Original Article

Comparative Experimental Study of Drying Temperatures (30°C vs 50°C) on Tannin and Mineral Retention in Moringa oleifera Leaves

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ABSTRACT

Background: Moringa oleifera leaves are nutrient-rich plant materials containing minerals and bioactive compounds with potential food and health applications. Drying temperature may affect their composition through moisture reduction and concentration effects. However, evidence comparing moderate drying temperatures (30°C and 50°C) and their impact on tannin and mineral content remains limited. This study aimed to evaluate the effects of drying at 30°C and 50°C on tannin and selected mineral concentrations in moringa leaves.

Methods: A quantitative comparative laboratory experimental study was conducted using non-human plant samples. Fresh moringa leaves were dried at 30°C and 50°C under controlled conditions, with each treatment performed in triplicate. Tannin content was determined using UV–Visible spectrophotometry with calibration-based quantification, while mineral concentrations of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and iron (Fe) were measured using Atomic Absorption Spectrophotometry (AAS) or ICP-OES. Inferential statistical analyses were conducted following assumption checks to compare measured concentrations between treatments.

Results: Drying at 50°C produced consistently higher measured concentrations of tannins and minerals compared with drying at 30°C, indicating a coherent temperature-associated pattern across all analyzed parameters. Iron exhibited the largest numerical difference between treatments. These findings suggest that drying temperature influenced the measured chemical composition of moringa leaf powder, most likely through enhanced moisture reduction and concentration-related analytical effects.

Conclusion: Moderate drying temperature (50°C) increased measured tannin and mineral concentrations relative to 30°C under laboratory conditions. However, these differences should be interpreted cautiously, as they likely reflect concentration effects rather than true nutrient retention or improved nutritional efficacy. Further studies incorporating moisture-normalized analysis, bioavailability assessment, and functional evaluation are required before translating these findings into clinical or public health recommendations

Keywords: Moringa oleifera; drying temperature; measured concentration; tannins; minerals; laboratory experimental study.

Implications for Practice:

- Drying moringa leaves at moderate temperatures such as 50°C may enhance processing efficiency while producing powder with higher measured mineral and tannin concentrations.
- The findings may inform small-scale and LMIC-oriented food processing strategies where energy efficiency and drying time are critical considerations.
- Additional research on nutrient bioavailability, storage stability, and consumer acceptability is needed before application in clinical nutrition or community health programs.

Introduction

Moringa leaves (*Moringa oleifera*) are widely recognized as a nutrient-dense plant source containing vitamins, minerals, and diverse bioactive compounds that support physiological function and may contribute to chronic disease prevention (Darmawan et al., 2024; Hanif & Berawi, 2022). Among the most relevant constituents are tannins (Kiswandono, 2017) and essential minerals such as magnesium (Mg), sodium (Na), calcium (Ca), potassium (K), and iron (Fe), which play important roles in metabolic regulation, cardiovascular function, bone integrity, and hematological balance (Japaries et al., 2023). Because of this nutritional profile, moringa leaves have gained increasing attention as a functional food ingredient, particularly in low- and middle-income countries (LMICs) where micronutrient deficiencies remain prevalent and locally available plant resources are frequently integrated into community-based nutrition strategies.

Drying represents one of the most commonly applied preservation techniques for moringa leaves because it extends shelf life, limits microbial growth, and facilitates storage and transportation (Nugroho, 2024). However, the drying temperature is a critical processing parameter that influences both moisture removal efficiency and the chemical composition of the final product. From a processing–composition perspective, temperature affects drying kinetics, which, in turn, regulate the rate of water loss and thermal exposure. Reduced moisture content may increase the relative proportion of solid constituents, potentially leading to higher measured concentrations of minerals or phytochemicals without necessarily reflecting true nutrient retention. Conceptualizing this relationship is essential to avoid misinterpretation of analytical results derived from dried plant materials.

Previous studies report that moderate oven-drying temperatures, such as 50°C, can effectively reduce moisture content while maintaining acceptable levels of nutritional compounds, although heat-sensitive components, such as vitamin C, may undergo oxidative degradation during heating (Ali et al., 2017). In contrast, drying at lower temperatures (approximately 30–35°C) may better preserve certain vitamins and antioxidant activity but generally requires longer drying durations, which can reduce processing efficiency and increase contamination risk in non-industrial environments (Aznury et al., 2021; Paramita, 2023). Evidence from other plant materials, such as *Phaleria macrocarpa*, suggests that moderate temperatures may optimize phenolic stability by balancing incomplete drying at low temperatures and thermal decomposition at higher temperatures (Stephenus et al., 2023). These findings illustrate an ongoing scientific tension between nutrient stability and processing efficiency, indicating that optimal drying conditions depend on both target compounds and processing context.

The implications of drying practices differ substantially between industrial food systems and LMIC processing environments. Industrial facilities typically employ controlled-drying technologies with regulated airflow, humidity control, and standardized post-processing, enabling consistent moisture normalization and quality assurance. In contrast, many LMIC settings rely on relatively simple ovens or low-technology drying approaches where energy efficiency, drying duration, and equipment accessibility become dominant constraints. Consequently, moderate temperatures such as 50°C may represent a practical compromise in LMIC contexts, balancing processing feasibility with acceptable preservation of measured nutritional composition.

Mineral composition, particularly iron, magnesium, and calcium, is of special importance for public health nutrition, including anemia prevention and bone health (Alim et al., 2023). Some studies suggest that lower drying temperatures may better preserve mineral integrity, whereas others report higher measured mineral levels at moderate temperatures due to greater moisture reduction (Fatmawati et al., 2024; Supriadi et al., 2024). These apparently conflicting findings highlight the need to distinguish between true nutrient retention and concentration effects associated with drying processes. Laboratory analyses indicate that moringa leaf powder may contain substantial mineral concentrations, depending on the drying method and analytical approach (Gopalakrishnan et al., 2016). In contrast, excessive thermal exposure can degrade certain nutrients through degradation mechanisms (Soltan et al., 2019).

To clarify the conceptual relationship between processing conditions and measured composition, a simplified processing–composition framework is presented in Figure 1. The framework illustrates how drying temperature influences drying kinetics, moisture reduction, and analytical concentration effects, ultimately shaping the measured levels of tannins and minerals. Such a model provides a theoretical basis for interpreting experimental findings within both laboratory and LMIC processing contexts.

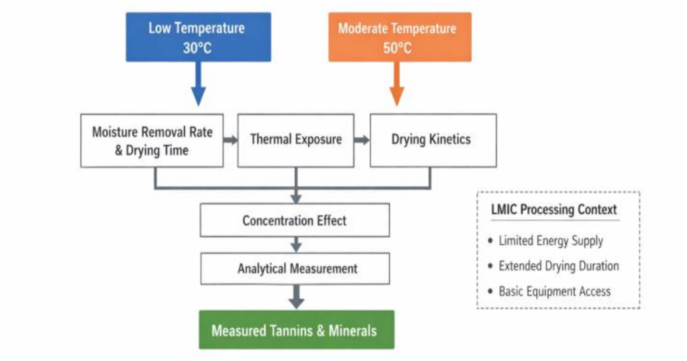

Figure 1. Processing–Composition Conceptual Framework

Despite the expanding literature on moringa processing, direct comparative laboratory evidence examining drying temperatures of 30°C and 50°C and their combined effects on tannins and macro-minerals (Mg, Na, Ca, K, and Fe) remains limited (Alakali et al., 2015). Temperatures in the 40–50°C range are frequently reported to preserve nutritional quality while improving drying efficiency. Yet, few studies explicitly evaluate how these temperatures shape measured composition through moisture-driven concentration mechanisms (Anggestia et al., 2023). Addressing this gap is important for developing processing recommendations that are scientifically grounded yet applicable to diverse production settings.

Therefore, this study aimed to comparatively analyze the effects of drying temperatures of 30°C and 50°C on tannin and mineral content (Ca, Mg, K, Na, and Fe) in moringa leaves using a laboratory comparative experimental approach. Based on drying kinetics theory, it was hypothesized that drying at 50°C would produce higher measured concentrations of tannins and minerals than drying at 30°C, primarily due to more effective moisture reduction rather than enhanced nutrient retention. The findings are expected to contribute to a clearer processing–composition framework and provide evidence relevant to both laboratory research and practical drying strategies in LMIC food systems.

Methods

Study Design

This study employed a quantitative comparative laboratory experimental design (Swandono et al., 2025) using non-human plant material to evaluate the effects of two drying temperature treatments (30°C and 50°C) on tannin and mineral composition in moringa leaves. The design emphasized transparent experimental procedures and analytical reproducibility, consistent with structured reporting principles commonly applied in laboratory-based intervention studies. The comparison focused on temperature-induced changes in measured chemical composition, rather than biological efficacy or clinical outcomes.

Two drying treatments were applied, and each temperature condition was conducted in triplicate to enhance analytical reliability, reduce random measurement variability, and allow inferential statistical evaluation. Drying was performed using a blower oven under controlled laboratory conditions (El-Zaatari et al., 2021; Nurkhasanah & Dhurhania, 2023). Temperature stability and procedural fidelity were periodically monitored to ensure adherence to standardized operating procedures. Because this study involved only plant samples and did not include human participants or animal experimentation, formal ethical approval was not required. The research complied with general scientific integrity principles, and ethical exemption was justified because no human or animal subjects were involved.

Processing Procedures

Fresh moringa leaves (*Moringa oleifera*) were selected based on uniform maturity and absence of visible physical damage to reduce biological variability. Leaves were cleaned to remove surface contaminants, separated from stems, and arranged in a single layer to ensure uniform airflow and consistent thermal exposure during drying. Drying was conducted in a mechanical drying oven with precise temperature control set to 30°C or 50°C. The selection of these temperatures was grounded in principles of drying kinetics, where lower temperatures are associated with slower moisture diffusion and reduced thermal stress. In contrast, moderate temperatures improve drying efficiency through accelerated evaporation. This temperature range was selected to represent a balance between processing efficiency and nutritional preservation.

The drying process lasted approximately 5–7 hours, depending on the temperature treatment, until the moisture content reached 2–10%, a range considered effective for inhibiting microbial growth and maintaining product stability. Drying at 30°C required a longer duration than at 50°C due to slower moisture removal. Oven temperature, sample positioning, and airflow consistency were periodically monitored to maintain intervention fidelity and minimize procedural variability. After drying, moringa leaves were ground into powder and sieved to obtain uniform particle size before laboratory analysis, thereby reducing heterogeneity during analytical measurements.

Nutritional Content Analysis

Tannin Analysis

Tannin content in dried moringa leaf powder was analyzed using UV–Visible spectrophotometry following the Indonesian Herbal Pharmacopoeia (FHI) Edition II (2017). This technique quantifies compounds based on absorbance at specific ultraviolet or visible wavelengths, where absorbance is proportional to concentration. Instrument calibration was performed using tannic acid standard solutions prepared from analytical-grade reagents, and blank measurements were conducted before each analytical run to ensure baseline stability and measurement reliability.

A standard tannic acid solution was prepared by dissolving 1.00 mg of tannic acid in 10 mL of analytical-grade ethanol. The maximum absorbance wavelength (λ_{max}) was determined before measurement, and a calibration curve was constructed using a 100 ppm stock solution. Sample absorbance was measured at the determined λ_{max}, and tannin concentration was calculated using a linear regression equation:

$$Y = AX + B$$

Where:
A = 0.0051 (slope)
B = 0.0245 (intercept)
R^2 = 0.9965
Y = measured absorbance
X = tannin concentration
For concentration determination, the equation was rearranged as:

$$X = (Y - 0.0245) / 0.0051$$

This spectrophotometric method is widely used for the quantitative analysis of tannins and related bioactive compounds due to its sensitivity, linearity, and analytical robustness.

Mineral Analysis (Ca, Mg, K, Na, and Fe)

Mineral content analysis was conducted using Atomic Absorption Spectrophotometry (AAS) or Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), both of which are established techniques for micro- and macro-element determination in plant materials. Sample preparation involved drying, grinding, and acid digestion to solubilize mineral elements before analysis. Certified standard solutions were used for calibration, and instrument performance was verified prior to measurement to ensure analytical validity.

Mineral concentrations were measured based on element-specific absorption wavelengths, including calcium (Ca) at approximately 422.7 nm and magnesium (Mg) at 285.2 nm, while potassium (K), sodium (Na), and iron (Fe) were analyzed using standard wavelengths appropriate for AAS detection. Absorbance values obtained from the samples were compared against calibration curves generated from certified standards to determine measured mineral concentrations.

Data Collection and Quality Control

The analytical workflow followed a structured sequence consisting of sample preparation, drying intervention, grinding and sieving, chemical digestion, instrumental measurement, data recording, and verification. Quality control procedures included blank correction, calibration verification, and duplicate reading checks to ensure consistency and reduce analytical bias. All measurement data were recorded in standardized digital files and reviewed for unit consistency and transcription accuracy.

Data Analysis

Statistical analysis was performed using a quantitative inferential approach. Independent sample t-tests were applied to compare mean tannin concentrations between drying temperatures (30°C and 50°C). Prior to analysis, data distribution was assessed for normality and homogeneity to ensure compliance with statistical assumptions.

Mineral content data for Ca, Mg, K, Na, and Fe were analyzed using analysis of variance (ANOVA) to evaluate differences between temperature treatments. When

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significant differences were detected, post hoc comparisons were conducted using Duncan or Tukey tests to identify specific group differences. Statistical significance was determined at a p-value < 0.05. In addition to significance testing, effect size estimation was applied to evaluate the magnitude of temperature effects on measured chemical composition. This analytical approach was used to evaluate the influence of drying temperature on measured tannin and mineral concentrations in moringa leaf powder within a processing–composition framework.

Results

Mineral Content (Ca, Mg, K, Na, and Fe)

The measured concentrations of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and iron (Fe) in moringa leaf powder differed between the two drying temperature treatments. Prior to inferential testing, assumption checks were conducted to evaluate data distribution and variance comparability. Visual inspection and assumption assessment indicated no substantial deviation from normality and no critical variance imbalance between groups, supporting the application of parametric statistical procedures as described in the Methods section. Overall, samples dried at 50°C consistently exhibited higher measured mineral concentrations than those dried at 30°C, indicating a coherent temperature-related pattern across all analyzed minerals. This pattern was observed for both macro- and micro-mineral elements and suggests that drying temperature influenced the analytical composition of the powder matrix under the applied laboratory conditions.

For macro minerals, calcium and magnesium showed modest but consistent increases at the higher drying temperature. Calcium increased from 458.56 mg/100 g at 30°C to 474.87 mg/100 g at 50°C, while magnesium increased from 736.50 mg/100 g to 779.40 mg/100 g. A similar directional trend was observed for potassium and sodium, with potassium increasing from 238.34 mg/100 g to 248.78 mg/100 g and sodium from 89.90 mg/100 g to 93.45 mg/100 g when the drying temperature was raised from 30°C to 50°C. Although the magnitude of change varied among elements, the consistent upward direction suggests a temperature-associated concentration effect.

Among all minerals analyzed, iron (Fe) exhibited the largest numerical difference between treatments, increasing from 6278.50 mg/100 g at 30°C to 7493.00 mg/100 g at 50°C. While inferential comparisons indicated a notable difference between temperature conditions, the magnitude of the iron values should be interpreted cautiously. These values represent measured concentrations under specific analytical conditions and may reflect concentration effects associated with moisture reduction or matrix-related analytical factors rather than absolute increases in intrinsic iron content.

A detailed numerical comparison of mineral concentrations is presented in **Table 1.** The tabulated values provide a quantitative basis for evaluating the direction and relative magnitude of mineral changes between treatments.

Table 1. Results of Ca, Mg, K, Na, and Fe Analysis

Parameters	Unit	Temperature 30°C	Temperature 50°C
Ca	mg/100 g	458.56	474.87
Mg	mg/100 g	736.50	779.40
K	mg/100 g	238.34	248.78
Na	mg/100 g	89.90	93.45
Fe	mg/100 g	6278.50	7493.00

To enhance interpretability, **Figure 2** presents a graphical comparison of mineral concentration patterns across drying temperatures. The visual representation highlights the consistent directional increase observed across all minerals and complements the numerical trends shown in **Table 1.**

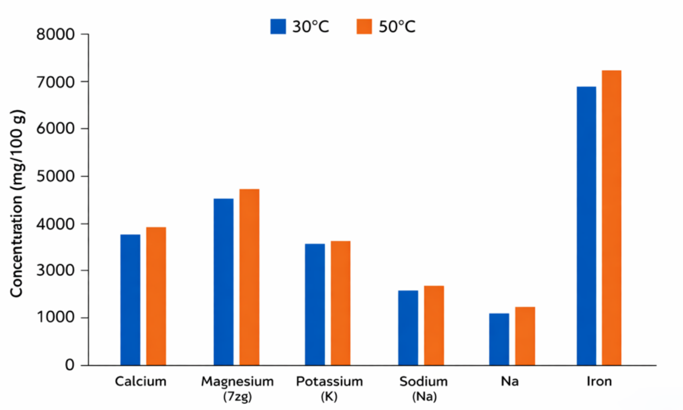

Figure 2. Comparison of measured mineral concentrations (Ca, Mg, K, Na, and Fe) in moringa leaf powder dried at 30°C and 50°C.

Tannin Content

Following mineral analysis, the effect of drying temperature on tannin concentration was evaluated. Assumption checks indicated that the distribution of tannin data was suitable for parametric comparison. Samples dried at 50°C showed higher measured tannin concentrations than those dried at 30°C, increasing from 5.3971 mg ETA/g to 17.1863 mg ETA/g. The magnitude of this difference suggests a strong temperature-associated effect on measured tannin levels, consistent with enhanced moisture removal and concentration of phenolic compounds during drying. The complete results of tannin analysis are summarized in **Table 2.**

Table 2. Tannin Analysis Results

Parameters	Method	Temperature 30°C	Temperature 50°C
Total Tannin	UV–Vis Spectrophotometry (FHI II 2017)	5.3971 mg ETA/g	17.1863 mg ETA/g

Overall Pattern of Results

Taken together, the results of mineral and tannin analyses demonstrate a consistent pattern in which drying at 50°C produced higher measured concentrations compared with drying at 30°C. The statistical comparisons and graphical visualization collectively indicate that drying temperature influenced the analytical composition of moringa leaf powder. However, these differences are interpreted within a processing–composition framework, suggesting that the observed increases primarily reflect concentration effects associated with moisture reduction rather than direct enhancement of intrinsic nutrient content.

Discussion

This study provides laboratory-based evidence that drying moringa leaves at 50°C resulted in higher measured concentrations of tannins and selected minerals compared with drying at 30°C. Within a health-oriented interpretation, these findings should be understood primarily as processing-related changes in analytical composition rather than direct indicators of improved nutritional status or clinical benefit. Drying temperature acts as a critical processing variable that influences moisture reduction, which in turn alters the relative concentration of chemical constituents detected during analysis.

From a theoretical perspective, the observed pattern can be explained through

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drying kinetics. Moderate temperatures accelerate moisture diffusion and evaporation, leading to reduced water content and a higher relative proportion of solids in the dried matrix. This mechanism likely contributed to the consistent increase in measured mineral and tannin levels at 50°C. While such increases may appear nutritionally advantageous, they do not necessarily reflect enhanced nutrient retention at the molecular level. Instead, they highlight how processing conditions can influence analytical outcomes and must therefore be interpreted cautiously when translated into health recommendations.

The notably high measured iron values represent an important analytical consideration. Several mechanisms may explain this pattern, including concentration effects caused by moisture reduction, matrix interactions during digestion, and enhanced extraction efficiency after grinding. These factors may elevate measured concentrations without indicating a true increase in intrinsic iron content. For health-focused interpretation, this distinction is critical, as misinterpretation of analytical values could lead to overestimation of nutritional benefits. Similar observations have been reported in plant drying studies where apparent mineral increases were attributed to physicochemical concentration rather than biological enhancement. When positioned within broader public health and LMIC contexts, the findings gain practical relevance. In many low- and middle-income settings, moringa leaves are processed using relatively simple drying technologies where energy efficiency, processing time, and contamination risk are major considerations. Moderate drying temperatures such as 50°C may provide a feasible compromise by shortening drying duration and improving operational efficiency while maintaining acceptable measured nutritional composition. Faster drying may also reduce microbial exposure during processing, which has indirect implications for food safety in resource-limited environments.

However, the translation of laboratory findings into health practice requires caution. Higher measured concentrations do not automatically equate to improved bioavailability, absorption, or clinical outcomes. Nutrient bioavailability, storage stability, sensory acceptance, and long-term dietary integration remain critical factors that were not evaluated in the present study. From a nursing and public health perspective, recommendations related to moringa consumption or processing should therefore be framed within a broader evidence base that includes functional and population-level assessments. This study has several limitations that shape its interpretation. The analysis focused on tannins and selected minerals and did not include moisture-normalized comparisons, antioxidant activity measurements, or in vivo nutritional evaluation. In addition, only two drying temperatures were examined, limiting broader generalization across diverse processing environments. Nevertheless, the study contributes to health-oriented food processing research by integrating drying kinetics theory with an applied LMIC perspective, emphasizing that processing parameters influence measured chemical composition and must be interpreted within their methodological context.

Overall, the findings suggest that moderate drying temperatures may be operationally advantageous for producing moringa leaf powder in LMIC settings, offering a balance between processing efficiency and measured nutritional quality. Future research should incorporate bioavailability testing, functional health outcomes, and community-based implementation studies to better inform evidence-based recommendations for clinical nutrition and public health programs.

Implications and limitations

This study contributes conceptually to the processing–composition framework by providing comparative laboratory evidence that moderate drying temperatures influence the measured concentrations of tannins and minerals in *Moringa oleifera* leaves primarily through moisture reduction and concentration-related analytical effects rather than true nutrient enhancement or retention. The findings extend drying kinetics theory by highlighting the importance of distinguishing analytical concentration effects from intrinsic nutritional changes when interpreting compositional analyses of dried plant materials. In addition, the study offers a scientific basis for understanding how processing parameters shape laboratory outcomes in food and health-related research, particularly in resource-constrained settings. Nevertheless, several limitations should be acknowledged, including the absence of moisture-normalized measurements, nutrient bioavailability assessments, antioxidant analyses, and functional or in vivo evaluations. Furthermore, only two drying temperatures (30°C and 50°C) were investigated under controlled laboratory conditions, limiting the generalizability of the findings to other drying methods, temperatures, and environmental contexts.

Relevance to Practice

The findings suggest that drying moringa leaves at moderate temperatures such as 50°C may represent a practical and feasible processing strategy for nursing nutrition programs, community health initiatives, and small-scale food production systems, particularly in Low- and Middle-Income Countries (LMICs) where access to advanced drying technologies is limited. Faster moisture removal at moderate temperatures may improve processing efficiency, shorten drying duration, reduce contamination risk during handling and storage, and support the production of more stable moringa leaf powder for community-based nutritional interventions. Healthcare professionals, nutritionists, and community health workers may consider recommending standardized moderate-temperature drying procedures when developing locally produced moringa-based supplements or complementary foods. Policymakers and health institutions may also use these findings to support simple, energy-efficient food processing guidelines suitable for resource-limited settings. However, implementation in clinical nutrition or public health programs should be accompanied by further evidence regarding nutrient bioavailability, storage stability, and health outcomes before large-scale adoption is recommended.

Conclusion

This study demonstrated that drying *Moringa oleifera* leaves at 50°C produced higher measured concentrations of tannins and selected minerals (Ca, Mg, K, Na, and Fe) than drying at 30°C, primarily due to moisture reduction and concentration-related analytical effects rather than improved nutrient retention. These findings strengthen the processing–composition framework by emphasizing drying temperature as an important determinant of measured chemical composition while highlighting that higher concentrations do not necessarily indicate greater bioavailability or clinical benefit. Moderate drying temperatures may offer practical advantages for small-scale production and Low- and Middle-Income Country (LMIC) settings by improving drying efficiency and reducing contamination risk during processing. However, the translation of these findings into nutritional, nursing, or public health recommendations remains limited by the absence of moisture-normalized analyses, bioavailability assessments, storage stability evaluations, and functional outcome studies, indicating the need for further laboratory and community-based research.

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CrediT Authorship Contributions Statement

Aris Fitriyani: Conceptualization, Methodology, Supervision, Writing - Original Draft

Maisje Marlyn Kuhu: Investigation, Data Curation, Formal Analysis, Writing - Review & Editing

Widjijati: Resources, Project Administration, Validation, Visualization

Conflicts of Interest

The authors declare that there are no conflicts of interest affecting the results of this study. All authors had full access to the data and are responsible for the content and integrity of the study.

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