
EFFECT OF DRYING TECHNIQUES ON MOISTURE CONTENT AND ESSENTIAL OIL YIELD OF CLOVE AND NUTMEG

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ABSTRACT

*Drying is an important postharvest process that affects moisture content, simplicia stability, and essential oil yield of aromatic materials. This study aimed to evaluate the effects of sun drying, hot-air/oven drying, and vacuum drying on moisture content and essential oil yield of clove (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*) simplicia, and to relate the moisture content and essential oil yield results to GC/FID and GC-MS chemical profile benchmarks from previous studies. Clove and nutmeg simplicia were identified macroscopically and organoleptically, subjected to phytochemical screening, and dried using three drying methods. The dried simplicia were extracted by steam distillation, and essential oil yield was calculated based on oil weight relative to dried simplicia weight. Data were analyzed using mean±standard deviation, one-way ANOVA, and Tukey's HSD test. The results showed that all drying methods reduced moisture content to below 10%. Vacuum drying produced the lowest moisture content in clove (8.63±0.25%) and nutmeg (8.53±0.25%), and the highest essential oil yield in clove (13.33±0.15%) and nutmeg (6.60±0.10%). Hot-air/oven drying produced the lowest yield. GC benchmark data indicated eugenol as the main marker of clove oil, while myristicin and monoterpenes were more relevant for nutmeg oil. Statistical analysis supported significant differences in yield among treatments, whereas chemical quality still requires confirmation using actual chromatographic analysis. Vacuum drying may be the most promising method for processing clove and nutmeg simplicia, particularly in terms of essential oil recovery and controlled postharvest quality.*

KEYWORDS

Clove; Nutmeg; Vacuum drying; Essential oil yield; GC/FID



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INTRODUCTION

Essential oils are a group of volatile secondary metabolites widely used in pharmaceutical, food, cosmetic, aromatherapy, and perfume applications because of their characteristic aromas and broad biological activities (Liñán-Atero et al., 2024; Thamkaew et al., 2021). Indonesia has great potential for essential oil development because it is rich in aromatic spice plants, including clove (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*), which are important essential-oil-producing commodities (Ashokkumar et al., 2022).

Clove is an aromatic plant whose essential oil has been extensively studied because it contains eugenol as a major component. Eugenol serves as a principal quality marker of clove oil and has been reported to exhibit antioxidant, antimicrobial, and anti-inflammatory activities, as well as potential applications in food and pharmaceutical fields (Liñán-Atero et al., 2024; Pandey et al., 2024). In contrast, nutmeg essential oil is more characterized by monoterpenes and phenylpropanoids, such as sabinene, α -pinene, β -pinene, terpinen-4-ol, safrole, and myristicin (Ashokkumar et al., 2022; Trifan et al., 2023). These differences in chemical characteristics indicate that eugenol is more relevant as the main marker of clove oil, whereas myristicin and monoterpenes are more appropriate as quality markers of nutmeg oil (Khairan et al., 2024; Trifan et al., 2023). Previous natural-product studies have shown that secondary metabolites such as flavonoids, polyphenols, and antioxidant compounds can provide an initial basis for assessing the bioactivity potential and quality of herbal materials before more specific instrumental analyses are performed (Deniessa et al., 2026; Siregar et al., 2026).

One important step in the processing of aromatic simplicia is drying. The drying process aims to reduce moisture content so that the material is more stable during storage; however, improper drying can cause the loss of volatile components due to heat, oxidation, or light exposure (Al-Hamdani et al., 2022; Thamkaew et al., 2021). For essential-oil-producing materials, the selection of a drying method is important because volatile compounds can readily evaporate and undergo compositional changes during postharvest processing (Thamkaew et al., 2021; Żbik et al., 2023).

Common drying methods used in simplicia processing include sunlight drying, oven/hot-air drying, and vacuum drying. Sunlight drying is easy to apply and inexpensive, but it is strongly affected by environmental conditions. Oven/hot-air drying provides better temperature control, but it may still cause the loss of some volatile compounds. Vacuum drying, meanwhile, is a potential alternative for preserving volatile compounds because it operates at a lower effective temperature under reduced pressure (Al-Hamdani et al., 2022; Thamkaew et al., 2021; Żbik et al., 2023).

Several studies have shown that drying methods can affect the quality of aromatic materials. (Żbik et al., 2023) reported that vacuum drying could better preserve volatile components and the physicochemical properties of aromatic plants than convective drying. (Al-Hamdani et al., 2022) also showed that more controlled drying methods can help maintain herbal quality compared with direct drying, which is highly dependent on environmental conditions. These findings highlight the importance of evaluating drying

methods for aromatic simplicia such as clove and nutmeg to obtain low moisture content and optimal essential oil yield.

In addition to moisture content and yield, the chemical quality of essential oils can be evaluated through chromatographic profiles. GC/FID is widely used to quantify specific volatile compounds such as eugenol in clove oil, whereas GC-MS provides more information for identifying complex compound profiles in nutmeg oil (Khairan et al., 2024; Trifan et al., 2023). In this study, GC/FID and GC-MS data were used as benchmarks from previous studies, rather than as primary data; therefore, the main interpretation focused on moisture content and essential oil yield.

Studies on the effects of drying methods on essential oils have been widely conducted in various aromatic plants, but studies simultaneously comparing sunlight, oven/hot-air, and vacuum drying in terms of moisture content and essential oil yield of clove and nutmeg remain limited. Therefore, this study aimed to evaluate the effects of sunlight, oven/hot-air, and vacuum drying on the moisture content and essential oil yield of clove (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*) simplicia, and to relate the moisture content and yield results to GC/FID and GC-MS chemical profile benchmarks from previous studies.

RESEARCH METHOD

Research Design

This study used a one-factor laboratory experimental design, with drying method as the factor, consisting of sunlight, oven/hot-air, and vacuum drying. Each treatment was performed in three replicates for both clove and nutmeg simplicia. The main parameters observed were final moisture content and essential oil yield, while simplicia identification and phytochemical screening were used for initial material characterization.

Identification and Phytochemical Screening

Simplicia identification was performed macroscopically and organoleptically to confirm material conformity before drying and essential oil distillation. Macroscopic observations included shape, color, texture, and physical condition, while organoleptic observations included the characteristic aroma and taste. This identification is important because differences in material, simplicia origin, and postharvest conditions can affect secondary metabolite content and essential oil composition (Haro-González et al., 2021).

Clove simplicia were identified based on the characteristics of dried flower buds with a nail-like shape, brown to dark-brown color, strong characteristic aroma, and pungent taste (Liñán-Atero et al., 2024). Nutmeg simplicia were identified based on the characteristics of dried seeds with an oval shape, grayish-brown color, hard texture, and characteristic aromatic odor (Ashokkumar et al., 2022; Trifan et al., 2023).

Phytochemical screening was performed qualitatively to determine the presence of major secondary metabolite groups in clove and nutmeg simplicia. The compounds examined included alkaloids, flavonoids, phenolics/tannins, saponins, terpenoids, and steroids. The tests were based on color reactions, precipitate formation, or foam formation indicating the possible presence of specific metabolite groups in the natural materials (Maheshwaran et al., 2024; Nurrahman et al., 2025).

The alkaloid test was performed using Mayer's and Dragendorff's reagents. The test sample was treated separately with Mayer's and Dragendorff's reagents, and the formation of precipitates was observed. A positive alkaloid result was indicated by a white or yellowish precipitate with Mayer's reagent and an orange to reddish-brown precipitate with

Dragendorff's reagent. The absence of a precipitate indicated a negative alkaloid result (Maheshwaran et al., 2024).

The flavonoid test was performed using the Shinoda method with the addition of magnesium powder and concentrated HCl. A positive flavonoid result was indicated by the development of red, orange, or reddish-orange coloration after reagent addition. This color change indicates the possible presence of flavonoid compounds reacting with magnesium under acidic conditions (Maheshwaran et al., 2024).

The phenolic and tannin test was performed using FeCl₃ reagent. The test sample was treated with FeCl₃ solution, and the resulting color change was observed. A positive phenolic/tannin result was indicated by dark green, dark blue, or bluish-black coloration. This color change indicates the formation of a complex between iron ions and phenolic groups in tannins or polyphenols (Haro-González et al., 2021; Maheshwaran et al., 2024).

The saponin test was performed using the foam test. The sample was vigorously shaken with hot water or distilled water, and the formation of stable foam was observed. A positive saponin result was indicated by stable foam that did not disappear immediately after standing. Foam formation is related to the surfactant properties of saponins in aqueous media (Maheshwaran et al., 2024).

The terpenoid test was performed using Liebermann–Burchard reagent. The test sample was treated with the appropriate reagent, and the resulting color change was observed. A positive terpenoid or triterpenoid result is generally indicated by red, orange, reddish-brown, or brownish-purple coloration. This color reaction is used as an initial indication of terpenoid compounds in natural materials (Maheshwaran et al., 2024; Trifan et al., 2023).

The steroid test was also performed using Liebermann–Burchard reagent. A positive steroid result was indicated by green, bluish-green, or blue-green coloration. The absence of a characteristic color change indicated a negative steroid result (Maheshwaran et al., 2024).

The phytochemical screening results were expressed semi-quantitatively using a negative sign (–) for not detected, weak positive (+), moderate positive (++), and strong positive (+++) based on the intensity of the color reaction, precipitate, or foam formed.

Drying

Clove and nutmeg simplicia were cleaned of physical impurities and weighed as the initial weight before drying. The simplicia were then divided into three treatment groups: sunlight drying, hot-air/oven drying, and vacuum drying, with three replicates for each treatment. Drying was continued until the moisture content of the simplicia reached below 10%. Reducing moisture content is important to improve material stability, inhibit microbial growth, and prepare the material for essential oil distillation (Thamkaew et al., 2021).

Sunlight Drying

Sunlight drying was performed by placing the clove and nutmeg simplicia in a clean, dry area with good air circulation. The simplicia were spread evenly to promote more uniform water evaporation. Drying was continued until the moisture content reached below 10%. This method was used as a comparison because it is easy to apply, inexpensive, and commonly used in herbal processing, but it is strongly affected by ambient temperature, air humidity, light intensity, airflow, and drying duration (Al-Hamdani et al., 2022; Thamkaew et al., 2021). For aromatic materials, sunlight drying needs to be controlled because light exposure and temperature fluctuations can affect physicochemical quality and volatile compound stability (Al-Hamdani et al., 2022).

Hot-Air/Oven Drying

Hot-air drying was performed using an oven at a controlled temperature of approximately 45–50°C. Clove and nutmeg simplicia were evenly placed in the drying container and dried until the moisture content reached below 10%. The oven method was used because its drying temperature is more controlled than sunlight drying, allowing moisture reduction to proceed more consistently (Thamkaew et al., 2021). Nevertheless, heat exposure during oven drying requires attention because volatile compounds in aromatic simplicia may evaporate or undergo compositional changes during heating (Thamkaew et al., 2021). In clove, oven drying at 50°C has been reported to affect essential oil composition, including changes in the proportions of eugenol, acetyl eugenol, and caryophyllene (Liñán-Atero et al., 2024; Thamkaew et al., 2021).

Vacuum Drying

Vacuum drying was performed using a vacuum dryer at approximately 40°C under reduced pressure. Clove and nutmeg simplicia were dried until the moisture content reached below 10%. This method was used because reduced pressure lowers the boiling point of water, allowing water evaporation to occur at a lower effective temperature than conventional drying (Žbik et al., 2023). This condition is advantageous for aromatic materials because it can reduce excessive heat exposure and potentially preserve volatile compounds that are sensitive to high temperatures (Thamkaew et al., 2021; Žbik et al., 2023). Vacuum drying of aromatic plants has been reported to better preserve volatile compound profiles and physicochemical properties than convective drying, making it relevant for essential-oil-producing simplicia (Žbik et al., 2023).

Moisture Content Determination

Moisture content determination was performed to evaluate the effectiveness of each drying method in reducing the water content of clove and nutmeg simplicia. Moisture content was measured after drying was completed for each treatment group: sunlight, hot-air/oven, and vacuum drying. The target moisture content was set below 10% because low moisture content can help maintain material stability during storage, inhibit microbial growth, and reduce the risk of enzymatic deterioration in dried herbal materials (Thamkaew et al., 2021).

Moisture content was determined gravimetrically by calculating the decrease in sample weight before and after drying. The initial weight was the weight of the simplicia before drying, while the final weight was the weight after drying had been completed and the weight had become relatively stable. Each drying treatment was performed in three replicates. Moisture content was calculated using the following formula:

$$\text{Moisture content (\%)} = \frac{W_o - W_t}{W_o} \times 100\%$$

Note:

- initial weight is the weight of the simplicia before drying,
- final weight is the weight of the simplicia after drying.
- Moisture content data are presented as mean ± standard deviation from three replicates for each drying method (Krumm et al., 2026).

Steam Distillation of Essential Oils

Dried clove and nutmeg simplicia from each drying method were weighed at 500 g for essential oil extraction. Essential oil extraction was performed using steam distillation because this method is widely used to obtain essential oils from aromatic plant materials

containing volatile compounds. Steam distillation is a common essential oil extraction method because it is simple, relatively economical, and uses water vapor to carry volatile compounds from plant tissues (Machado et al., 2022; Pheko-Ofithile & Makhzoum, 2024).

The simplicia were placed in the steam-distillation apparatus, and water vapor was passed through the material to carry volatile components from the plant tissues. The vapor carrying the essential oil was then directed to a condenser, where it was cooled and converted into a condensate consisting of water and essential oil. This principle is consistent with essential oil distillation, in which volatile components are carried by steam, condensed, and collected as a distillate containing aqueous and oil phases (Chilev & Peshev, 2025; Machado et al., 2022).

The condensate was collected in a receiving vessel, and the essential oil was separated from the aqueous phase using a separatory funnel based on the difference in density between the oil and water phases. The resulting essential oil fraction was then dried using anhydrous sodium sulfate to remove residual water. The use of a separatory funnel and anhydrous sodium sulfate has been reported in the separation and purification of essential oils, particularly to obtain an oil fraction with less residual water or impurities during separation (Chilev & Peshev, 2025). The dried essential oil was then transferred to a tightly closed dark vial and stored in a light-protected place until yield determination.

Essential Oil Yield Determination

Essential oil yield determination was performed to assess the efficiency of essential oil recovery from clove and nutmeg simplicia under each drying method. Yield was calculated after steam distillation was completed and the essential oil had been separated from the aqueous phase. The separated essential oil was then dried using anhydrous sodium sulfate to remove residual water before weighing.

Essential oil yield was calculated as the ratio of the weight of essential oil obtained to the weight of dried simplicia used in the distillation process. Essential oil weight refers to the oil fraction obtained after separation and drying, while dried simplicia weight refers to the dried material used as the distillation sample. Yield is an important parameter because it reflects extraction efficiency and the effect of processing conditions on essential oil recovery from aromatic materials (Machado et al., 2022; Pheko-Ofithile & Makhzoum, 2024).

The formula used to calculate essential oil yield was as follows:

$$\text{Essential oil yield (\%)} = \frac{\text{essential oil (gram)}}{\text{dried simplicia (gram)}} \times 100\%$$

Note:

- essential oil weight is the weight of oil obtained after steam distillation, separation from the aqueous phase, and drying with anhydrous sodium sulfate;
- dried simplicia weight is the weight of the dried simplicia used in the distillation process. Essential oil yield data are presented as mean $\pm$ standard deviation from three replicates for each drying method.
- yield comparisons among drying methods were subsequently analyzed statistically using one-way ANOVA and the Tukey HSD post hoc test when a significant difference was found at $p < 0.05$ (Mala & Kiran, 2021).

GC/FID and GC-MS Benchmark Review

The GC/FID and GC-MS benchmark review was conducted to strengthen the interpretation of the potential chemical quality of clove and nutmeg essential oils based on

previous studies describing the chromatographic profiles of these two plant oils (Gotmare & Gotmare, 2021; Khairan et al., 2024; Liñán-Atero et al., 2024; Trifan et al., 2023). Benchmark data were used as literature comparisons because chromatographic analysis was not performed as primary data in this study; therefore, chemical quality interpretation remains based on previous research findings (Gotmare & Gotmare, 2021; Trifan et al., 2023). Accordingly, GC/FID and GC-MS data were not treated as direct analytical results from the study samples, but as a basis for comparison to describe potential marker compounds in clove and nutmeg essential oils (Khairan et al., 2024; Liñán-Atero et al., 2024).

For clove essential oil, the review focused on eugenol because it is the main marker of clove oil and is commonly used in chromatographic quality control (Liñán-Atero et al., 2024). For nutmeg essential oil, the review focused on myristicin, sabinene, α -pinene, β -pinene, terpinen-4-ol, and safrole because nutmeg oil is more characterized by monoterpenes and phenylpropanoids than by eugenol (Khairan et al., 2024; Trifan et al., 2023).

The collected data included researcher names, sample types, analytical methods, marker compounds, concentration values or relative area percentages, and their relevance to interpretation of the present study (Gotmare & Gotmare, 2021; Khairan et al., 2024; Trifan et al., 2023). Benchmark data were analyzed descriptively and comparatively, without statistical testing, because they originated from different studies with variations in materials, extraction methods, instrument conditions, and reporting procedures (Kusuma et al., 2025; Liñán-Atero et al., 2024). Thus, the GC/FID and GC-MS benchmarks in this study were used as scientific comparisons, while confirmation of essential oil chemical quality still requires actual chromatographic analysis of the study samples (Gotmare & Gotmare, 2021; Liñán-Atero et al., 2024; Trifan et al., 2023).

Data Analysis

Moisture content and essential oil yield data were analyzed using the mean $\pm$ standard deviation of three replicates for each drying method to describe trends and variation among treatments (Krumm et al., 2026). The data were presented in tables and bar charts to compare the results of sunlight, hot-air/oven, and vacuum drying for clove and nutmeg simplicia (Krumm et al., 2026).

Differences in moisture content and essential oil yield among drying methods were analyzed using one-way ANOVA at a 95% confidence level to determine whether significant differences existed among treatments (Krumm et al., 2026). When one-way ANOVA showed a significant difference with $p < 0.05$, the analysis was continued using the Tukey's HSD test to identify treatment groups that differed significantly (Juarros-Basterretxea et al., 2024).

GC/FID and GC-MS benchmark data from previous studies were analyzed descriptively and comparatively and were not tested using ANOVA because they originated from different studies with variations in materials, extraction methods, instruments, chromatographic conditions, and reporting procedures (Krumm et al., 2026; Liñán-Atero et al., 2024). If actual eugenol concentration data from GC/FID become available in a subsequent study, statistical analysis can be performed to determine the effect of drying method on eugenol concentration in clove essential oil (Krumm et al., 2026).

RESULT AND DISCUSSION

Simplicia Identification and Phytochemical Screening

Macroscopic and organoleptic characteristics showed that the materials used were consistent with the characteristics of clove and nutmeg simplicia. Clove consisted of dried flower buds with a nail-like shape, dark-brown color, dry and brittle texture, and strong aroma. Nutmeg consisted of dried seeds with an oval shape, grayish-brown color, hard texture, and characteristic aromatic odor. The screening results showed the dominance of phenolics/tannins in clove and terpenoids in nutmeg, as presented in Table 1.

Table 1. Identification and phytochemical screening results of the simplicia

Parameter	Clove	Nutmeg	Interpretation
Part/shape	Dried flower buds; nail-like	Dried seeds; oval	Identity conforms
Color/texture	Dark brown; dry and brittle	Grayish brown; hard	Physical characteristics conform
Aroma	Strong characteristic	Characteristic aromatic	Aromatic material
Alkaloids	–	–	Not detected
Flavonoids	+	+	Weakly detected
Phenolics/tannins	+++	++	Dominant in clove
Saponins	–	–	Not detected
Terpenoids	++	+++	Dominant in nutmeg
Steroids	–	+	Weakly detected in nutmeg

Note: (+++) strong; (++) moderate; (+) weak; (–) not detected.

The dominance of phenolics/tannins in clove is consistent with the characteristics of clove essential oil, which contains eugenol as a major volatile phenolic compound and the main quality marker of clove oil (Gotmare & Gotmare, 2021; Liñán-Atero et al., 2024). In contrast, the dominance of terpenoids in nutmeg is consistent with the characteristics of nutmeg oil, which is more strongly characterized by monoterpenes and phenylpropanoids such as sabinene, α -pinene, β -pinene, terpinen-4-ol, safrole, and myristicin (Khairan et al., 2024; Trifan et al., 2023).

These results indicate that phytochemical screening can be used as an initial step to describe the tendency of secondary metabolite groups in natural materials before quantitative testing or further chromatographic analysis (Nurrahman et al., 2025; Siregar et al., 2026).

Effect of Drying Methods on Moisture Content and Essential Oil Yield

All methods produced moisture contents below 10%. Vacuum drying produced the lowest moisture content in both clove and nutmeg and simultaneously produced the highest essential oil yield. In contrast, oven/hot-air drying produced the lowest yield for both simplicia. A summary of the results and Tukey HSD groupings is presented in Table 2.

Table 2. Moisture content and essential oil yield under different drying methods

Method	Clove moisture content (%)	Nutmeg moisture content (%)	Clove yield (%)	Nutmeg yield (%)
Sunlight	9.27 $\pm$ 0.31 ^a	9.37 $\pm$ 0.31 ^a	12.93 $\pm$ 0.15 ^b	6.30 $\pm$ 0.10 ^b
Oven/hot air	9.10 $\pm$ 0.30 ^a	9.17 $\pm$ 0.31 ^{ab}	12.43 $\pm$ 0.15 ^c	5.90 $\pm$ 0.10 ^c
Vacuum	8.63 $\pm$ 0.25 ^a	8.53 $\pm$ 0.25 ^b	13.33 $\pm$ 0.15 ^a	6.60 $\pm$ 0.10 ^a

Note: values within the same column with different superscript letters indicate significant differences based on Tukey HSD ($p < 0.05$).

Table 3. Summary of one-way ANOVA results

Parameter	F(2,6)	p	Interpretation
Clove moisture content	3.979	0.079	Not significant
Nutmeg moisture content	6.803	0.029	Significant
Clove yield	27.111	0.001	Significant
Nutmeg yield	37.000	<0.001	Significant

Note: statistics were calculated from the means, standard deviations, and n=3 available in the source manuscript.

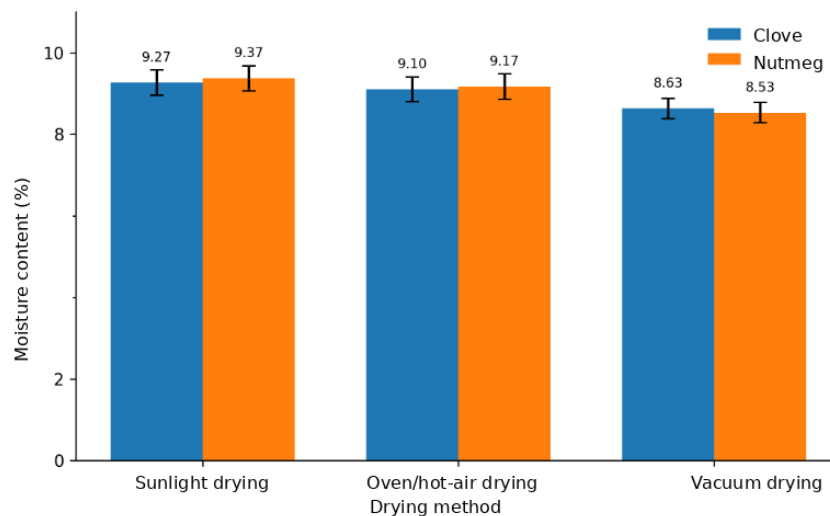


Figure 1. Moisture content of clove and nutmeg simplicia after three drying methods

In clove, the difference in moisture content among methods did not reach statistical significance ($p=0.079$), although vacuum drying produced the lowest numerical value. In nutmeg, drying method had a significant effect ($p=0.029$). The Tukey test showed differences mainly between sunlight and vacuum drying, while the oven/hot-air group was intermediate. These results indicate that the effectiveness of moisture removal is influenced not only by temperature but also by pressure and the characteristics of the plant tissue.

Under reduced pressure, vacuum drying lowers the boiling point of water, allowing water removal to occur at a lower effective temperature. This principle is relevant to aromatic materials because it can limit excessive heating and reduce the time the material remains in a moist condition. These findings are consistent with reports that vacuum drying can better preserve the physicochemical properties and volatile profiles of some aromatic plants than convective drying, although the specific response depends on the type of material (Thamkaew et al., 2021; Żbik et al., 2023).

Essential oil yield differed significantly in clove ($p=0.001$) and nutmeg ($p<0.001$). All treatment pairs showed significant differences based on the Tukey's HSD test. Vacuum drying produced the highest yield, sunlight drying produced an intermediate yield, and oven/hot-air drying produced the lowest yield. This consistent pattern in both materials supports the possibility that convective heating in the oven may increase the loss of some volatile components before distillation, whereas vacuum drying may better balance moisture removal and essential oil retention.

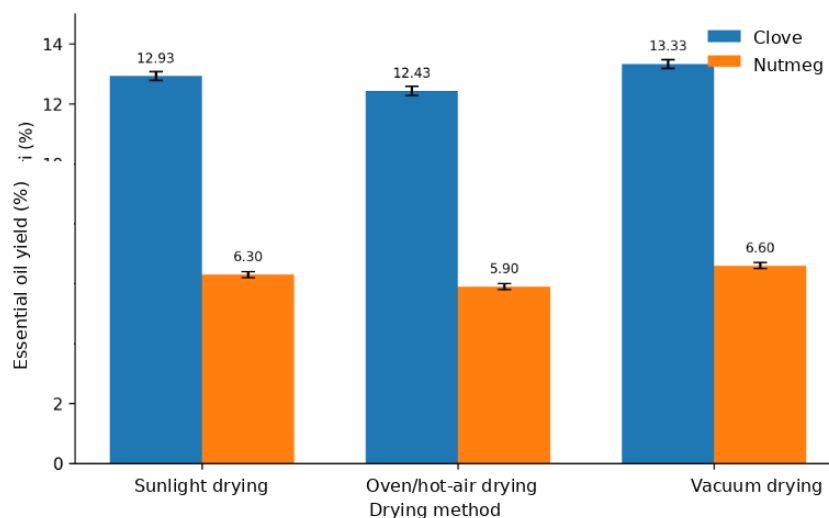


Figure 2. Essential oil yield of clove and nutmeg after three drying methods

Sunlight drying produced a higher yield than oven drying, but it still has limitations, including fluctuations in temperature, humidity, and light intensity, as well as contamination risks. Therefore, sun drying can be used when resources are limited, but it is less suitable for process standardization. Oven drying is easier to control, but temperature and drying duration need to be optimized to avoid volatile compound loss. These findings reinforce the importance of determining the drying endpoint based on moisture content and product retention rather than drying time alone (Al-Hamdani et al., 2022; Thamkaew et al., 2021).

Clove produced a higher yield than nutmeg under all treatments. This difference is related to the plant part and matrix characteristics. Clove flower buds are known to be rich in essential oil, with eugenol as a major component, whereas nutmeg seeds contain essential oil together with fixed oil and oleoresin components. Therefore, the absolute yield comparison between the two species should be interpreted based on material characteristics rather than solely as a difference in distillation efficiency (Ashokkumar et al., 2022; Liñán-Atero et al., 2024).

GC/FID and GC-MS Benchmark

The chromatographic benchmark was used to place the yield results in the context of potential chemical quality. The data in Table 4 show that eugenol is consistently the main marker of clove oil, whereas nutmeg oil is more appropriately evaluated using a combination of myristicin and major monoterpenes. The wide range of values among studies indicates that material origin, pretreatment, extraction method, and instrument conditions can affect the reported composition.

The benchmark data show that a high yield alone is not sufficient to conclude chemical quality. In clove, the performance of the drying method needs to be confirmed through eugenol determination using GC/FID or GC-MS. In nutmeg, GC-MS is more relevant because the quality profile involves myristicin, sabinene, α -pinene, β -pinene, terpinen-4-ol, and other volatile compounds. Therefore, the advantage of vacuum drying in this study is primarily demonstrated by the moisture content and yield parameters, while retention of marker compounds still requires actual chromatographic testing.

Table 4. Benchmark of essential oil marker compounds from previous studies

Source	Sample	Method	Marker	Value/area (%)	
(Gotmare & Gotmare, 2021)	Clove oil obtained by hydrodistillation	GC/FID	Eugenol	±82.27	GC/FID is relevant for clove eugenol quantification
(Kusuma et al., 2025)	Clove oil from flowers	GC-MS	Eugenol	97.24	Clove flowers showed the highest eugenol content compared with stems and leaves
(Ben Hassine et al., 2021)	Clove bud/flower essential oil	GC-MS	Eugenol	68.70–87.40	Pretreatment can affect the eugenol composition of clove essential oil
(Ahamad et al., 2022)	Clove essential oil	GC-MS	Eugenol	59.16	Eugenol remains the dominant component, but the oil profile may vary according to material source and sample quality
(Akotowanou et al., 2024)	Clove oil	GC/GC-MS	Eugenol	59.11	Eugenol remains the dominant component
(Trifan et al., 2023)	Clove essential oil from various studies	Review GC-based studies	Eugenol	55.28–97.80	Benchmark range for clove chemical quality
(Trifan et al., 2023)	Nutmeg essential oil	GC-MS	Sabinene	21.71	Major component of nutmeg oil

Note: all values are secondary data from previous studies and are not results of direct testing of the samples in this study.

Overall, vacuum drying provided the best combination of low moisture content and high yield. However, its application at production scale needs to consider equipment cost, capacity, energy consumption, material-bed thickness, and processing time. Further studies should compare energy and chemical quality parameters so that the technical benefits of vacuum drying can be evaluated more comprehensively.

Analysis of Results

The results showed that the clove and nutmeg simplicia used in this study were consistent with the expected macroscopic and organoleptic characteristics of the respective aromatic materials. Clove was identified as dried flower buds with a dark-brown color and strong characteristic aroma, while nutmeg was identified as dried seeds with an oval shape, hard texture, and characteristic aromatic odor. Confirmation of material identity provides an important basis before drying, phytochemical screening, and essential oil distillation.

Phytochemical screening showed differences in secondary metabolite characteristics between clove and nutmeg. Clove showed strong dominance of phenolics/tannins, whereas nutmeg showed strong dominance of terpenoids. These findings support the chemical characteristics of each simplicia: clove is more relevantly associated with eugenol as the main volatile phenolic compound, whereas nutmeg is more relevantly associated with terpenoid and phenylpropanoid groups such as sabinene, α -pinene, β -pinene, terpinen-4-ol, safrole, and myristicin.

For moisture content, all drying methods reduced the moisture content of the simplicia to below 10%. Vacuum drying produced the lowest final moisture content, at $8.63 \pm 0.25\%$ in clove and $8.53 \pm 0.25\%$ in nutmeg. This indicates that vacuum drying was more effective in reducing water content than sunlight and oven/hot-air drying. This effectiveness can be associated with reduced pressure, which allows water to evaporate at a lower effective temperature, resulting in more controlled drying and less excessive heat exposure to the aromatic materials.

For essential oil yield, vacuum drying also produced the highest yield in both simplicia, namely, $13.33 \pm 0.15\%$ for clove and $6.60 \pm 0.10\%$ for nutmeg. In contrast, oven/hot-air drying produced the lowest yields, namely $12.43 \pm 0.15\%$ for clove and $5.90 \pm 0.10\%$ for nutmeg. This pattern indicates that the drying method affects not only moisture content but also the efficiency of essential oil recovery. The lower yield obtained with oven/hot-air drying may be caused by heat exposure that potentially promotes evaporation of some volatile components before distillation.

The summary heatmap further indicates that vacuum drying is the most promising method because it provided the best results across both parameters: moisture content and essential oil yield. Sunlight drying produced intermediate results, whereas oven/hot-air drying was relatively effective in reducing moisture content but less optimal for maintaining essential oil yield. Therefore, the selection of a drying method should consider two aspects simultaneously: the ability to reduce moisture content and the ability to preserve volatile components contributing to essential oil yield.

GC/FID and GC-MS benchmarks from previous studies indicate that eugenol is the main marker of clove essential oil, whereas myristicin and monoterpenes are more relevant quality markers for nutmeg essential oil. Therefore, a high essential oil yield cannot directly be interpreted as superior chemical quality before actual chromatographic analysis is performed. For clove, the most relevant further analysis is eugenol quantification using GC/FID, while for nutmeg, GC-MS is more appropriate for mapping the main volatile compound profile.

Overall, the findings of this study indicate that vacuum drying is the most promising method among the three methods tested because it produced the lowest moisture content and the highest essential oil yield in both clove and nutmeg simplicia. However, the chemical quality of the essential oils still needs to be confirmed through actual GC/FID and GC-MS analyses so that the relationship between drying method, yield, and marker compound composition can be demonstrated more comprehensively.

CONCLUSION

Drying method affects the moisture content and essential oil yield of clove (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*) simplicia. All methods produced moisture contents below 10%. Vacuum drying produced the lowest moisture content, namely $8.63 \pm 0.25\%$ in clove and $8.53 \pm 0.25\%$ in nutmeg, as well as the highest yields, namely $13.33 \pm 0.15\%$ and $6.60 \pm 0.10\%$, respectively. The effect of drying method on clove moisture content was not significant, whereas nutmeg moisture content and the yields of both simplicia differed significantly. Oven/hot-air drying produced the lowest yields, indicating the possible loss of volatile components during heating. Therefore, vacuum drying shows the greatest potential for controlled postharvest processing. GC/FID analysis of clove oil and GC-MS analysis of nutmeg oil are still required to confirm the effects of drying on eugenol, myristicin, and the main monoterpenes.

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