

# The Effect of Shade and Harvest Age on Biomass and Patchouli Oil Production in the Lowlands

Dominggus Ngongo Riti<sup>A</sup>, Ani Kurniawati<sup>A</sup>, Waras Nurcholis<sup>B, C</sup>

<sup>A</sup> Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Jl. Meranti, IPB Darmaga Campus, Bogor 16680, West Java, Indonesia

<sup>B</sup> Tropical Biopharmaca Research Center, IPB University, Jl. Taman Kencana, IPB Taman Kencana Campus, Bogor 16128, West Java, Indonesia

<sup>C</sup> Department of Biochemistry, Faculty of Mathematics and Natural Sciences, IPB University, Jl. Tanjung IPB Dramaga Campus, Bogor 16680, West Java, Indonesia

\*Corresponding author; email: [ani\\_kurniawati@apps.ipb.ac.id](mailto:ani_kurniawati@apps.ipb.ac.id)

## Abstract

This study investigated the effects of different shade levels and harvest ages on the growth, biomass yield, and essential oil production of the patchouli (*Pogostemon cablin* Benth.) cultivar Sidikalang, cultivated in a lowland environment. The experiment was conducted in Bogor from August 2023 to February 2024, using a nested design with three shade treatments (no shade, 55%, and 75%) and three harvest ages (4, 5, and 6 months). The results indicated that 75% shade significantly enhanced vegetative growth, including plant height, number of secondary branches, and leaf production, suggesting that this level of shading is beneficial for patchouli cultivation in lowland areas. However, these effects were not significantly different from those observed under 55% shade. The highest essential oil yields were obtained from patchouli plants grown under 75% shade and harvested at 4 months, as well as from those grown under full sunlight and harvested at 6 months.

Keywords: patchouli alcohol, essential oil yield, low light

## Introduction

Patchouli (*Pogostemon cablin*) is a well-known essential oil-producing plant, widely traded internationally under the name Patchouli Oil (Huda et al., 2021). The patchouli industry makes a significant contribution to household income, accounting for 31–97% of family earnings in some regions (Jati et al., 2019). One of the key compounds in patchouli oil is patchouli alcohol (PA), which is highly valued in the perfume industry for its role as an aroma binder. The quality of patchouli essential oil is

primarily determined by its patchouli alcohol content, as specified by the Indonesian National Standard (SNI 06-2385-2006). Patchouli alcohol belongs to the sesquiterpene class of compounds and is synthesized from isopentenyl diphosphate (IPP) via the mevalonate pathway (Setiawan and Sukanto, 2016). This pathway, a secondary metabolic process in patchouli, is influenced by photosynthesis and is highly dependent on environmental conditions, genetic factors, phenological stage, and cultivation techniques (Russo and Honermeier, 2017).

Despite its economic importance, patchouli production in Indonesia remains low and is subject to annual fluctuations. This decline is believed to be associated with a reduction in cultivated land area, which decreased from 17,400 hectares in 2021 to 12,800 hectares in 2022 (BPS, 2024). Expanding patchouli cultivation can be achieved by utilizing land beneath other plant canopies, such as fruit trees, forestry species, or plantation crops. However, a primary challenge in such intercropping systems is reduced light intensity, which varies according to the age and density of the shade-providing plants and the season. Young main crops provide minimal shade, while mature stands can create heavy shading conditions. Environmental factors, particularly climate and weather, significantly influence the essential oil content of patchouli (Ditjenbun, 2021). Light intensity directly affects photosynthesis, which is closely linked to organic matter and biomass production. Other factors impacting patchouli oil quality include harvest criteria such as plant age at harvest, the specific plant parts harvested, growing location, and post-harvest handling methods (Kusumaningrum et al., 2016). Harvesting patchouli at too young a stage results in a high leaf-to-stem ratio, which can lower oil quality (Hariyani et al., 2015).

The agroforestry approach has proven effective for increasing agricultural productivity, as demonstrated by the successful cultivation of medicinal and aromatic plants such as *Calendula officinalis* L., *Dracocephalum moldavica* L., *Melissa officinalis* L., and *Satureja hortensis* L. (Zubay et al., 2021). Patchouli is also recommended for cultivation under tree stands, as shown by its successful growth beneath standing trees at the foot of Mount Lawu in Berjo Village, Ngargoyoso District, Karanganyar Regency (Pertiwi et al., 2022). Similarly, Harli (2016) reported that patchouli can be intercropped beneath cocoa and coconut trees.

Patchouli cultivation under shade presents unique challenges, as patchouli plants require adequate light for continuous photosynthesis. The key components of photosynthesis are water, CO<sub>2</sub>, and light (Dobhal et al., 2024), and the absence or deficiency of any of these elements can inhibit the process (Setiawan and Sukamto, 2016). Additionally, anatomical structures directly involved in photosynthesis may undergo changes when plants are grown under shade. For example, Honorato et al. (2023) reported that *Thymus vulgaris* L. plants grown in full sunlight exhibited a higher density of trichome glands, particularly on the adaxial leaf surface, compared to those grown in shade.

Shading can positively influence vegetative growth and modulate secondary metabolism in plants (Ribeiro et al., 2018). By altering light conditions and microclimates, shading affects both plant growth and the production of secondary metabolites (Milenkovic et al., 2021; Ilic et al., 2022). Determining the optimal shade level is essential to maximize patchouli production under plant canopies. While moderate shade (~50%) has been shown to improve growth parameters such as stem diameter and leaf production (Maryani and Gusmawartati, 2011), there is limited information on the effects of higher shade levels, especially in lowland environments.

Physiologically, patchouli plants grown under 55% shade have demonstrated increased photosynthetic rates and chlorophyll content compared to unshaded plants (Setiawan and Sukamto, 2016). Higher chlorophyll content enhances photosynthate production, which benefits overall plant growth and development (Pangestu et al., 2019). Stomata play a crucial role in photosynthesis by regulating transpiration, respiration, and gas exchange (Haryudin et al., 2002), while trichomes help control leaf temperature, protect against herbivores, and reduce water loss (Khokhar et al., 2012).

However, the effects of light intensity on stomatal opening and trichome gland density in patchouli remain unclear. Honorato et al. (2023) observed that *Thymus vulgaris* L. plants grown in sunlight had a higher density of trichome glands, especially on the adaxial leaf surface.

This study aims to evaluate the effects of varying shade levels and harvest times on the growth and essential oil yield of the “Sidikalang” patchouli variety in lowland areas. Understanding these factors will help optimize cultivation practices to enhance biomass and oil production, thereby improving the economic sustainability of patchouli farming in Indonesia’s lowlands.

## Materials and Methods

### Research Location and Experimental Design

The research was conducted at the Cikabayan Experimental Station, IPB University, Bogor, Indonesia, located at coordinates 6°33'05.3" S and 106°42'55.9" E. The study took place from August 2023 to February 2024. A nested randomized complete block design (RCBD) was employed, with shade level as the main plot factor and harvest age as the subplot factor. The shade treatments included three levels: 0%, 55%, and 75%. Harvest ages were 4, 5, and 6 months after planting (MAP). Each treatment combination was replicated four times, resulting in a total of 36 experimental units. Each unit consisted of a 12 m<sup>2</sup> plot containing 20 plants, totalling 720 plants.

### Planting and Maintenance

Shade structures were constructed using bamboo frames measuring 28 m in length, 7 m in width, and 2 m in height. Patchouli seedlings were transplanted into holes measuring 30 cm × 30 cm × 30 cm, spaced at 0.5 m × 1 m intervals. Seedlings were transplanted once they developed 3–4 pairs of leaves.

Regular maintenance included replacing dead plants with seedlings of the same age within 2–4 weeks after planting (WAP), daily watering during the first 3–4 WAP, and regular weeding to reduce competition from surrounding vegetation. Fertilization was applied in two stages; the First application was 4 weeks after planting, consisting of Urea (4.2 g.m<sup>-2</sup>), SP-36 (6 g.m<sup>-2</sup>), and KCl (9 g.m<sup>-2</sup> based on recommended doses of 70 kg.ha<sup>-1</sup>, 100 kg.ha<sup>-1</sup>, and 150 kg.ha<sup>-1</sup> respectively (Trisilawati and Hadipoetryanti, 2015). The second application was three months after planting, consists of Urea at 7.8 g.m<sup>-2</sup>, corresponding to 130 kg.ha<sup>-1</sup>.

## Harvesting

Plants were harvested by cutting 15 cm above ground level to promote shoot regrowth for subsequent harvests (Trisilawati and Hadipoentryanti, 2015). After harvesting, the plant material was sun-dried for 5 hours, followed by indoor drying for 3–5 days until the moisture content reached 15%. The dried biomass was cut into 2–3 cm pieces and subjected to steam distillation using a simple distillation apparatus. Approximately 1 kg of dried material was distilled with water at 100°C, maintaining a biomass-to-water ratio of 1:6 for 2–3 hours per batch (Heptiana, 2020). The essential oil was filtered through polyester mesh to remove water, and the oil yield was determined by weighing the bottle containing the oil, minus the weight of the empty bottle.

## Growth Measurements

Morphological parameters, measured biweekly, included plant height, the number of primary and secondary branches, and leaf count. Leaf thickness and leaf area were assessed at three months after planting using the ImageJ application. Stomata and trichome densities were observed microscopically by applying clear nail colour to the abaxial leaf surface, covering it with clear tape, and transferring the tape to a glass slide. Observations were made under a microscope at 40× magnification, and images were captured for manual counting.

Yield parameters measured included fresh weight, dry weight, oil weight, and oil yield percentage. Fresh biomass was weighed using an analytical scale and expressed in grams per square meter (g.m<sup>2</sup>). Dry biomass was measured after drying using a digital scale. Oil weight was measured using a calibrated pycnometer. Oil yield percentage was calculated as:

$$\text{Yield (\%)} = \frac{\text{Weight of patchouli oil}}{\text{Weight of raw biomass}} \times 100\%$$

Microclimate data were recorded using a lux meter and an Elitech GSP-6 Humidity and Temperature Data Logger on daily light intensity, temperature, and humidity.

## Data Analysis

Data were analyzed using one-way ANOVA to assess significant differences between treatments. When significant effects were detected, Duncan's Multiple Range Test (DMRT) at a 5% significance level was applied for mean separation. All analyses were performed using the DSAASTAT 2023 software.

## Results and Discussion

### Microclimatic Conditions

This study coincided with a long, dry season in 2023, characterized by extreme hot weather and very low rainfall intensity. This condition occurs from the beginning of planting until the plants are three months old, requiring manual watering during this period.

Microclimatic data recorded during the active growth phase of patchouli plants revealed different patterns of temperature, humidity, and light intensity across different shade treatments (Figure 1). Temperatures below 75% shade consistently remain lower than in non-shaded conditions, where more significant fluctuations are observed. As illustrated in Figure 1A, temperatures below 55% shade exhibit a pattern similar to that of non-shaded conditions, peaking around the sixth post-planting week before declining continuously until the fourteenth week. This pattern suggests that denser shade effectively reduces temperature fluctuations, potentially minimizing heat stress on plants.

Humidity levels, displayed in Figure 1B, increased similarly across all treatments, peaking at twelve weeks after planting. This rise in humidity corresponds to a decrease in light intensity, as shown in Figure 1C. Light intensity under no shade was consistently higher, reaching above 60 klux, compared to the 55% and 75% shade levels, which were significantly lower, generally ranging from under 30 klux. This reduction in light intensity under higher shade levels indicates that shading can enhance moisture retention by limiting the exposure of plants to direct sunlight, thereby helping to maintain stable environmental conditions around the plants. These findings align with similar observations by Murillo-Amador et al. (2013), suggesting that denser shade can improve microclimatic conditions that support optimal plant growth.

### Patchouli Growth

Shade treatment has a significant impact on patchouli growth, affecting plant height, branch development, and leaf production. As shown in Figure 2A, while shade does not significantly affect plant height at 4 WAP, 75% and 55% shade promote greater elevations of 8 and 12 WAP. At 16 WAP, plants under 75% shade were the tallest. This suggests that the reduced availability of light in the shade encourages vertical growth as a photomorphogenic response.

Increasing the number of primary, secondary, and tertiary branches is important because it supports

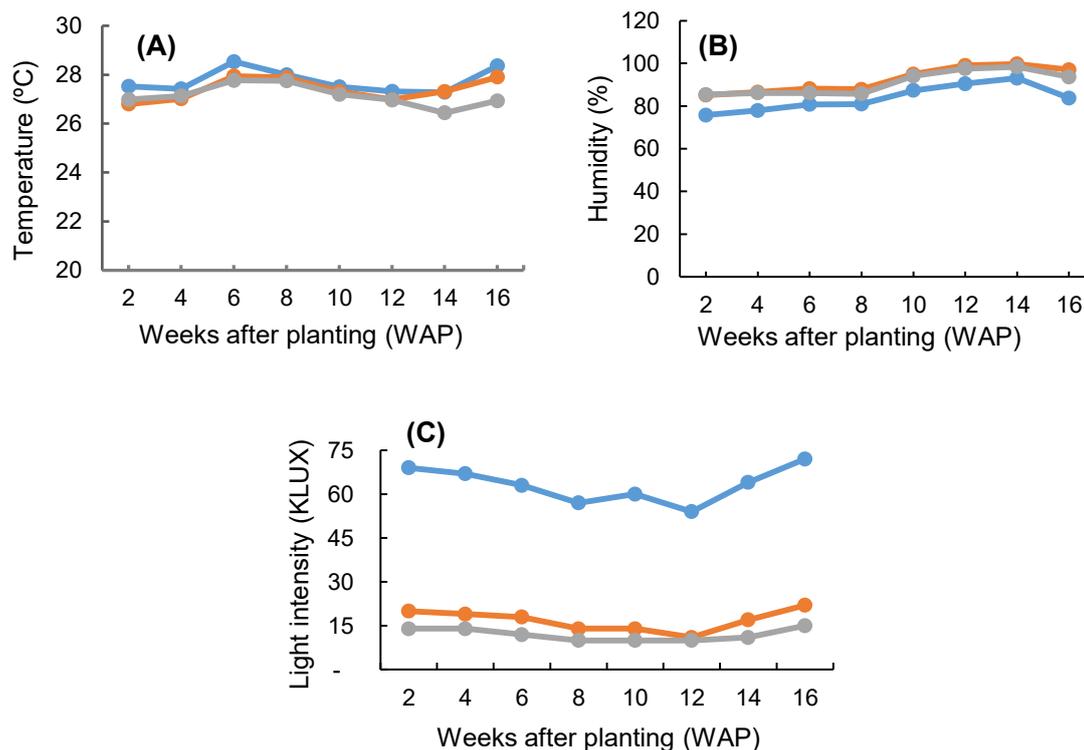


Figure 1. Microclimatic conditions under various shade levels: (A) temperature, (B) humidity, and (C) light intensity

their production. However, what is interesting is that during this observation, the tertiary branch has not appeared in the form of branches, making it difficult to identify it as such. The number of primary branches (Figure 2B) showed no significant difference between shade treatments during the active growth period, suggesting that primary branches were less responsive to shade during the early growth stages. The primary branches, which are attached directly to the main stem, do not increase in number with shade, despite the growth of taller plants in the shade. This pattern may be caused by the elongation of the segments, which extends the distance between the nodes, thereby limiting the formation of primary branches, regardless of the plant's height (Nurlala et al., 2022).

Secondary branching exhibits a pronounced response to shading early in the growth period. As shown in Figure 2C, 75% shade significantly increased the number of secondary branches at 8 weeks after planting (WAP). By 12 weeks after planting (WAP), both 55% and 75% shade levels promoted secondary branching significantly more than no shade. Specifically, plants under 55% shade showed a notable increase in secondary branches compared to unshaded plants at 12 weeks after planting (WAP), although the difference between 55% and 75% shade was not statistically significant. However, by 16 WAP, shading no longer had a significant

effect on secondary branching. This pattern may be explained by the role of sunlight in suppressing auxin production in shoot meristems. At the same time, cytokinin synthesis continues at the root tips, altering the auxin-to-cytokinin ratio and weakening apical dominance, thereby promoting lateral shoot growth. The observed increase in secondary branching under shaded conditions supports the hypothesis that shading reduces apical dominance through hormonal modulation, encouraging lateral growth.

Leaf production was also enhanced by shading treatments (Figure 2D). Both 75% and 55% shade significantly increased leaf number at 4, 8, and 12 weeks after planting (WAP) compared to unshaded plants, with the highest leaf count observed under 75% shade at 16 WAP. The increase in leaf number, particularly under denser shading, appears to be linked to enhanced secondary branching, which provides more nodes for leaf attachment. This finding aligns with Febjislami et al. (2018), who reported a similar correlation between branch and leaf numbers in *Orthosiphon aristatus*. Additionally, Kurniawati et al. (2014) noted that more extended harvest periods are associated with more leaves, suggesting that harvest timing also influences leaf production.

Throughout the growth period, shaded plants consistently produced more leaves than unshaded plants, highlighting the benefits of shading for patchouli

cultivation in lowland areas. By creating a favorable microclimate, shading can increase leaf production. This conclusion is further supported by Ribeiro et al. (2018), who found that patchouli plants grown under various coloured shade nets (blue, red, and black) produced higher leaf biomass when harvested at five months of age. Shaded conditions in lowland environments help manipulate the microclimate, providing lower temperatures and higher humidity, which are more conducive to patchouli growth.

### Morphological and Anatomical Characters of Patchouli Leaves

Patchouli grown under shade develops wider and thinner leaves compared to those grown without shade (Table 1). Conversely, plants grown in full sunlight tend to have thicker leaves than those grown in shade. The physiological response to shading includes an increase in leaf area as well as higher concentrations of chlorophyll a, chlorophyll b, and total chlorophyll. Increasing leaf area is a strategy plants use to maximize light absorption by expanding the surface available for capturing light, while often reducing the number of leaves to compensate for limited light availability (Pamungkas, 2014).

Shading did not have a significant effect on trichome density (Table 1). Trichomes are categorized into two types based on their function: glandular trichomes, which secrete substances such as sugars, salts, and terpenes, and non-glandular trichomes, which do not secrete and consist of one or more cells (Ramdhini et al., 2021). In this study, trichome observations and quantification focused solely on the adaxial leaf surface, following Garcia et al. (2022), as adaxial trichomes are key determinants of natural variation in trichome distribution. The primary focus was on non-glandular trichomes due to their protective role; these trichomes shield leaf surfaces from insect herbivory and mitigate damage from excessive heat during dry seasons (Ganggaram et al., 2020).

Trichome density did not differ significantly between shaded and unshaded patchouli plants, indicating that variations in light intensity do not affect trichome density. Similar findings have been reported for other essential oil plants such as *Ocimum gratissimum*, where light intensity had no impact on trichome gland density (Fernandes et al., 2013). However, contrasting results were observed by Honorato et al. (2023), who found that *Thymus vulgaris* L. plants grown without shade exhibited higher trichome density than

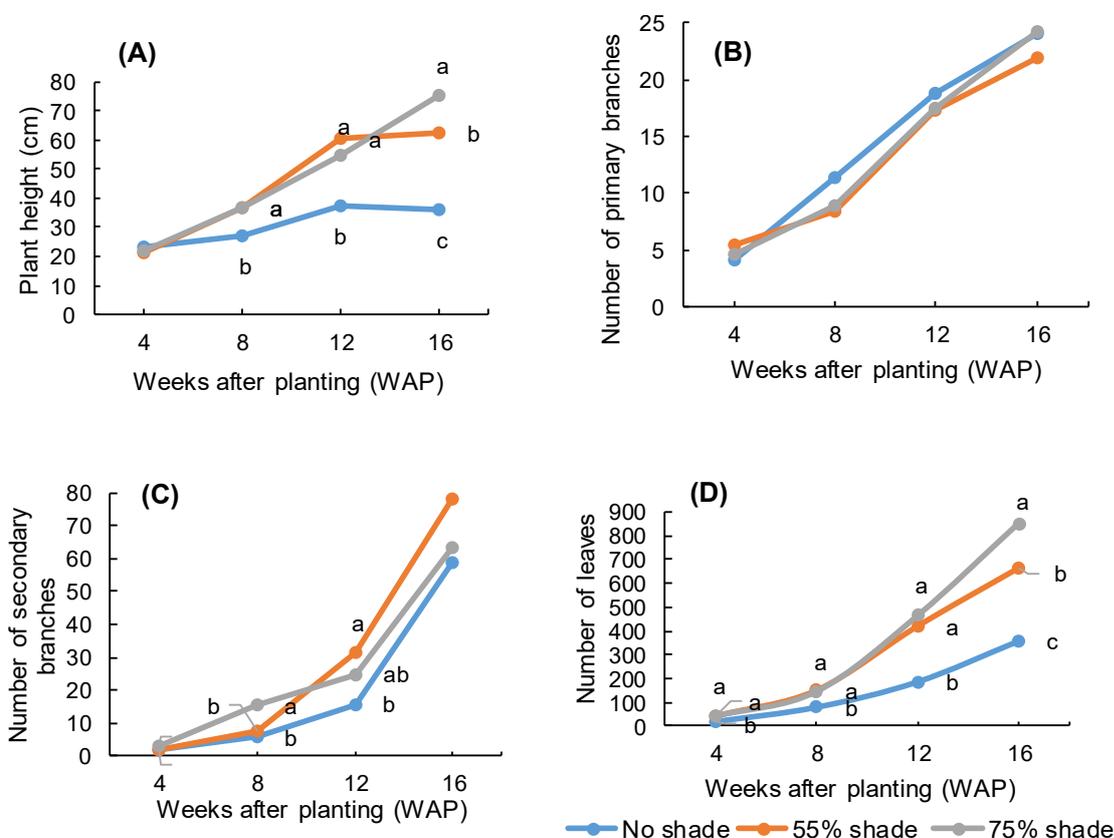


Figure 2. Effect of shade on patchouli plant growth: (A) plant height, (B) primary branch Number, (C) secondary branch number, and (D) leaf number. Different letters in the same week indicate significant differences at the 5% level according to DMRT.

those grown under shade. This discrepancy may be attributed to differences in study locations; the current study was conducted in lowland conditions, whereas the *Thymus vulgaris* research took place in highland environments. Climatic variations between these regions are likely responsible for the observed differences in trichome density.

Visually, the morphology of stomata and trichomes appeared similar in both shaded and unshaded plants (Figure 3). Observations were made on the adaxial leaf surface using a microscope at 40× magnification, with all images captured under consistent magnification settings.

### Biomass and Oil Production

Both wet and dry biomass weights of patchouli harvests were significantly influenced by shading treatments. Plants grown under 55% and 75% shade produced higher biomass compared to unshaded

plants, although the difference between the two shading levels was not statistically significant (Table 2). Harvesting at six months resulted in the highest dry biomass, significantly exceeding yields at four and five months. This pattern suggests that higher shade intensity combined with longer harvest durations in lowland environments promotes increased wet and dry biomass accumulation. These findings align with previous research indicating that shading optimizes growing conditions by reducing temperature and improving moisture retention, both of which support biomass growth in patchouli.

During the initial growth phase after transplanting (August–September 2023), high temperatures caused significant stress to unshaded plants, leading to slowed growth. The extreme heat increased evaporation rates, resulting in fewer secondary branches and leaves compared to shaded plants. Unshaded plants exhibited narrower, thicker, and reddish leaves. Since leaves are the primary organs

Table 1. Effect of shade on leaf anatomical characteristics

Shade levels (%)	Leaf area (cm <sup>2</sup> )	Leaf thickness (μm <sup>2</sup> )	Number of stomata per mm <sup>2</sup>	Number of trichome per mm <sup>2</sup>
Unshaded (0)	11.12 c	436.06 a	8.14 a	6.86
55	30.33 b	296.74 b	6.64 b	6.62
75	33.93 a	283.31 b	6.24 b	5.90

Notes: Different letters in the same column indicate a significant difference according to DMRT at α= 0.05.

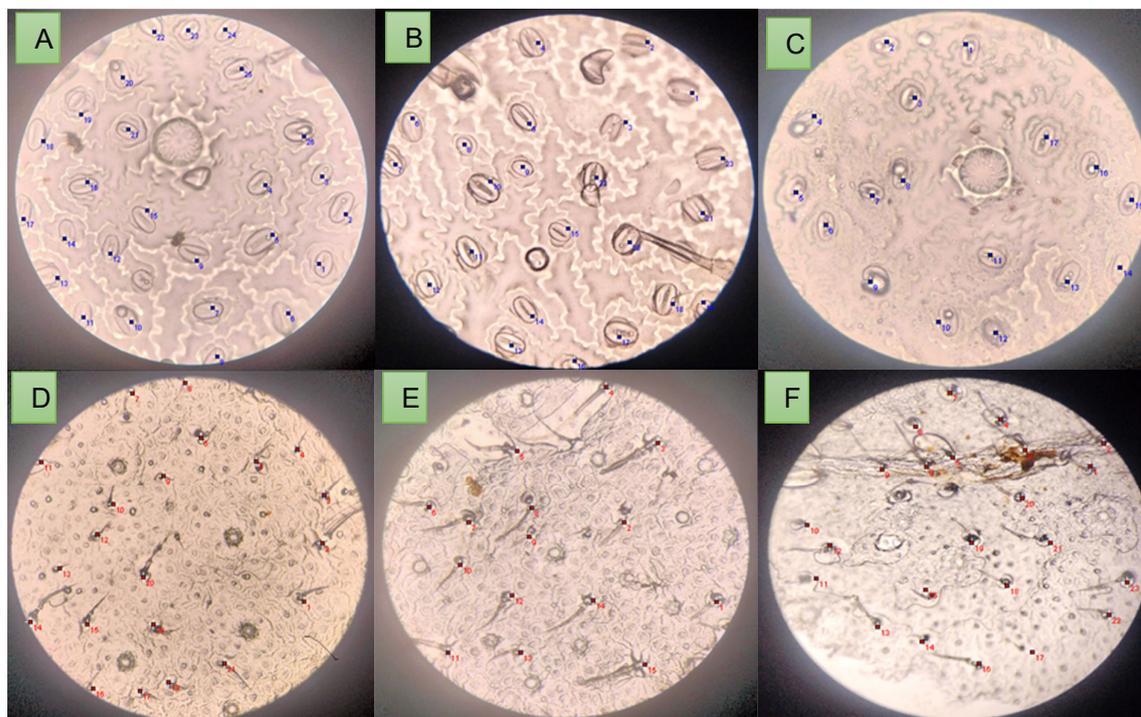


Figure 3. Patchouli leaf stomata (blue) and trichomes (red); unshaded leaf stomata (A), stomata under 55% (B) and 75% shade (C), unshaded trichomes (D), trichomes under 55% (E) and 75% shade.

of photosynthesis, shading can impact leaf growth and photosynthesis. Both stomatal factors (light intensity, temperature, water availability) and non-stomatal factors (photosynthetic enzymes, O<sub>2</sub>, CO<sub>2</sub> levels) can limit photosynthetic capacity (Yi-bo et al., 2021).

Shading also had a significant impact on the weight of patchouli oil. Both 75% and 55% shade treatments produced similar oil weights; however, the oil weight under 75% shade was significantly higher than in unshaded plants, whereas the 55% shade treatment did not differ significantly from the control. Oil yield correlated strongly with wet and dry biomass, indicating that oil volume depends on the amount of biomass available for distillation.

Regarding oil yield percentage, shade level had no significant effect, but harvest age did. The minimal impact of shading on oil yield percentage may be due to higher moisture content in shaded plants, which reduces transpiration and enhances water use efficiency, supporting growth and organ development (Murillo-Amador et al., 2013). Increased dry biomass under shade likely slows physiological maturity, resulting in similar essential oil levels at harvest compared to unshaded plants. Conversely, water stress in unshaded plants may accelerate physiological maturity through increased secondary metabolic activity. As plants age, physiological maturity peaks, maximizing the efficiency of productive organs and yield. The highest oil yield in this study was 2.15% at six months, exceeding the 1.25%–1.76% range reported by Amaliah et al. (2024) in Kutai Kertanegara and North Penajam Paser.

Other factors influencing patchouli oil yield include cultivation practices, post-harvest handling, and refining processes. More extended harvest periods allow greater biomass accumulation; for example,

extending harvest to four months after planting and four months after the previous harvest maximizes oil content (Hariyani et al., 2015). Post-harvest drying also affects oil yield; in this study, biomass was dried for 5–6 days. Nuwa (2023) recommends optimal drying times of four days for leaves and eight days for stems to maximize oil extraction. High moisture content in fresh biomass can inhibit the evaporation of essential oils during distillation due to strong interactions between the oils and plant tissues. Additionally, factors such as distillation equipment, duration, plant origin, climate, and plant structure play important roles in determining essential oil yield.

The interaction between shading and harvest age has a significant effect on essential oil yield (Table 3). The highest yield was obtained from unshaded plants harvested at 6 months after planting (MAP) and from plants grown under 75% shade harvested at 4 MAP. This result is due to the shaded conditions, which promote higher biomass production, although the essential oil content tends to be lower. On the contrary, under full sunlight, biomass production decreases, but the essential oil content increases.

#### Correlations Between Growth Parameters

The results of the Pearson's correlation showed a positive and negative relationship in each variable (Figure 3). The fresh weight was positively correlated with the weight of patchouli essential oil yield by 0.86% and positively correlated with the dry weight by 0.93%. Dry weight was positively correlated with the weight of patchouli essential oil yield by 0.88%. Additionally, fresh weight also has a significant impact on dry weight. Regular irrigation likely increased the dry weight of patchouli plants. Well-irrigated Sage plants (*Salvia officinalis* L.) have a higher dry weight yield than rainfed plants (Delfine et al., 2024).

Table 2. Effect of shade and harvest age on patchouli biomass and oil production

Treatments	Fresh weight (kg.ha <sup>-1</sup> )	Dry weight (kg.ha <sup>-1</sup> )	Oil weight (kg.ha <sup>-1</sup> )	Essential oil yield (%)
<b>Shade levels (%)</b>				
Unshaded (0)	4121.80 (67.02 c)	613.36 (26.23 b)	12.97 (3.64 b)	1.88 (0.720)
55	8851.63 (100.66 b)	1248.48 (37.50 a)	18.24 (4.45 a)	1.42 (0.717)
75	11795.67 (116.31 a)	1414.63 (40.20 a)	22.77 (5.10 a)	1.57 (0.718)
<b>Harvest (MAP)</b>				
4	4817.78 (72.43 b)	603.21 (26.09 c)	7.01 (2.89 c)	1.13 (0.715 b)
5	9491.76 (102.15 a)	1130.53 (35.95 b)	18.97 (4.62 b)	1.58 (0.718 ab)
6	10459.56 (109.41 a)	1542.73 (41.89 a)	28.01 (5.76 a)	2.15 (0.722 a)

Note: The values in parentheses indicate that the data changed based on  $\sqrt{(x + 0.5)}$ . Different letters indicate a significant difference according to DMRT at  $\alpha = 0.05$ .

Table 3. Interaction between shading level and harvest age on essential oil yield (%)

Shade levels (%)	Harvest age (MAP)		
	4	5	6
Unshaded	0.82 b (0.714 b)	1.09 b (0.716 b)	2.80 a (0.730 a)
55	1.00 b (0.714 b)	1.32 b (0.718 b)	1.22 b (0.717 b)
75	1.02 b (0.715 a)	1.55 b (0.720 b)	1.37 b (0.718 b)

Note: The values in parentheses indicate that the data were transformed based on  $\sqrt{(x + 0.5)}$ . Different letters indicate a significant difference at a 5% rate, according to DMRT.

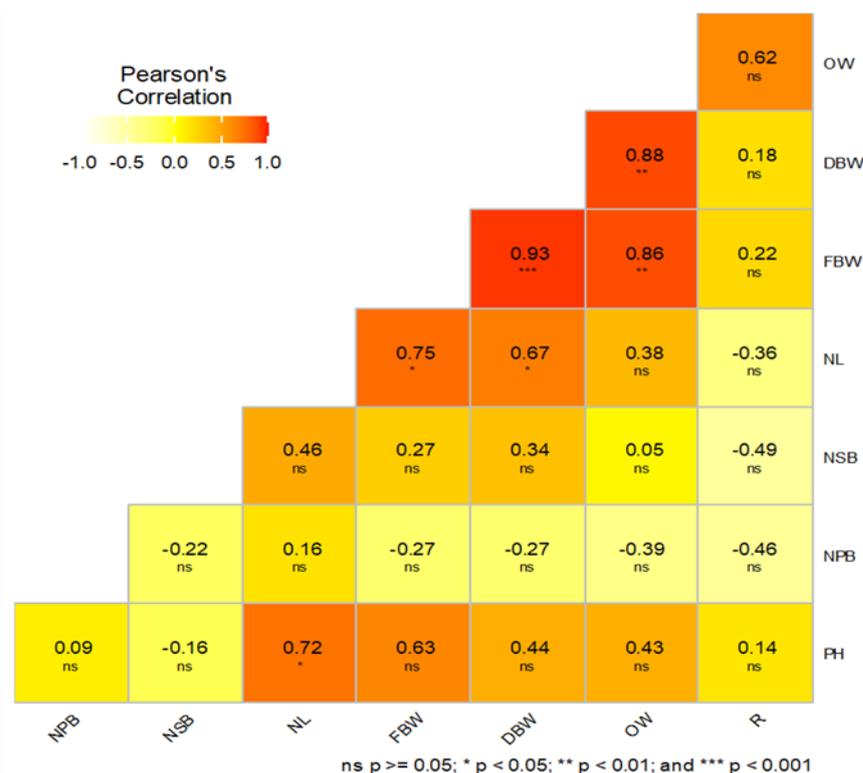


Figure 4. Pearson's correlation between growth variables at various harvest ages and shade levels. PH= plant height, NPB= number of primary branches, NSB= number of secondary branches, NL = number of leaves, FBW= fresh biomass weight, DBW= dry biomass weight, OW= oil weight, R= yield.

The result also confirms that patchouli have beneficial properties when cultivated under the shade. The thyme plant (*Timus vulgaris* L) is one example of a plant where the use of shade is detrimental to the growth and production of essential oils (Honorato et al., 2023). In addition, the cultivation of patchouli under shade in the lowlands has the advantage of having higher temperatures compared to highland temperatures. CO<sub>2</sub> and rising temperatures affect the composition of secondary metabolites, yields, and concentrations of essential oils (Dobhal et al., 2024).

secondary branches, and leaf production, indicating that levels of shading are essential for patchouli cultivation in lowland areas. The highest essential oil yield was obtained from patchouli under 75% shade and harvested at four months, or from those grown under full sunlight and harvested at six months. Further studies should examine patchouli growth and oil production under the trees. It is also essential to investigate the cultivation of patchouli in lowlands at several groundwater levels during the dry season, as patchouli tends to wilt at high temperatures.

## Conclusions

Shading at 75% significantly enhances patchouli vegetative growth, including plant height, number of

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