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Article

Effect of Growing Location on The Chemical Profile of The Essential Oil of Papua Nutmeg (*Myristica argentea* Warb.) based on GC-MS analysis

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Abstract. *Myristica argentea* Warb. is an endemic Indonesian nutmeg species with potential as an economically valuable essential oil source. This study evaluated the effect of growing location on the chemical profile of *M. argentea* seed essential oil from two locations in Maluku: West Seram on Seram Island, characterized by inland mountainous forest, and Hutumuri on Ambon Island, a low-lying coastal area. Essential oils were obtained by steam distillation and analyzed using Gas Chromatography-Mass Spectrometry. The oil yields from West Seram and Hutumuri were 1.95% and 1.78%, respectively. Twenty compounds were identified in both samples, with sabinene as the dominant component (26.34% in West Seram and 32.75% in Hutumuri), followed by β-phellandrene, safrole, and (+)-α-pinene. Although qualitative composition was similar, quantitative differences were observed in several compounds, particularly sabinene, safrole, and myristicin. The contrasting environmental characteristics may be associated with variations in secondary metabolite biosynthesis and essential oil composition. The relatively high safrole content, particularly in Hutumuri, highlights the need for safety assessment and quality standardization before potential industrial applications. These findings provide baseline information on geographical variation in the chemical profile of *M. argentea* essential oil.

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1. Introduction

Indonesia is a megadiverse country with exceptionally high plant diversity and a rich diversity of medicinal plants; however, ethnobotanical documentation remains geographically uneven, and many of these plants have yet to be scientifically explored [1]. This biological richness has encouraged the use of various plant species as traditional medicines that have been passed down through generations in Indonesia communities [2]. One plant of particular importance as both a spice and a medicinal plant is nutmeg. Nutmeg is a signature commodity of eastern Indonesia, particularly the Maluku Islands, and has long been recognized and utilized for its diverse uses and economic value. Its economic potential has driven the expansion of nutmeg cultivation through plantations across various regions of Maluku. Nutmeg essential oil is used as a raw material in the pharmaceutical, cosmetic, and beverage industries, while its leaves are used in various herbal spa products for relaxation [3-4].

Nutmeg (*Myristica fragrans* Houtt.) belongs to the family *Myristicaceae* and is an evergreen tropical tree with a characteristic aroma and flavor [5-6]. Nutmeg seeds contain 5-15% essential oil, which is widely used in the perfume and pharmaceutical industries [7]. Various studies have reported that nutmeg exhibits diverse biological and pharmacological activities, including antidysenteric, antibacterial, antifungal, antimalarial, larvicidal, antioxidant, anti-inflammatory, antiviral, antithrombotic, hepatoprotective, neurostimulatory, anticonvulsant, anticancer, aphrodisiac, stomachic, and nootropic activities [8-13].

In addition to common nutmeg (*M. fragrans*), Indonesia is also home to another endemic nutmeg species, Papua nutmeg (*M. argentea* Warb.), which grows naturally in the Papua region and the Maluku Islands [14]. This species is not yet as widely utilized commercially or studied scientifically as common nutmeg, despite its considerable potential as a source of bioactive compounds [15]. *M. argentea* shares similar morphological characteristics and growing conditions with *M. fragrans*, bears oval-shaped fruits, and all parts of the plant including the flesh, seed, mace, and leaves can be used in traditional medicine [16-17]. It possesses pharmacological activity as an antioxidant and antibacterial agent [18].

Essential oils are mixture of volatile aromatic compounds produced by plants that plays important role in plant defense mechanisms. In addition, essential oils are known to possess various biological activities with potential applications in health and industry [19]. The composition of secondary metabolites in plants is influenced by both internal and external factors. Internal factors are mainly related to genetics, while external factors include cultivation conditions, soil type, soil pH, nutrient content, temperature, light intensity, humidity, rainfall, altitude, geographical position, and harvest time [20-23]. Various studies have shown that essential-oil-producing plants can exhibit considerable variation in both the quality and quantity of the oil produced in response to the environmental conditions of their growing sites [24]. Different environmental conditions can also affect the accumulation and composition of secondary metabolites through changes in plant physiological and biosynthethic processes. Furthermore, variations in climatic conditions and abiotic factors can lead to differences in secondary metabolit accumulation among populations or growing locations [22].

Studying variation in secondary metabolites requires a metabolomic approach to obtain a comprehensive picture of the chemical composition of a sample. One widely used metabolomic approach is metabolic fingerprinting, which employs chromatographic and spectroscopic techniques to identify metabolite patterns in a sample [21]. This approach has been widely applied in the quality control of herbal materials, including geographical origin tracing, adulteration detection, and species authentication based on their chemical characteristics [25].

Various analytical techniques have been developed to identify and differentiate chemical composition of samples, one of which is Gas Chromatography–Mass Spectrometry (GC-MS) [26]. This technique is widely used in pharmaceutical research, forensics science, environmental science, and natural-product research because it can separate and identify individual chemical components based on their mass spectral characteristics [27-29]. GC-MS offers high sensitivity and resolution, enabling the detection of both volatile and semivolatile compounds, including metabolites present at low concentrations in complex matrices [26],[30].

Although several studies have reported the chemical composition of the essential oils from *M. fragrans*, information on the chemical profile of *M. argentea* essential oil remains relatively limited. Previous studies have characterized *M. argentea* essential oil from a single location [14] and used GC-MS fingerprinting combined with chemometric analysis to differentiate *M. argentea* and *M. fragrans* [16]. However, information on variations in the chemical profile of *M. argentea* essential oil among different growing locations within the same species remains limited, particularly in the Maluku region. Differences in habitats, such as inland forest and coastal environments, may result in distinct ecological conditions and potentially contribute to variations in secondary metabolite biosynthesis. Such environmental conditions have been reported to influence the biosynthesis of monoterpenes and phenylpropanoids in several aromatic plant species [31-32].

Based on this knowledge gap, this study was conducted to analyze and compare the chemical profile of the essential oil of Papua nutmeg seeds (*M. argentea* Warb.) collected from two different growing locations in Maluku using GC-MS analysis. The novelty of this study lies in its comparative assessment of the influence of growing location on the chemical composition of *M. argentea* essential oil, an Indonesian nutmeg species that remains underexplored, thereby addressing a specific gap that has not previously been investigated for this species. The findings of this study are expected to provide scientific information on the chemical profile variation of Papua nutmeg essential oil, support raw material quality standardization, and serve as a basis for developing the utilization of *M. argentea* essential oil in the pharmaceutical, food, cosmetic, and other biodiversity-based industries.

2. Experimental Section

2.1. Materials

The main material used in this study was Papua nutmeg seeds (*M. argentea* Warb.) obtained from two different locations in Maluku Province, namely West Seram, Seram Island (MA01), and Hutumuri, Ambon Island (MA02). The chemicals used included distilled water, n-hexane (pro-analysis grade), and anhydrous sodium sulfate (Na_2SO_4).

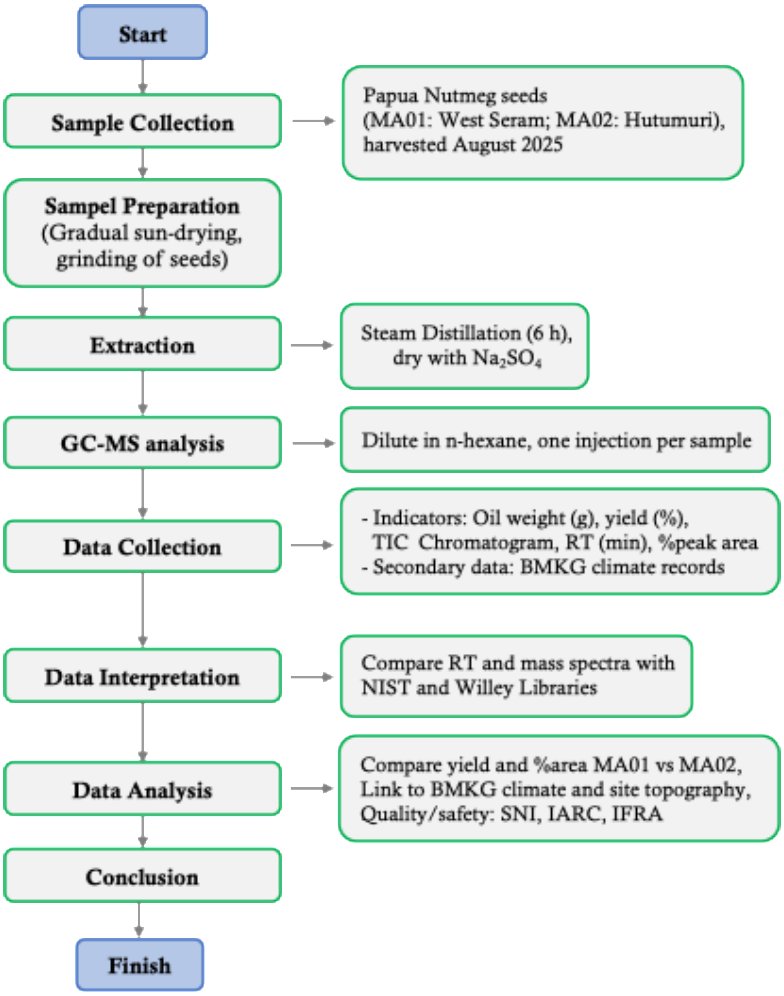


Figure 1. Schematic/Flowchart of research

2.2. Methods

2.2.1 Extraction of Papua Nutmeg Essential Oil (*M. argentea* Warb.)

Papua Nutmeg (*M. argentea*) seeds were harvested on August 2025, during the middle of the rainy season, and were subsequently dried by gradual sun-drying without direct exposure to intense sunlight. Whole, dry Papua nutmeg seeds were weighed at 1.3 kg for sample MA01 and 1.058 kg for sample MA02. The samples were then ground to reduce the particle size and increase the surface area for extraction. Essential oil extraction was carried out using the steam distillation method. Each sample was distilled once for 6 h. The resulting essential oil was separated from the aqueous phase and dried over anhydrous sodium sulfate to remove residual water. The essential oil was subsequently stored in a tightly sealed amber glass bottle, protected from light, until further analysis was carried out. The essential oil yield was calculated as the ratio of the weight of essential oil obtained to the dry weight of the sample and expressed as a percentage (%).

2.2.2 Chemical Profile Analysis Using Gas Chromatography-Mass Spectrometry (GC-MS)

Chemical profile analysis of the essential oil was carried out using a GC-MS instrument to identify the volatile compounds contained in the essential oil of Papua nutmeg seeds (*M. argentea* Warb.). Each essential oil sample was analyzed once. Prior to analysis, the essential oil was diluted in n-hexane to an appropriate concentration and then injected into the GC-MS system. Compound separation was

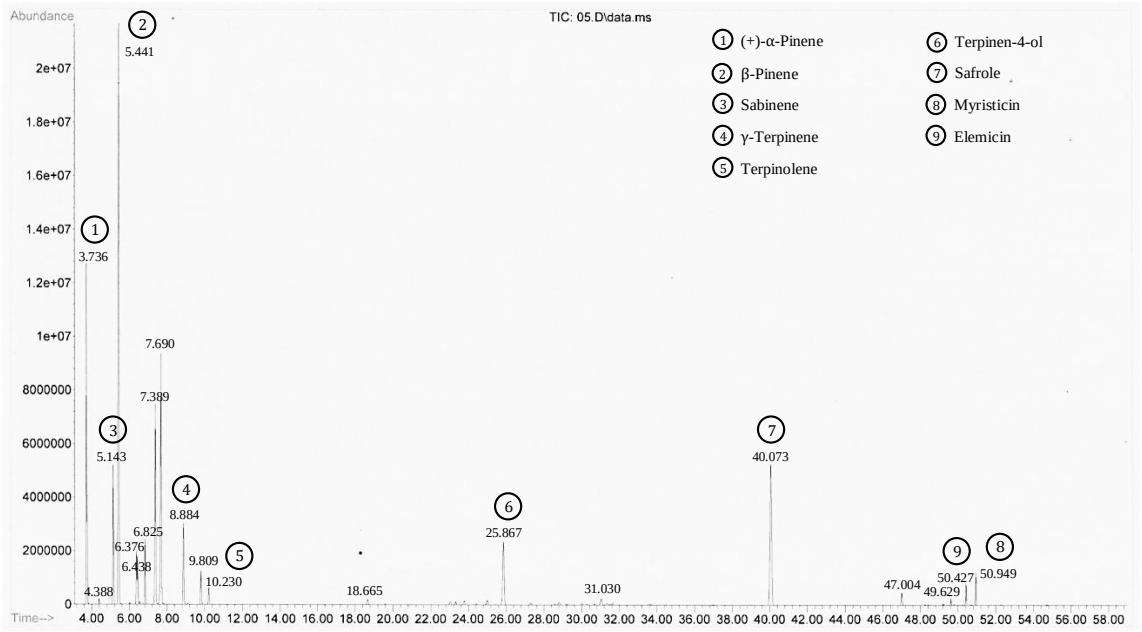
performed using an HP-5MS capillary column (30 m × 0.25 mm × 0.25 μm). Helium was used as the carrier gas at a constant flow rate of 1.0 mL min^{-1}. The injector temperature was maintained at 250°C and the detector temperature at 280°C. The oven temperature program started at 60°C and was held for 2 min, then increased at a rate of 5°C min^{-1} up to 280°C, and held for 10 min. All detected compounds were quantified based on the percentage relative peak area (%). Compound identification was performed tentatively by comparing the relative retention times and mass spectra with the National Institute of Standards and Technology (NIST) and Wiley reference libraries integrated into the GC-MS system [33]. The identification results are presented as the compound name, retention time, and relative peak area percentage for each detected component.

3. Results and Discussion

The plant material used in this study consisted of dry Papua nutmeg seeds obtained from West Seram (SBB), Seram Island (MA01), and Hutumuri, Ambon Island (MA02). Extraction using the steam distillation method showed that the essential oil obtained from MA01 was 25.36 g with a yield of 1.95%, while MA02 yielded 18.83 g with a yield of 1.78%. These yield were higher than those reported by Maryati (2023) [14], who reported an essential oil yield of 1.35 ± 0.13% (v/w) for *M. argentea* seeds using water-steam distillation. The observed difference in yield may be attributed to differences in growing location and environmental conditions. Genetic and environmental factors such as temperature, rainfall, altitude, and soil fertility are known to affect the biosynthesis and accumulation of volatile compounds in plants [34-36].

GC-MS analysis of the Papua nutmeg essential oil resulted in total ion chromatograms (TICs), as presented in Table 1 and Figure 2. The chromatograms of both samples showed similar qualitative profiles, but differences in peak intensity were observed, indicating quantitative variation between locations. This indicates that although the compound composition is relatively similar, the proportion of each component appeared to vary between the two sampling locations.

A



B

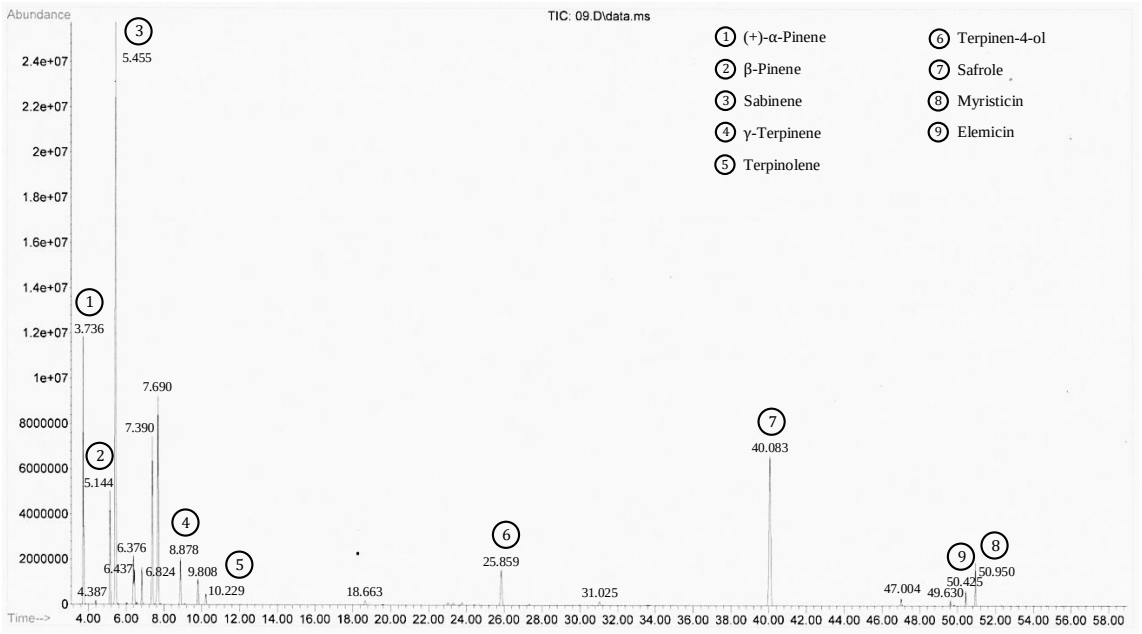


Figure 2. GC-MS chromatogram of essential oil extracted from Papua nutmeg seeds (*M. argentea* Warb.): A. MA01, Papua nutmeg from West Seram (SBB) – Seram Island; B. MA02, Papua nutmeg from Hutumuri – Ambon Island

Table 1. Characterization of the essential oil composition of Papua nutmeg seeds (*M. argentea* Warb.) using Gas Chromatography-Mass Spectrometry (GC-MS)

No.	Name of Compound (Molecular formula; CAS Number)	RT* (min)	Peak area percentage (%)	
			MA01	MA02
1	(+)-α-Pinene ($C_{10}H_{16}$; 7785-70-8)	3.73	11.70	10.01
2	Camphene ($C_{10}H_{16}$; 79-92-5)	4.38	0.18	0.16
3	β-Pinene ($C_{10}H_{16}$; 127-91-3)	5.14	5.24	4.89
4	Sabinene ($C_{10}H_{16}$; 3387-41-5)	5.45	26.34	32.75
5	β-Myrcene ($C_{10}H_{16}$; 123-35-3)	6.37	2.16	2.16
6	α-Phellandrene ($C_{10}H_{16}$; 99-83-2)	6.43	1.73	1.41
7	α-Terpinene ($C_{10}H_{16}$; 99-86-5)	6.82	2.69	1.71
8	D-Limonene ($C_{10}H_{16}$; 5989-27-5)	7.38	9.67	8.94
9	β-Phellandrene ($C_{10}H_{16}$; 555-10-2)	7.69	12.90	11.79
10	γ-Terpinene ($C_{10}H_{16}$; 99-85-4)	8.88	3.96	2.53

No.	Name of Compound (Molecular formula; CAS Number)	RT* (min)	Peak area percentage (%)	
			MA01	MA02
11	o-Cymene ($C_{10}H_{14}$; 527-84-4)	9.80	1.78	1.49
12	Terpinolene ($C_{10}H_{16}$; 586-62-9)	10.23	0.91	0.62
13	Sabinenehydrate ($C_{10}H_{18}O$; 546-79-2)	18.66	0.35	0.34
14	Terpinen-4-ol ($C_{10}H_{18}O$; 562-74-3)	25.86	4.90	3.01
15	α-Terpineol ($C_{10}H_{18}O$; 98-55-5)	31.02	0.47	0.32
16	Safrole ($C_{10}H_{10}O_2$; 94-59-7)	40.08	12.33	14.38
17	Methyleugenol ($C_{11}H_{14}O_2$; 93-15-2)	47.01	0.63	0.40
18	Eugenol ($C_{10}H_{12}O_2$; 97-53-0)	49.62	0.20	0.22
19	Elemicin ($C_{12}H_{16}O_3$; 487-11-6)	50.427	0.69	0.54
20	Myristicin ($C_{11}H_{12}O_3$; 607-91-0)	50.95	1.16	1.74

*Retention time

Overall, 20 compounds were successfully identified in both samples. The dominant compounds included sabinene, β-phellandrene, safrole, and (+)-α-pinene, followed by β-pinene, γ-terpinene, terpinolene, terpinen-4-ol, myristicin, and elemicin. These compounds are the major constituents responsible for the characteristic aroma of nutmeg and are known to contribute to various biological activities, including antioxidant, antimicrobial, and anti-inflammatory activities [10][37-40].

Sabinene was the most abundant constituent in both samples, accounting for 26.34% in MA01 and 32.75% in MA02. Sabinene is a monocyclic monoterpene known to possess antimicrobial, antioxidant, and anti-inflammatory activities [41]. The higher sabinene content in MA02 indicates a possible influence of environmental conditions on the enhanced biosynthesis of certain monoterpene compounds, although this tendency requires confirmation through replicate analyses.

Safrole was detected as the second most abundant component, at 12.33% (MA01) and 14.38% (MA02). Safrole is a phenylpropanoid compound with various biological activities; however, it is also recognized for its genotoxic potential. The International Agency for Research on Cancer (IARC) classifies safrole as Group 2B (possibly carcinogenic to humans) based on evidence of carcinogenicity in experimental animals, particularly in relation to liver cancer [42-43]. Therefore, the relatively high safrole content in both samples, especially MA02, warrants careful consideration in the safety evaluation and standardization of *M. argentea* essential oil products.

Given that the European Commission has prohibited the addition of safrole as a pure flavoring substance in food products and has established maximum limits for its natural content in certain food products, such as soups, sauces, and non-alcoholic beverages [42], and that the International Fragrance Association (IFRA) restricts the total safrole content in cosmetic/fragrance products to a maximum of 0.01% in the final product [44], the safrole content in the essential oil of *M. argentea* MA02 (14.38%) clearly far exceeds these safety limits if used without further processing. Therefore, the utilization of *M. argentea* essential oil in the food, cosmetic, and pharmaceutical sectors requires

mitigation strategies, such as substantial dilution to below the applicable regulatory thresholds. The separation of the safrole-rich fraction through fractionation techniques may also serve as an alternative mitigation strategy for this class of alkenylbenzene compounds; however, specific validation on *M. argentea* essential oil is still required before this approach can be definitively recommended.

β-phellandrene was detected at 12.90% (MA01) and 11.79% (MA02), while (+)-α-pinene was detected at 11.70% (MA01) and 10.01% (MA02). (+)-α-pinene is a bicyclic monoterpene commonly found in essential oils and has been reported to exhibit anti-inflammatory activity [45]. β-phellandrene has also been identified as one of the major constituents of the essential oils of other aromatic plants, which have demonstrated antimicrobial activity against several anaerobic bacteria and *Candida albicans* [46]. The difference in the levels of these two compounds indicates variation in terpenoid biosynthetic pathways between growing locations.

Myristicin, one of the characteristic marker compounds of nutmeg essential oil, accounted for 1.16% in MA01 and 1.74% in MA02. This compound has been reported to exhibit promising pharmacological activities, particularly antioxidant, anti-inflammatory, and antiproliferative effects [47]. According to the Indonesian National Standard (SNI 06-2388-2006), myristicin content is generally used as a quality parameter for nutmeg oil, with a minimum value of 5% [48]. The myristicin content in both samples was below this standard and was also lower than the range of 2.12-5.98% reported by A'Mun [49].

However, this low myristicin content is consistent with patterns reported for other endemic Indonesian nutmeg species, using the same SNI analytical method, Karmanah et al (2020) [5] reported a myristicin content of only 1.3% in the seeds of Ambon Forest nutmeg (*M. fatua*), markedly lower than that of Banda nutmeg (*M. fragrans*, 8.72%), suggesting that the low myristicin content in *M. argentea* likely reflects a species-specific chemotype rather than an indication of inferior quality. This is further supported by chemotaxonomic evidence from Khamnuan et al. (2026) [16], who reported that *M. fragrans* is consistently characterized by high sabinene and pinene levels, whereas *M. argentea* is characterized by higher safrole levels, with myristicin serving as one of the key differentiating markers between the two species.

In addition to these major compounds, other monoterpenes were identified, including β-myrcene (2.16% in MA01 and 2.16% in MA02), α-phellandrene (1.73% and 1.41%), α-terpinene (2.69% and 1.71%), D-limonene (9.67% and 8.94%), and o-cymene (1.78% and 1.49%). Several minor constituents were detected in trace amounts, including camphene (0.18% and 0.16%), sabinene hydrate (0.35% and 0.34%), α-terpineol (0.47% and 0.32%), methyleugenol (0.63% and 0.40%), and eugenol (0.20% and 0.22%).

The differences in chemical composition between MA01 and MA02 may be attributed to environmental factors. Based on BMKG climatological data for the period February 2025-Januari 2026, the average air temperature and relative humidity of West Seram (Seram Island) and Hutumuri (Ambon Island) were relatively similar (27.1°C and 87.0% in West Seram; 26.8°C and 85.9% in Hutumuri), whereas total rainfall during this period was considerably higher in Hutumuri (6,126.2 mm) than in West Seram (3,298.6 mm) [50]. Topographically, Hutumuri is a gently sloping coastal area (elevation 0-50 m a.s.l) with coarse-textured soil (gravel and coral fragments) near the shoreline, transitioning to medium sand further inland [51], whereas West Seram is dominated by hilly-to-mountainous terrain with an average elevation of ~114 m a.s.l. and a clay-slit-sandy soil texture [52]. These difference in rainfall, elevation, and soil texture between the two locations are presumed to contribute to the observed variation in secondary metabolite biosynthesis.

Interestingly, the pattern of variation among individual compounds in this study was not uniform in relation to the differences in rainfall between the two locations. Most monoterpenes (10 of the 11 identified compounds) showed higher levels in West Seram (lower rainfall), consistent with findings by Lotfi et al. (2024) [53] in *Stachys lavandulifolia*, which demonstrated that variations in essential oil content and composition among populations were associated with environmental and edaphic

conditions. However, sabinene the dominant component in both samples along with Safrole and Myristicin, showed higher levels in Hutumuri (higher rainfall). This pattern is consistent with the findings of Martin et al. (2019) [54] in *Iryanthera polyneura*, where some terpenoids were more abundant during the rainy season, whereas others increased during the dry season. In contrast, Zamani et al. (2025) (55) reported that temperature and rainfall were not significantly correlated with essential oil composition in *S. lavandulifolia*, indicating that the influence of climatic factors is not always consistent. A similar variation in compound-specific responses has also been reported in another member of the *Myristicaceae* family, *Osteophloeum platyspermum*, in which certain groups of terpene compounds exhibited different patterns between the dry and rainy seasons [56]. These findings suggest that the effects of rainfall, elevation, and soil texture on secondary metabolite biosynthesis in *M. argentea* are compound-specific rather than representing a single uniform effect across all terpenoid and phenylpropanoid groups.

Environmental factors such as temperature water availability, light intensity, and soil conditions can influence the accumulation and composition of secondary metabolites by altering physiological processes and biosynthethic pathways in plants [23],[32],[35-36]. In the present study, the interpretation of the role of environmental factors provides an initial contextual framework based on regional climatological data and the geographical characteristics of the two locations rather than on direct measurements of environmental parameters. Therefore, further research incorporating direct measurements of meteorological parameters and soil physicochemical characteristics at the sampling sites is needed to provide a more comprehensive assessment of the relationship between environmental conditions and variations in the chemical profile of *M. argentea* essential oil.

4. Conclusion

This study identified 20 compounds in the essential oil of Papua nutmeg seeds (*M. argentea* Warb.) collected from two different growing locations using GC-MS. The major constituents included (+)-α-pinene, β-pinene, sabinene, β-phellandrene, γ-terpinene, terpinolene, terpinen-4-ol, safrole, myristicin, and elemicin. Quantitative differences in the relative abundances of several constituents were observed between the two locations, particularly for sabinene, safrole, and myristicin, which were higher in the sample from Hutumuri (Ambon Island). These differences may be attributed to environmental factors such as rainfall, elevation, and soil texture between the two locations. However, since each sample was analyzed by a single GC-MS injection, these differences should be regarded as preliminary indications rather than statistically validated distinctions. The higher safrole content found at one location (Hutumuri, Ambon Island) underscores the need for standardization and quality control to ensure the safe use of Papua nutmeg essential oil. Further studies are needed to include additional growing locations, include analytical replication and to investigate the pharmacological and toxicological properties of this essential oil.

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