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Response Surface Optimization of Drying Conditions for Processing Apa' Leaves (*Albertisia papuana* Becc.) as a Plant, Based Natural Flavoring Ingredient

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Abstract. *Optimizing drying conditions while preserving quality attributes remains a key challenge in developing plant-based natural flavorings. This study aimed to determine suitable drying conditions for Albertisia papuana Becc. (Apa') leaves by evaluating the effects of drying temperature and time on moisture, ash, crude protein, and glutamic acid contents. Drying experiments were performed using Response Surface Methodology (RSM) with a Central Composite Design (CCD) at drying temperatures of 50–70 °C and times of 6–10 h. Moisture, ash, crude protein, and glutamic acid were analyzed as response variables. Drying temperature and time significantly affected moisture content ($p < 0.05$), but their effects on ash, crude protein, and glutamic acid were not statistically significant within the investigated range. The desirability function suggested drying at approximately 60–62 °C for 8 h as a practical operating condition for reducing moisture while maintaining the measured quality attributes. Under these conditions, moisture content was approximately 3.4–3.5%, while ash (6.0–6.2%), crude protein (20.4–20.6%), and glutamic acid (1.24–1.28 mg g^{-1} dry weight) remained within the observed experimental ranges. Moisture and ash contents met the Indonesian National Standard for dried spices (SNI 01-4273-1996). Overall, moderate drying conditions effectively reduce moisture while preserving nutritional quality, providing a scientific basis for processing A. papuana leaves as a plant-based natural flavoring.*

Keywords: *Albertisia papuana*; *drying; response surface methodology; crude protein; glutamic acid.*

Type of the Paper: Regular Article.

1. Introduction

Consumer demand for convenient, safe, and clean-label food products has accelerated the search for natural alternatives to synthetic additives. Flavor enhancers are widely used to improve food palatability, with monosodium glutamate (MSG) being one of the most common compounds because of its characteristic umami taste. Although several studies have suggested links between excessive MSG intake and metabolic disturbances, the evidence remains inconsistent, particularly in humans. Many reported adverse effects were observed under experimental conditions using doses higher than typical dietary consumption. Consequently, MSG is generally recognized as safe when consumed within acceptable intake levels [1-5]. Nevertheless, increasing consumer preference for clean-label products has encouraged interest in plant-based natural flavoring ingredients as sustainable alternatives to synthetic additives. Recent studies show that numerous

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edible plants contain naturally occurring umami-related compounds—including free amino acids and minerals—that contribute to desirable flavors and offer considerable potential as natural flavorings [6,7]. Advances in food processing especially drying, play a key role in preserving these compounds while improving product stability and shelf life [7].

One promising indigenous plant is *Albertisia papuana* Becc., locally known as Apa' leaf, which the Dayak community in Kalimantan has long used as a traditional culinary flavoring. The leaves are commonly added directly to soups and vegetable dishes to enhance aroma and savory taste without extensive processing. *A. papuana* grows naturally in secondary forests, logged-over areas, riverbanks, and lowland regions of Kalimantan at elevations up to approximately 600 m above sea level, particularly on red-yellow podzolic soils [8]. Because of its abundance, simple use, and cultural acceptance, this species represents a promising local resource for developing sustainable plant-based natural flavoring while supporting biodiversity conservation, food sovereignty, and rural livelihoods [8,9].

Earlier work has shown that *A. papuana* leaves have a potential as a natural MSG alternative, based on both traditional culinary use and preliminary chemical analysis. Recent investigations have identified several umami-related compounds in the leaves, particularly free amino acids such as glutamic acid and aspartic acid, along with naturally occurring minerals that contribute to their characteristic umami taste [10]. Among these compounds, glutamic acid is widely recognized as the main contributor to umami in plant-derived flavorings and is often used as a chemical indicator of umami potential. Although 5′-nucleotide compounds like guanosine monophosphate (GMP) and adenosine monophosphate (AMP) can enhance umami perception through synergistic interactions with glutamic acid, their measurement was beyond the scope of this study.

Despite these promising attributes, Apa' leaves are still mostly used fresh in traditional cooking without standardized postharvest processing, which limits their shelf life, chemical stability, and commercial utilization. Drying is a key preservation technique because it reduces moisture content, prevents microbial growth, improves storage stability, and slows chemical deterioration. However, inappropriate drying can also accelerate the degradation of quality-related compounds and reduce the functional properties of plant-derived ingredients [7,11]. Therefore, selecting appropriate drying conditions is essential for preserving product quality while extending shelf life.

Response Surface Methodology (RSM) is a widely used statistical tool for optimizing food processing operations because it can simultaneously assess the effects and interactions of multiple variables while reducing the number of experiments needed [12,13]. Numerous studies have applied RSM to optimize drying conditions for medicinal herbs, spices, fruits, and aromatic plants. However, most of these studies have primarily focused on drying efficiency or single quality

attributes, with little attention given to indigenous plants intended specifically as natural flavorings. Furthermore, no published study has used RSM to establish scientifically optimized drying conditions for *A. papuana* leaves by jointly evaluating moisture content, ash, crude protein content, and glutamic acid as integrated quality indicators. This gap matters because drying conditions directly affect product stability and chemical quality—both critical for the future commercialization of plant-based natural flavorings.

The novelty of this study lies in applying RSM to optimize drying conditions of an underutilized indigenous plant while integrating multiple quality attributes—moisture, ash, crude protein, and glutamic acid—to establish scientifically based drying parameters for *A. papuana* leaves. Unlike earlier studies that mainly focused on drying efficiency or single quality parameters, this study offers a comprehensive evaluation of drying conditions to support the development of standardized postharvest processing for this traditional plant-based natural flavoring.

The quality of dried Apa' leaves was evaluated using moisture content, ash content, crude protein content, and glutamic acid concentration. Moisture content indicates storage stability, while ash content reflects the total mineral residue after combustion. Crude protein serves as a nutritional quality parameter, and glutamic acid is the main chemical indicator for umami characteristics in plant-derived flavorings. Simultaneous evaluation of these quality attributes provides a more comprehensive assessment of drying performance than moisture reduction alone.

This study aimed to optimize the drying temperature and time of *Albertisia papuana* Becc. leaves using Response Surface Methodology (RSM) to identify conditions that reduce moisture content while preserving the measured quality attributes. The findings offer a scientific foundation for standardized postharvest processing and support the future development of *A. papuana* as a sustainable plant-based natural flavoring.

2. Materials and Methods

2.1. Research Materials

Fresh Apa' leaves collected from a secondary forest in Mansalong District, Nunukan Regency, North Kalimantan, Indonesia, were the main material for this study. The plant is locally known as Apa' and has long been used by the Dayak community as a natural flavor enhancer. The scientific name, *Albertisia papuana* Becc., follows the taxonomic description by Forman (1986) in *Flora Malesiana* and the currently accepted nomenclature in Plants of the World Online [10]. Analytical-grade chemicals and reagents, used in this study, included concentrated sulfuric acid (95–98%, Darmstadt, Germany), copper sulfate pentahydrate (Darmstadt, Germany), potassium sulfate (Darmstadt, Germany), sodium hydroxide pellets (Darmstadt, Germany), boric acid (Darmstadt, Germany), standardized hydrochloric acid solution (0.1 N, Darmstadt, Germany),

0.5% ninhydrin reagent (Sigma,Aldrich, St. Louis, MO, USA), L,glutamic acid standard (≥99%, Sigma,Aldrich, St. Louis, MO, USA), and distilled water**.**

2.2. Research Procedure

The experimental procedure consisted of three stages: 1) sorting, weighing, and washing of *Apa'* leaves; 2) drying treatment according to specified conditions; and 3) analysis of moisture levels, ash composition, crude protein content, and glutamic acid concentration.

2.3. Drying Process of Apa' Leaves

Drying temperature and time were selected based on preliminary experiments. Preliminary trials evaluated temperatures of 20, 40, and 60 °C with drying times of 2, 4, and 6 h. Drying at 60 °C for 6 h provided better retention of crude protein and glutamic acid while achieving satisfactory moisture reduction than lower temperatures. Therefore, the optimization was centered at 60 °C, and the experimental ranges of 50–70 °C and 6–10 h were selected to investigate conditions below and above this center point. Temperatures above 70 °C were excluded because excessive heat may accelerate thermal degradation of heat-sensitive compounds and reduce product quality [14,15].

2.4. Experimental Design of Apa' Leaf Drying Using Response Surface Methodology (RSM)

The drying process was optimized using Response Surface Methodology (RSM) with a Central Composite Design (CCD) generated in Design,Expert® software version 13 (Stat,Ease Inc., Minneapolis, MN, USA). Two independent variables were investigated: drying temperature (X_1) and drying time (X_2). The experimental ranges (50–70 °C and 6–10 h) were selected based on preliminary experiments, which showed that drying at 60 °C provided better protein and glutamic acid retention with satisfactory moisture reduction. Therefore, 60 °C and 8 h were selected as the center point of the design. The CCD comprised four factorial points, four axial points ($\alpha = \pm 1.414$), and five center points, resulting in 13 randomized experimental runs. The experimental data were fitted to the following second-order polynomial model (Eq. 1):

$$Y = \beta 0 + \beta 1 X1 + \beta 2 X2 + \beta 12\, X1\, X2 + \beta 11\, X_1^2 + \beta 22\, X_2^2 + \epsilon \quad (1)$$

where *Y* is the predicted response; β_0 is the intercept; β_1 and β_2 are the linear coefficients; β_{12} is the interaction coefficient; β_{11} and β_{22} are the quadratic coefficients; X_1 and X_2 are the actual (uncoded) independent variables for drying temperature (°C) and drying time (h), respectively; and ε is the random error. Model significance and adequacy were evaluated using analysis of variance (ANOVA), the coefficient of determination (R^2), adjusted R^2, predicted R^2, the lack-of-fit test, and residual analysis. The optimum drying conditions were identified using the numerical optimization function based on the desirability approach.

2.5.Moisture Content Analysis

Moisture content was measured using the thermogravimetric approach, based on mass reduction from water evaporation during heating at a constant temperature [16]. Approximately

2g of dried *Apa'* leaf sample was weighed using an analytical balance, placed in an aluminum dish, and inserted into a thermogravimetric oven (moisture analyzer). Drying was carried out at 105 °C until a constant mass reached. Moisture content was calculated from the difference between the initial and final sample masses and reported as a percentage (%) [17]. The formula used to calculate moisture can be found in Eq. (2).

$$\text{Moisture Content (\%)} = \frac{W1-W2}{W1} X\ 100\ \% \quad (2)$$

Explanation
W_1 = pre-drying sample weight (g)
W_2 = post-drying sample weight (g)

2.6. Ash Content Analysis

Ash content was determined by the dry ashing method according to AOAC Official Method 923.03, following the procedure described by Fayyaz et al. [18] Approximately 2.0 g of dried Apa' leaf powder was weighed into a pre-weighed, previously ignited porcelain crucible. The sample was first charred on a hot plate to minimize spattering, then incinerated in a muffle furnace at 550 °C for 4–6 h, until a light grayish-white ash was obtained, indicating complete combustion of organic matter. After cooling in a desiccator for about 30 min, the crucible was reweighed until a constant mass was reached. Ash content was calculated as the percentage of ash weight relative to the initial dry sample weight using Eq. (3).

$$\text{Ash Content (\%)} = \frac{W1-W2}{Ws} X\ 100\ \% \quad (3)$$

Explanation
W_1 = weight of the empty porcelain crucible (g)
W_2 = weight of the porcelain crucible with ash (g)
W_s = initial dry sample weight (g)

2.7. Crude Protein Content Analysis

Crude protein content was determined using the Kjeldahl method according to AOAC Official Method 2001.11 [19]. This method was selected because crude protein served as a supporting proximate composition parameter for evaluating changes in the chemical composition of Apa' leaves during drying. Approximately 0.5 g of dried leaf powder was digested with concentrated H_2SO_4 in the presence of a K_2SO_4–$CuSO_4$ catalyst until a clear solution was obtained. After dilution, the digest was distilled after adding 40% NaOH, and the released ammonia was collected in 4% boric acid containing mixed indicators before titration with standardized 0.1 N H_2SO_4. Total nitrogen was calculated from the titration volume and converted to crude protein using a nitrogen-to-protein conversion factor of 6.25. Because the Kjeldahl method measures total nitrogen, the reported values represent crude protein rather than true protein and may include nitrogen from non-protein compounds [19,20].

Crude protein content was calculated using Eq. (4) as follows:

$$\text{Crude Protein (\%)} = \frac{(Vs-Vb)x\ N\ x\ 14{,}007\ x6{,}25}{W\ x\ 1000} \text{ x } 100 \quad (4)$$

Explanation
V_s = volume of H_2SO_4 used for sample titration (mL)
V_b = volume of H_2SO_4 used for blank titration (mL)
N = normality of H_2SO_4
14,007 = atomic weight of nitrogen
6,25 = nitrogen-to-protein conversion factor
W = sample weight (g)

2.8. Glutamic Acid Analysis

Free amino acids, expressed as L,glutamic acid equivalents, were determined using a ninhydrin-based colorimetric method coupled with UV–Vis spectrophotometry. Approximately 1g of dried Apa' leaf powder was extracted with 50 mL of distilled water at 25–30 °C for 15 min under continuous stirring and filtered through Whatman No. 1 filter paper. An aliquot (1 mL) of the filtrate was mixed with 1 mL of 0.1% (w/v) ninhydrin solution prepared in ethanol, heated in a water bath for 5 min, cooled, and the absorbance was measured at 570 nm using a UV,1900i UV–Vis spectrophotometer (Shimadzu Corporation, Kyoto, Japan**)**. A calibration curve was prepared using L,glutamic acid standards (5–50 mg L^{-1}) treated under identical conditions. Free amino acid concentration was calculated from the calibration equation, corrected for extraction and dilution factors, and expressed as mg L,glutamic acid equivalents g^{-1} dry sample. All measurements were performed in duplicate and reported as mean ± standard deviation Eq. (5). [21,22]:

$$A = aC + b \quad (5)$$

The concentration of L,glutamic acid equivalents in the sample extract was then calculated using Eq. (6).

$$\text{Glutamic acid (mg g ,1)} = \frac{C\ x\ V\ x\ DF}{m\ x\ 1000} \quad (6)$$

where (A) is the sample absorbance at 570 nm; (C) is the concentration obtained from the calibration curve (mg L^{-1}); (a) is the slope of the calibration curve; (b) is the intercept; (V) is the total extraction volume (50 mL); (DF) is the dilution factor; and (m) is the dry sample mass (1 g).

2.9. Statistical Analysis

The experimental data were analyzed using MINITAB Release 14 (Minitab Inc., State College, PA, USA). Response Surface Methodology (RSM) with a Central Composite Design (CCD) was used to develop second-order polynomial models describing the effects of drying temperature and time on the measured responses. Three-dimensional response surface and contour plots were generated using Design,Expert® version 7.0 (Stat,Ease Inc., Minneapolis, MN, USA).

The significance of the regression model and individual model terms was evaluated by analysis of variance (ANOVA) at a significance level of $p < 0.05$**.** Model adequacy was assessed using the coefficient of determination (R^2), adjusted R^2, predicted R^2, and the lack-of-fit test.

3. Results and Discussion

The experiments result for moisture content, crude protein content, and glutamic acid concentration are presented in Table 1.

Table 1. Moisture, ash, crude protein, and glutamic acid content of dried Apa' leaves under different drying conditions.

Run	Symbol	Temperature (°C)	Time (h)	Moisture content (%)	Ash content (%)	Crude protein content (%)	Glutamic acid (mg g^{-1} dry weight)
1	P1	50	6	5.78 ± 0.81	5.8 ± 0.64	20.3 ± 0.07	1.35 ± 0.10
2	P2	70	6	3.95 ± 0.33	6.2 ± 0.07	19.1 ± 0.20	1.10 ± 0.16
3	P3	50	10	4.74 ± 0.23	6 ± 0.07	20.8 ± 0.40	1.42 ± 0.08
4	P4	70	10	3.46 ± 0.35	6.5 ± 0.17	18.5 ± 0.76	0.95 ± 0.11
5	P5	45.86	8	4.65 ± 0.57	5.6 ± 0.49	20.8 ± 0.49	0.88 ± 0.24
6	P6	74.14	8	3.02 ± 0.21	6.6 ± 0.21	21.4 ± 0.40	1.50 ± 0.33
7	P7	60	5.17	5.94 ± 0.27	6 ± 0.17	19.9 ± 1.63	1.20 ± 0.21
8	P8	60	10.83	3.62 ± 0.27	6.3 ± 0.21	20.2 ± 0.42	1.18 ± 0.04
9	P9	60	8	3.46 ± 0.28	6.1 ± 0.31	20.6 ± 0.21	1.25 ± 0.08
10	P10	60	8	3.44 ± 0.16	6.1 ± 0.49	20.5 ± 0.78	1.27 ± 0.03
11	P11	60	8	3.56 ± 0.23	6 ± 0.16	20.6 ± 0.64	1.26 ± 0.08
12	P12	60	8	3.65 ± 0.51	6.1 ± 0.18	20.4 ± 0.21	1.28 ± 0.27
13	P13	60	8	3.84 ± 0.38	6.2 ± 0.14	20.5 ± 0.78	1.24 ± 0.01

Based on Table 1, moisture content ranged from 3.02 ± 0.21% (P6, 74.14 °C for 8 h) to 5.94 ± 0.27% (P7, 60 °C for 5.17 h). Ash content ranged from 5.60 ± 0.49% (P5, 45.86 °C for 8 h) to 6.60 ± 0.21% (P6, 74.14 °C for 8 h). All treatments remained below the maximum ash content limit of 7%, indicating that the dried Apa' leaf samples met the applicable quality standard.

Crude protein content ranged from 18.50 ± 0.76% (P4, 70 °C for 10 h) to 21.40 ± 0.40% (P6, 74.14 °C for 8 h). Glutamic acid content ranged from 0.88 ± 0.24 mg g^{-1} dry weight (P5, 45.86 °C for 8 h) to 1.50 ± 0.33 mg g^{-1} dry weight (P6, 74.14 °C for 8 h). The center-point treatments (60 °C for 8 h) showed relatively consistent glutamic acid contents, ranging from 1.24 ± 0.01 to 1.28 ± 0.27 mg g^{-1} dry weight, indicating good experimental reproducibility.

3.1. Moisture Content

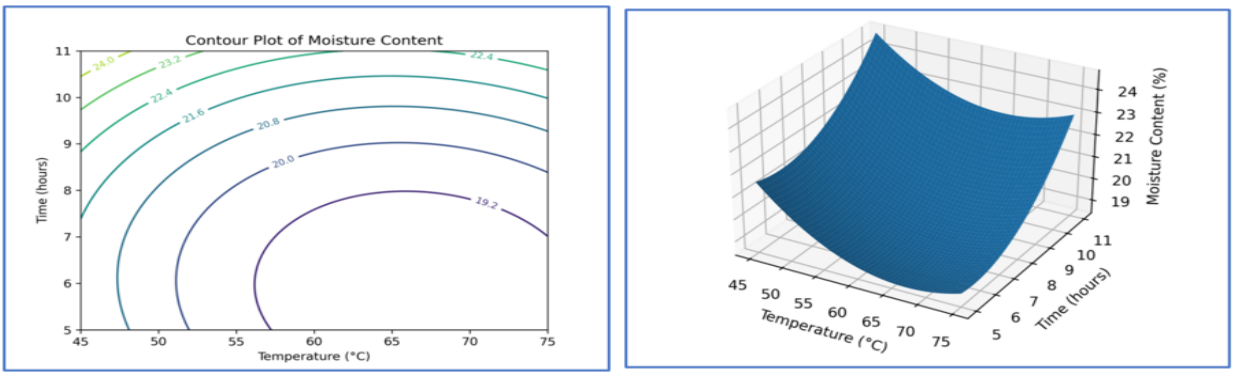
Moisture content ranged from 3.02 ± 0.21% (P6, 74.14 °C for 8 h) to 5.94 ± 0.27% (P7, 60 °C for 5.17 h). Most treatments met the Indonesian National Standard for dried spices (SNI ≤ 4%), except for P1 and P7. The quadratic regression model was statistically significant ($p = 0.002$) with a non-significant lack of fit ($p = 0.18$), indicating good model adequacy. Drying time had the strongest effect on moisture reduction ($p = 0.001$), followed by its quadratic effect ($p = 0.0008$); temperature had a moderate influence, and the interaction term was not significant.

The model showed satisfactory predictive capability ($R^2 = 0.91$. adjusted $R^2 = 0.86$. predicted $R^2 = 0.79$), consistent with Alim et.al [23], who reported that RSM effectively predicted moisture changes during *Moringa oleifera* leaf drying. The highest moisture content at the intermediate temperature but shortest drying time indicates that drying time was more influential than temperature, as insufficient drying duration limited internal moisture diffusion during the falling rate period—a trend also reported by Thanh et al. [24]. The fitted second-order polynomial model Eq. (1) was:

$$Y = 52.31 - 0.842X_1 - 1.965X_2 + 0.0048X_1X_2 + 0.0061X_1^2 + 0.142X_2^2$$

where Y is the predicted moisture content (%), X_1 is drying temperature (°C), and X_2 is drying time (h).

The negative linear coefficients indicate that increasing drying temperature and time reduced moisture content, while the positive quadratic coefficients reflect the nonlinear behavior of moisture diffusion as drying progressed. Similar nonlinear responses have been reported for *Moringa oleifera* leaf drying by Adekanye et al. [25].



(a) (b)

Fig. 1. Countour (a) and three-dimentional response surface (b) plots showing the effects of drying temperature and time on moisture content (%).

The contour and three-dimensional response surface plots (Fig. 1) showed that moisture content decreased progressively with increasing drying temperature and time. The optimum region was identified at approximately 60–65 °C and 8–9 h, with a predicted moisture content below 3.5%, meeting the Indonesian National Standard (SNI) for dried seasoning products. The elliptical

contour pattern indicates that both variables contributed to moisture reduction, although drying time exerted the stronger influence. At drying times shorter than 6 h, increasing temperature alone was insufficient to achieve the target moisture level, whereas extending drying time beyond 8 h markedly improved moisture removal. Similar response surface characteristics were reported by Widyasanti et al. [26], while Siqhny et al. [27] likewise showed that moisture diffusion became the controlling mechanism during the later drying stage. Numerical optimization predicted an optimum condition of 61.2 °C for 8.6 h, yielding a moisture content of 3.12% with an overall desirability of 0.95, confirming that moderate temperatures combined with sufficient drying duration provide efficient drying while minimizing thermal degradation.

3.2. Ash Content

Ash content varied only slightly across treatments, ranging from 5.60 ± 0.49% to 6.60 ± 0.21%. The quadratic regression model was statistically significant ($p < 0.05$) with a satisfactory coefficient of determination ($R^2 = 0.936$); however, the individual linear and interaction effects of drying temperature and time were not statistically significant ($p > 0.05$), indicating that ash content was less sensitive to drying conditions than moisture content.

Ash content is a proximate parameter representing the total inorganic residue after complete combustion rather than the concentration of individual mineral elements. Therefore, the measured values should be interpreted as indicators of the overall inorganic fraction. Similar values were reported by Hossain et al. [28], who noted that proximate ash analysis estimates total mineral residue but cannot identify specific mineral constituents without elemental analysis.

The relatively narrow ash content range suggests that drying temperature and duration had minimal influence on the inorganic fraction of Apa' leaves. Slight increases in ash percentage were likely associated with moisture removal rather than changes in mineral composition, consistent with findings by Nainggolan et al. [29] and Ullah et al. [30], who reported that hot-air drying substantially affected moisture content while producing only minor changes in ash content because inorganic constituents are generally resistant to thermal degradation. The fitted second-order polynomial model (Eq.1) was:

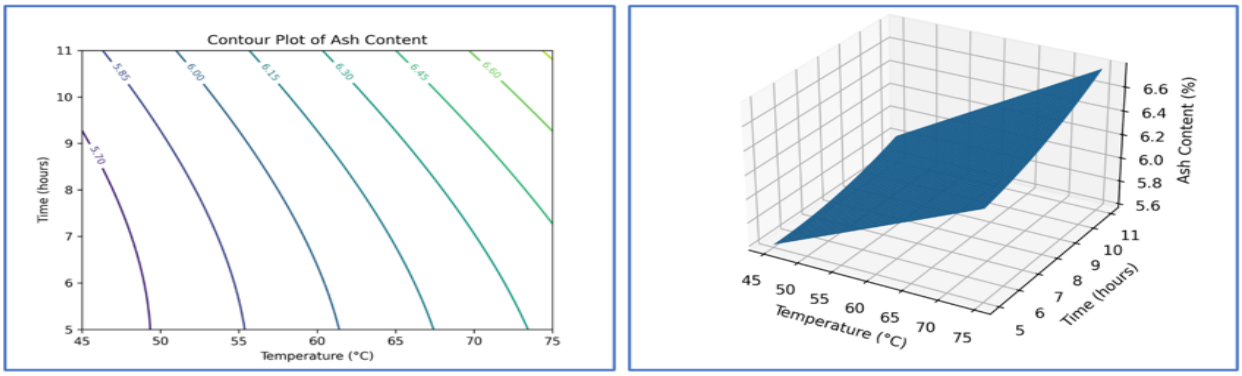
$$Y = 4.902 + 0.0189X_1 - 0.1172X_2 + 0.012X_1X_2 + 6.95 \times 10^{-8} X_1^2 + 0.0062X_2^2$$

where Y is the predicted ash content (%), X_1 is drying temperature (°C), and X_2 is drying time (h).

The small regression coefficients further confirm that drying temperature and time exerted only minor effects on ash content, consistent with previous RSM studies on herbal leaf drying [31]. The three-dimensional response surface plot illustrating this relationship is shown in Fig. 2.

The contour and three-dimensional response surface plots (Fig. 2) showed a relatively flat surface with widely spaced contour lines, indicating that drying temperature and drying time had only minor effects on ash content. The predicted optimum region was approximately 60–65 °C

and 8–9 h, corresponding to an ash content of about 6.2%, which remained below the maximum limit specified by the Indonesian National Standard (SNI 01.4273.1996. ≤7%). The absence of pronounced curvature is consistent with the non-significant interaction term in the quadratic model, indicating weak interaction between the two drying variables. Similar response surface characteristics were reported by Widyasanti et al. [26] during CCD-RSM optimization of kaffir lime leaf drying.



(a) (b)

Fig. 2. Contour (a) and three-dimensional response surface (b) plots showing the effects of drying temperature and time on ash content (%).

The limited variation in ash content indicates that the investigated drying conditions did not substantially affect the inorganic fraction of Apa' leaves. Consequently, drying optimization can primarily focus on moisture reduction while maintaining acceptable ash quality. Similar findings were reported by Oliveira-Alves et al. [32], who observed that ash content in dried leafy materials remained relatively stable across drying treatments. Overall, all treatments produced ash contents below the SNI limit, confirming that ash content remained a stable supporting quality parameter during the drying process.

3.3. Crude Protein Content

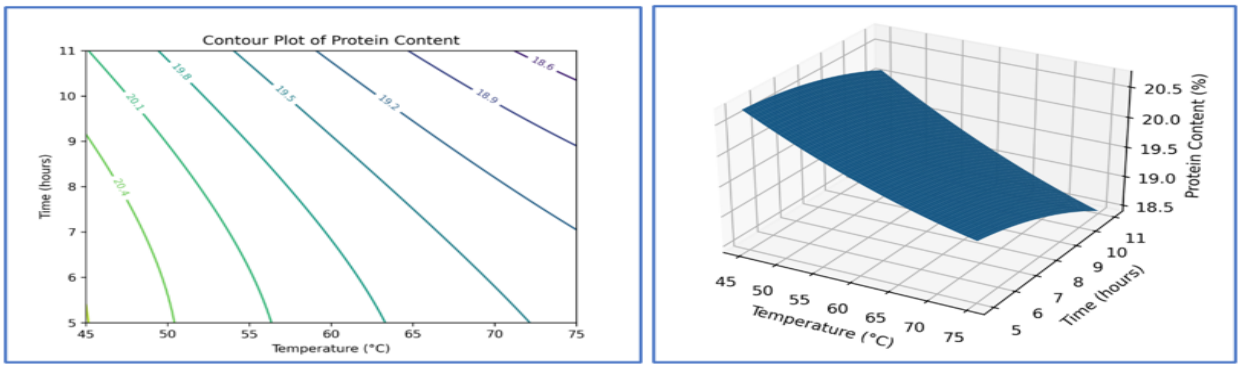
Crude protein content, determined by the Kjeldahl method, ranged from 18.50 ± 0.76% to 21.40 ± 0.40%, showing only slight variation among drying treatments. Because the Kjeldahl method measures total nitrogen, the reported values represent crude protein rather than true protein. The quadratic regression model was not statistically significant ($p > 0.05$) and exhibited a low coefficient of determination ($R^2 = 0.407$) with a negative adjusted R^2, indicating that the model did not adequately explain the variability in crude protein content. Likewise, none of the linear, quadratic, or interaction terms significantly affected crude protein content, suggesting that drying temperature and time had minimal influence on this parameter.

The observed stability agrees with previous studies showing that hot-air drying primarily removes moisture while causing only limited changes in crude protein content, as thermal treatment mainly induces protein denaturation or conformational changes without substantially

altering total nitrogen measured by the Kjeldahl method [33-36]. The fitted second-order polynomial model (Eq. 1) was:

$$Y=23.87 - 0.102X_1 + 0.214X_2 - 0.0201X_1X_2 + 0.00058X_1^2 - 0.0137X_2^2$$

where X_1 is drying temperature (°C) and X_2 is drying time (h). However, because the overall regression model was not statistically significant, this equation is presented for completeness and should not be interpreted as a predictive model for optimizing crude protein content. The three-dimensional response surface plot illustrating these effects is shown in Fig. 3.



(a) (b)

Fig. 3. Contour (a) and three-dimensional response surface (b) plots showing the effects of drying temperature and time on crude protein content (%).

The contour and three-dimensional response surface plots (Fig. 3) showed relatively flat surfaces without a distinct optimum region, indicating that drying temperature and time had minimal effects on crude protein content. These plots are presented only as visual representations of the experimental responses, consistent with the ANOVA results showing that crude protein was not a sensitive response variable under the investigated drying conditions. Nevertheless, the stability of crude protein indicates that the applied drying process preserved the overall nitrogenous fraction of Apa' leaves, allowing drying optimization to focus primarily on moisture reduction while maintaining crude protein quality.

3.4. Glutamic Acid

Glutamic acid is one of the principal free amino acids contributing to the umami taste of plant-derived foods, although umami perception results from its synergistic interaction with other free amino acids, peptides, and flavor-enhancing nucleotides [37,38]. In this study, glutamic acid was used as an indicator of umami-related quality. Using the ninhydrin spectrophotometric method, glutamic acid content ranged from 0.88 ± 0.24 to 1.50 ± 0.33 mg g^{-1} dry weight, indicating moderate variation among drying treatments.

The quadratic regression model was not statistically significant ($p > 0.05$) and showed a low coefficient of determination ($R^2 = 0.082$). Likewise, none of the linear, quadratic, or interaction terms significantly affected glutamic acid content, suggesting that drying temperature and time had minimal influence on glutamic acid retention within the investigated range. Similar findings

have been reported for leafy vegetables and medicinal plants, where moderate hot-air drying preserved free amino acids despite substantial moisture reduction, as the applied temperatures were insufficient to induce extensive thermal degradation or Maillard reactions [34,39]. For completeness, the fitted second-order polynomial model (Eq.1) was:

$$Y=1.26+0.33X_1-0.21X_2+0.06X_1X_2-0.13X_1^2-0.09X_2^2$$

where X_1 is drying temperature (°C) and X_2 is drying time (h). However, because the regression model was not statistically significant, this equation is presented only for completeness and should not be used as a predictive model for optimizing glutamic acid content.

3.5. Multi-Response Optimization of Moisture, Ash, Crude Protein, and Glutamic Acid Conten

The desirability function approach within Response Surface Methodology (RSM) was applied to identify drying conditions that reduced moisture content while maintaining acceptable values of ash, crude protein, and glutamic acid. Because only the moisture response produced a statistically significant regression model, moisture content was considered the primary optimization response, while ash, crude protein, and glutamic acid were included as quality constraints to verify that the selected drying conditions did not adversely affect overall product quality.

The optimization suggested drying conditions of approximately 60–62 °C for 8 h as a practical guide, corresponding to a predicted moisture content of approximately 3.4–3.5%, while ash (6.0–6.2%), crude protein (20.4–20.6%), and glutamic acid (1.24–1.28 mg g^{-1} dry weight) remained within the experimentally observed ranges. Moisture and ash contents also met the Indonesian National Standard for dried spices (SNI 01.4273-1996), which specifies maximum moisture and ash contents of 12% and 7%, respectively.

The overall desirability value (0.85–0.90) suggests that these drying conditions provide a practical compromise between effective moisture reduction and preservation of important quality attributes. However, because the regression models for ash, crude protein, and glutamic acid were not statistically significant, the optimization results should be interpreted primarily as guidance for process selection rather than as precise predictive optima. Similar recommendations have been reported in previous drying optimization studies, where moisture served as the principal optimization response while nutritional attributes were evaluated to confirm quality retention [40,26].

Overall, the selected drying conditions offer a practical balance between drying efficiency and product quality, supporting the production of plant-based natural flavor enhancers while preserving important nutritional characteristics.

4. Conclusion

This study showed that drying temperature and time significantly affected the moisture content of *Albertisia papuana* leaves, while ash, crude protein, and glutamic acid contents were not significantly influenced within the investigated range. These findings indicate that moderate drying conditions effectively reduce moisture while preserving the measured nutritional quality attributes. The desirability function suggested drying at approximately 60–62 °C for 8 h as a practical compromise between moisture reduction and quality retention. However, because only the moisture response produced a statistically significant regression model, while the models for ash, crude protein, and glutamic acid were not significant, the optimization results should be interpreted with caution. Overall, this study provides a scientific basis for selecting drying conditions for *A. papuana* leaves and supports their potential use as a plant-based natural flavoring ingredient. Future research should evaluate additional quality attributes, including sensory characteristics, shelf-life stability, and pilot- or industrial-scale drying performance, to further validate the practical application of the proposed drying conditions.

Abbreviations

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Data availability statement

The research data are available and will be shared with readers upon request.

CRediT authorship contribution statement

Titik Ismandari: Conceptualization, Methodology, Validation, Formal analysis, Supervision, Critical Evaluation, Editing Work, Completion. **Amarullah**: Conceptualization, Methodology, Experimental Work, Data Analysis and Manuscript Writing.

Declaration of Competing Interest

The authors confirm the absence of financial interests or personal relationships that cloud compromise the integrity and impartiality of the research findings disclosed in this paper.

Declaration of Use of AI in the Writing Process

The authors used ChatGPT (OpenAI) during the preparation of this manuscript to improve grammar, language clarity, sentence structure, and readability. After using this tool, the authors carefully reviewed, revised, and validated all content and take full responsibility for the scientific accuracy and integrity of the manuscript.

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