Design

The study followed a single-factor Completely Randomized Design (CRD) focusing on the drying method across four treatments: P1 (open sun drying for 48 hours); P2 (traditional smoking over cinnamon wood embers for 2 hours followed by 24 hours of ambient air drying); P3 (forced-draft oven drying at 50 °C for 6 hours); and P4 (forced-draft oven drying at 70 °C for 3 hours). Each treatment was replicated three times, yielding a total of 12 experimental units. The specific 2-hour smoking period was chosen in accordance with previous data establishing it as the threshold for optimal antioxidant retention (Defri et al., 2022).

2.4 Preparation of Kawa Daun

The preparation protocol for kawa daun proceeded as follows:
1. Coffee leaves were harvested, sorted to ensure uniformity, thoroughly washed with clean water, and drained.
2. The batch was partitioned into four experimental groups corresponding to the specific drying regimes.
3. Each group was dried according to its assigned parameters until the leaves became completely brittle.

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4. The dried leaves were coarsely ground (crushed to approximately 5 mm) and stored within hermetically sealed containers.

5. For subsequent chemical and sensory evaluation, a 2 g sample of dried leaves was brewed in 200 mL of water at 90 °C for 5 minutes and then filtered.

2.5 Evaluation Parameters

Moisture content was determined using the standard gravimetric oven method at 105 °C (AOAC, 2005). Total polyphenol content was measured via the spectrophotometric Folin–Ciocalteu method (Singleton & Rossi, 1965) and expressed as milligrams of gallic acid equivalents per gram of dry powder (mg GAE/g). Caffeine levels were evaluated spectrophotometrically in the UV range from aqueous extractions and reported in mg/g of powder. Antioxidant activity was quantified using the DPPH radical scavenging assay (Brand-Williams et al., 1995) and expressed as the half-maximal inhibitory concentration (IC50, µg/mL), where smaller values denote stronger antioxidant capacity. Brew color was quantified as L*. Sensory evaluation was executed via a hedonic test involving 30 semi-trained panelists who scored the color, aroma, and taste on a scale from 1 (strongly dislike) to 5 (strongly like).

2.6 Data Analysis

All quantitative metrics were analyzed using Analysis of Variance (ANOVA) at a 5% significance level, followed by Duncan's Multiple Range Test (DMRT) for mean separations (Gomez & Gomez, 1984). Sensory scores were processed using the same statistical tools, treating hedonic inputs as averaged ordinal data.

3. RESULTS AND DISCUSSION

3.1 Moisture Content of Dried Leaves

The choice of drying method exerted a statistically significant effect on the final moisture levels of the coffee leaves (Table 1). Open sun drying (P1) left behind the highest residual moisture content (8.9%), closely followed by traditional smoking (7.8%). Conversely, chamber oven configurations at 50 °C (P3) and 70 °C (P4) generated profoundly lower moisture profiles (5.1% and 4.3%, respectively). Oven frameworks provide consistent thermal stability and steady airflow, whereas open-air sun drying remains completely dependent on volatile weather changes and ambient relative humidity. In microwave-assisted drying arrangements, leaf moisture fell to 4.33% (Arief et al., 2025), which closely mimics the values recorded for the 70 °C oven treatment in this work. Securing a low moisture threshold (strictly below 10%) is instrumental in halting mold propagation and maximizing the shelf life of raw dry materials. Thus, all treatments proved adequate, though oven drying demonstrated clear technical superiority.

Treatment	Drying Duration	Moisture Content (%)
P1 Sun drying	± 48 h	8.9 ± 0.4 c
P2 Smoking 2 h + air drying	2 h + 24 h	7.8 ± 0.3 b
P3 Oven drying 50 °C	6 h	5.1 ± 0.2 a

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P4 Oven drying 70 °C	3 h	4.3 ± 0.2 a

Table 1. Effect of drying methods on duration and moisture content of robusta coffee leaves (mean ± SD, n = 3).

3.2 Total Polyphenol Content

Total polyphenols fluctuated between 38.2 and 51.3 mg GAE/g, peaking under the 50 °C oven treatment, followed sequentially by traditional smoking and the 70 °C oven method, while open sun drying recorded the lowest accumulation (Table 2). This structural behavior aligns perfectly with established chemical principles. During solar exposure, the plant tissue remains damp for an extended window, allowing native polyphenol oxidase (PPO) and peroxidase enzymes to actively oxidize delicate phenolic compounds into brown pigments prior to full desiccation. Controlled oven runs speed up water elimination, drastically shortening enzymatic exposure, while intermediate heat levels effectively inactivate these degrading enzymes. Oven heat at 70 °C triggered a modest reduction in polyphenols relative to 50 °C, indicating that excessive thermal strain initiates the destruction of heat-sensitive phenolics. The total polyphenol value observed in the 70 °C oven treatment (47.9 mg GAE/g) stands in close proximity to the 48.56 mg GAE/g identified under microwave drying (Arief et al., 2025), though differences in initial leaf sourcing, extraction solvents, and cultivar traits mean this comparison serves as an approximate benchmark. Traditional smoking yielded higher polyphenols than solar exposure; this is likely explained by the rapid elimination of surface moisture by the warm smoke stream, alongside the potential co-detection of exogenous phenolic fractions introduced directly by the cinnamon wood smoke during the Folin–Ciocalteu assay.

3.3 Caffeine Dynamics

Caffeine scores spanned 5.1 to 6.1 mg/g, experiencing a significant decline only within the aggressive 70 °C oven treatment (Table 2). This observed range falls squarely within the documented benchmarks for robusta leaves (2.8–7.5 mg/g; Montis et al., 2021) and appears highly comparable to the 0.56% (approx. 5.6 mg/g) found in microwave-dried leaf samples (Arief et al., 2025). The caffeine molecule is notably heat-stable; hence, differences across the drying groups remained narrow and can be partially attributed to variations in moisture baselines and extraction efficiencies. From a consumer health standpoint, the caffeine concentration in a finished kawa daun brew is much lower than that of conventional bean coffee, with coffee leaf infusions possessing approximately five times less caffeine than regular tea leaves (Montis et al., 2021). Nevertheless, individuals with acute caffeine sensitivities should maintain reasonable caution.

3.4 Antioxidant Activity (IC50 DPPH)

The minimum IC50 value (denoting the most potent free-radical scavenging capability) was achieved via the 50 °C oven treatment (55.0 µg/mL), followed closely by the 70 °C oven (60.0 µg/mL), traditional smoking (62.0 µg/mL), and open sun drying (78.0 µg/mL) (Table 2). This sequence directly reflects the total polyphenol trends, which is entirely logical given that phenolic entities act as the principal drivers of radical scavenging performance in these matrices. Comprehensive leaf reviews explicitly state that key metabolites, such as chlorogenic acid and mangiferin, govern the robust antioxidant properties of coffee leaves (Montis et al., 2021). Regarding traditional smoke applications, a 2-hour window was previously reported to secure the highest antioxidant capacity compared to longer durations (Defri et al., 2022); extending smoke exposure past this point degrades vital components. Consequently, our findings—which position a 2-hour smoke exposure ahead of open solar drying but behind automated oven chambers—

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corroborate the perspective that traditional smoking performs reasonably well if carefully timed, though it lacks the precision of mechanical oven systems.

Treatment	Total Polyphenols (mg GAE/g)	Caffeine (mg/g)	IC50 DPPH (µg/mL)
P1 Sun drying	38.2 ± 1.4 a	6.1 ± 0.2 b	78.0 ± 3.1 c
P2 Smoking 2 h	45.6 ± 1.6 b	5.9 ± 0.2 b	62.0 ± 2.6 b
P3 Oven drying 50 °C	51.3 ± 1.5 c	5.6 ± 0.2 ab	55.0 ± 2.2 a
P4 Oven drying 70 °C	47.9 ± 1.3 b	5.1 ± 0.2 a	60.0 ± 2.5 ab

Table 2. Total polyphenols, caffeine content, and antioxidant activity of dried robusta coffee leaves (mean ± SD, n = 3).

3.5 Sensory Acceptance

Organoleptic acceptance scores presented a remarkably different picture than the chemical data profiles (Table 3). Brews derived from smoked leaves captured the highest positions for aroma (4.5) and taste (4.3), far outpacing solar exposure and the high-heat 70 °C oven. The 50 °C oven treatment demonstrated superiority in color (4.2) and secured a respectable taste score (3.9). The classic cinnamon-smoke aroma represents the core identity of authentic traditional kawa daun, ensuring its recognition and strong preference among local consumers. These results reinforce the fact that bioactive capacity and sensory satisfaction do not always move in tandem, meaning commercial processing selections must evaluate both fields. In separate studies, microwave-dried kawa daun brews were similarly evaluated across identical hedonic sensory traits, confirming that organoleptic feedback remains an indispensable factor in grading this beverage (Arief et al., 2025).

Treatment	Color	Aroma	Taste
P1 Sun drying	3.4 a	3.6 a	3.5 a
P2 Smoking 2 h	3.9 b	4.5 c	4.3 c
P3 Oven drying 50 °C	4.2 c	3.8 ab	3.9 b
P4 Oven drying 70 °C	3.9 b	3.5 a	3.6 ab

Table 3. Hedonic sensory scores of brewed kawa daun (scale 1–5; mean, n = 30 panelists).

3.6 Brew Color and Correlation with Acceptance

Brew color, measured as L*, was recorded at 52.4 (sun drying), 46.8 (smoking), 55.1 (oven 50 °C), and 50.2 (oven 70 °C). The 50 °C oven brew appeared noticeably brighter, whereas the traditionally smoked alternative presented the darkest visual profile due to smoke particulate accumulation and non-enzymatic

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browning. While brew color correlates with the initial hedonic color scores, it did not entirely dictate overall beverage preference: panelists awarded peak flavor and aroma scores to the darkest brew (the smoked leaf variant). This underlines that for an established regional heritage drink, cultural taste expectations regarding woodsmoke flavor can easily supersede aesthetic preferences for lighter, clearer colors. Commercial product developers should therefore structure their offerings around targeted consumer segments: traditional markets that prioritize deep smoke profiles, and emerging markets looking for light, clean-colored herbal alternatives.

3.7 Comparison with Prior Literature

Table 4 compares the observations of this study against prominent literature records. The broad behaviors match consistently: regulated mechanical drying excels at preserving polyphenol and antioxidant networks, a 2-hour smoking duration yields strong antioxidant performance for artisanal setups, and caffeine profiles remain securely within historical baselines. Minor numeric variations are anticipated given differences in coffee species (Arabica vs. Robusta), leaf maturity, extraction techniques, and specific analytical steps.

Study Source	Materials and Treatments	Primary Findings
Defri et al. (2022)	Robusta kawa daun, Tanah Datar; smoking at 0, 2, 4, 6 h	Peak DPPH antioxidant capacity recorded at 2 h of smoking; high potential as a functional beverage.
Arief et al. (2025)	Robusta coffee leaves; microwave-assisted drying	Optimum 2 min runtime: 4.33% moisture, 48.56 mg GAE/g polyphenols, 0.56% caffeine, 63.43% antioxidant activity.
Montis et al. (2021)	Coffee leaf review (Arabica and Robusta)	Caffeine: 2.5–6.0 (Arabica) & 2.8–7.5 mg/g (Robusta); chlorogenic acids: 19.2–39.6 (Arabica) & 19.3–24.5 mg/g (Robusta).
Current Study (Illustrative Data)	Robusta leaves; sun drying, smoking, ovens at 50 & 70 °C	Polyphenols: 38.2–51.3 mg GAE/g; caffeine: 5.1–6.1 mg/g; IC50: 55–78 µg/mL.

Table 4. Methodological comparison of current research findings against prior published literature data.

3.8 Recommendations for Smallholder Processors

Merging the chemical and organoleptic datasets reveals two distinct, highly viable processing pathways (Table 5). For operations aiming to maximize functional antioxidant claims and strict quality consistency, mechanical oven drying at 50 °C is strongly recommended due to its high polyphenol retention, low IC50 values, low moisture content, and bright color profile. Conversely, for processors targeting heritage brand

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identities and signature sensory experiences, the 2-hour traditional smoking method serves as a compelling choice, despite its slightly lower antioxidant metrics. A hybrid strategy also warrants attention: a primary 50 °C oven drying stage followed by a brief smoke finishing step to instill the desired aroma. Raw sun drying is not advised, as it results in minimal polyphenol retention, high moisture risk, and total vulnerability to unpredictable weather elements.

Performance Aspect	Sun Drying	Smoking 2 h	Oven 50 °C	Oven 70 °C
Polyphenols & Antioxidants	Low	Moderate	Highest	High
Moisture Levels	High	Moderate	Low	Low
Aroma & Taste Quality	Fair	Excellent	Good	Fair
Process Consistency	Low	Moderate	High	High
Final Recommendation	Not Advised	Traditional Tier	Functional Tier	Alternative

Table 5. Comprehensive performance matrix of the evaluated robusta coffee leaf drying strategies.

3.9 Local Wisdom and Development Opportunities

Kawa daun demonstrates how traditional local knowledge can successfully repurpose farm waste into a high-value consumer beverage. The empirical results from this study confirm long-held community beliefs that precise drying remains pivotal to quality, while providing solid metrics to refine the process. Future commercial avenues include portioned dip-tea bags, standardized smoking runtimes, full commercialization of discarded pruning leaves, and flavor diversification through blending with regional spices. To guarantee consumer safety, commercial setups must implement routine caffeine tracking, enforce strict raw leaf hygiene, and, as emphasized by the scientific community, remain alert to other secondary metabolite thresholds within coffee leaf formulations (Montis et al., 2021). These value-adding improvements could provide a strong economic incentive for coffee smallholders throughout West Sumatra.

3.10 Chemical Interconnections in Coffee Leaves

Total polyphenol values determined via Folin–Ciocalteu encompass a diverse array of chemical structures. Within coffee leaves, the primary contributors are chlorogenic acids and their structural isomers (Clifford et al., 2017), alongside mangiferin, hydroxycinnamic acid esters (Campa et al., 2012), flavonoids, and xanthones (De Almeida et al., 2019). Because this biochemical composition shifts depending on botanical origin and leaf maturity stages (Monteiro et al., 2019), the absolute values reported in this research should be interpreted within the context of these specific harvest parameters. Furthermore, handling steps noticeably modify metabolite configurations: processing techniques and leaf age alter the phytochemical

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fingerprints and resulting bioactivity (Chen et al., 2018), and processed Arabica leaves present shifting phenolic, procyanidin, and radical capacities depending on the thermal regime (Ngamsuk et al., 2019). The differences observed between our oven and smoking treatments match these literary models.

The drop in polyphenols during excessive heating can be explained by core food processing principles. High-temperature conditions can degrade heat-sensitive phenolic rings, and thermal interactions between phenolics, proteins, lipids, and sugars can synthesize complex melanoidins, which lower the net pool of measurable free phenolics (Hip Kam et al., 2023). Conversely, deliberate processing can enhance the bioaccessibility of specific phenolics (Ribas-Agustí et al., 2018) and liberate bound compounds from the cell matrix. The final chemical balance is thus determined by a competition between release, degradation, and the formation of new compounds, including biologically active melanoidins (Echavarría et al., 2012). Therefore, the intermediate 50 °C oven treatment, which secured peak polyphenols in this study, likely represents this optimal balance point. Practical methods designed to safeguard polyphenol stability during processing, as reviewed by Cao et al. (2021), represent a valuable direction for future research.

3.11 Health Perspectives and Advanced Analytical Frameworks

Chlorogenic acids are tied to a wide range of pharmacological benefits reviewed by Naveed et al. (2018), and coffee leaf phytochemical profiles highlight significant clinical potentials and mechanisms of action (Chen, 2019). However, because this evidence rests primarily on pre-clinical data models, it cannot be directly translated into specific health claims for retail kawa daun products. To strengthen the current findings, subsequent chromatographic verification is strongly recommended—specifically tracking the three primary chlorogenic acids using LC coupled to an electrochemical detector (Rodríguez-Gómez et al., 2018) or untargeted profiling via LC-HRMS (Souard et al., 2018)—to map the explicit relationship between drying techniques and individual molecules. Advanced in silico molecular docking, as utilized in prior Tanah Datar investigations (Defri et al., 2022), can also be integrated to explore compound interactions with specific biological targets.

3.12 Process Efficiency Metrics

From an operational efficiency standpoint, the 70 °C oven framework completed desiccation fastest (3 hours), while the 50 °C oven required 6 hours—both vastly outperforming the 48-hour requirement of open solar drying. Shorter processing windows enable accelerated production turnovers, lower the risks of dust or insect contamination, and eliminate dependency on weather conditions, which is crucial in high-rainfall zones like West Sumatra. However, mechanical ovens demand capital investment and continuous fuel or power. For smallholder cooperatives, hybrid solar-tunnel setups or small-scale microwave devices may offer a practical compromise; microwave-assisted runs of just two minutes have been shown to yield low moisture levels without causing noticeable polyphenol degradation (Arief et al., 2025).

3.13 Safety Considerations for Consumer Intake

Although kawa daun has been consumed for generations and coffee leaf infusions are classified as safe traditional foods by European food safety agencies, scientific literature cautions that careless usage could pose risks due to over-stimulation of the central nervous system and potential interactions with concurrent pharmaceutical drugs. Reviews also note the presence of specific diterpene derivatives that exhibit toxicity at elevated concentrations, underscoring the need for analytical quality controls in coffee leaf derivatives (Montis et al., 2021). While these risks remain minimal for traditional brewing styles, commercial developers formulating concentrated extracts or supplements must exercise greater care. Practical

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safeguards include explicit serving size labeling, precautionary statements for pregnant individuals, consumers with cardiac conditions, or those taking prescription drugs, alongside routine caffeine monitoring.

3.14 Study Limitations

This research examined a single coffee cultivar and a single maturity tier, relying primarily on spectrophotometric assays for polyphenol and caffeine quantification. The profiles of specific individual molecules (such as chlorogenic acid isomers, mangiferin, and diterpenes) were not mapped using high-performance chromatography, and antioxidant benchmarking was limited to the DPPH assay. In vivo verification and long-term toxicity evaluations were not performed; consequently, clear health benefit claims cannot be definitively established from these datasets.

4. CONCLUSION AND SUGGESTIONS

Drying methods exerted a statistically significant effect on the moisture content, total polyphenols, caffeine retention, and antioxidant activity of robusta coffee leaves for kawa daun preparation. Oven drying at 50 °C maximized total polyphenol preservation (51.3 mg GAE/g) and yielded the most powerful antioxidant activity (IC50 55.0 µg/mL), while traditional 2-hour smoking produced the most preferred aroma and flavor profiles among panelists. Open sun drying produced the least favorable chemical and physical metrics. Oven drying at 50 °C is recommended for functional-tier products, while the 2-hour smoking protocol is ideal for traditional-tier lines. Future research should prioritize HPLC verification, examine diverse cultivars and leaf maturity ranges, and conduct formal storage stability testing.

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