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Water Requirements and Water Use Efficiency of Aceh Patchouli (*Pogostemon cablin* Benth.) at Low Light Intensity

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ABSTRACT

Aceh Patchouli is a C3 plant that does not require high water input and full light intensity to grow optimally, making it suitable for intercropping under main crops. This study aimed to determine the water requirements and adaptability of two Aceh patchouli varieties (Tapak Tuan and Sidikalang) under low light conditions using artificial shade. The experiment employed a nested box design with two factors: shade levels and plant varieties. Observed variables include macroclimate, microclimate, and agronomic parameters such as plant height, number of leaves, leaf area, dry leaf weight, and total biomass. Water requirement and water use efficiency (WUE) were also analyzed. Results showed that shading reduced plant water needs: 33.29% L/plant without shade, 32.80 L/plant under 30% shade (1.5% reduction), and 30.30 L/plant under 60% shade (9% reduction). The Tapak Tuan variety had a higher water requirement (33.30 L/plant) compared to Sidikalang (30.96 L/plant). Importantly, increasing shade levels led to improved water use efficiency, although the variety did not significantly influence WUE. The findings indicate that the use of shade in patchouli cultivation not only conserves water but also enhances efficiency, supporting its potential for sustainable intercropping systems in shaded or water-limited environments.

1. INTRODUCTION

Patchouli (*Pogostemon cablin* Benth), locally known as "nilam", is a type of aromatic plant that produces essential oils needed as raw materials for the soap, cosmetics, perfume and other industries. Aceh Province is one of the five largest patchouli production centers in Indonesia based on data from the Directorate General of Plantations, Ministry of Agriculture in 2023 with a land area of 1,018 Ha and a production of 147 tons per Ha (Dirjenbun, 2023). This patchouli plant has shallow roots so it is very susceptible to drought. Patchouli plants are generally cultivated on dry land by relying on rainwater as the main water source (Nasruddin *et al*., 2020). This dependence makes patchouli cultivation very vulnerable to climate change, which is the impact of global warming that is currently occurring. Changes in precipitation patterns and environmental temperatures as manifestations of climate change can affect water availability which has an impact on plant productivity, so adaptation efforts are needed in the cultivation system to maintain the sustainability of patchouli production. Global warming causes climate change that has an impact on increasingly extreme weather (Capua & Rahmstorf, 2023; IPCC, 2017).

Climate change results in changes in rainfall patterns that have occurred since the last few decades in several regions in Indonesia, such as shifts in the start of the rainy season and changes in rainfall patterns (Rejekiningrum *et al*., 2011). Shifts in rainfall patterns affect agricultural resources and infrastructure, causing shifts in planting times, seasons, and planting patterns, as well as land degradation (Rejekiningrum *et al*., 2011). Climate change also has an impact on increasing global temperatures. A 1°C increase in global average temperature is estimated to cause an increase in the evaporation process of land surface water by around 7%, while water that falls as precipitation is only 2-3% per degree (Allan *et al*., 2020). This information indicates that the water that can be utilized by plants in the future is increasingly limited due to climate change. Extreme climates often have a negative impact on food crop production in Indonesia (Perdinan *et al*., 2018). The frequency of drought is more dominant than flooding (Hidayati & Suryanto, 2015).

One of the important components in patchouli cultivation is the fulfillment of water needs for its life needs. Patchouli plants will experience a decrease in growth, development and production if they experience water shortage stress, although this plant also does not like flooded land (Nasruddin *et al*., 2016). According to Nasruddin *et al*. (2016), the Tapak Tuan, Sidikalang, and Lhokseumawe patchouli varieties have the same tolerance to drought stress based on chlorophyll content. Wulansari *et al*. (2018) stated that patchouli plants are C3 plants, or plants that do not require full light intensity. Not requiring full intensity is important as a basis for developing patchouli plants under other plant stands that still receive solar radiation above 75%. This will provide an opportunity for patchouli plants to be developed at low light intensity or under other plant stands as intercropping. The results of research by Nisa *et al*. (2024), Aceh patchouli plants planted with a mixed cropping system gave better performance compared to monoculture planting patterns. Intercropping system under the main plant stand will potentially optimize the utilization of land under the stand such as under plantation land (Hidayat *et al*., 2021). Patchouli development under the main plant stand is expected to reduce the massive land/forest clearing (deforestation) which is usually the habit of patchouli farmers in the interior.

In the initial stage, this study comprehensively examines the efficiency of water use in Aceh patchouli plants as an adaptation strategy to climate change, and evaluates the potential for developing Aceh patchouli cultivation under shade through an intercropping system to optimize land use under the stand. This study examines the efficiency of water use in Aceh patchouli plants as a strategy for adapting to climate change, and evaluates the potential for its cultivation under shade through an intercropping system to optimize land. The approach taken to evaluate the water needs of patchouli plants and the potential for developing patchouli under the stand is carried out with the Climate Smart Agriculture (CSA) concept, which focuses on increasing production, but still pays attention to efforts to adapt and mitigate climate change. The purpose of this study was to analyze the needs and efficiency of water use of two Aceh patchouli varieties, namely Tapak Tuan and Sidikalang at low light intensity/artificial shade. The results of the study are expected to be utilized by patchouli farmers and industry players as a basis for designing more efficient patchouli cultivation strategies, especially in areas with limited light and water due to the impact of climate change. Information on water needs and the efficiency of its use can support the development of an appropriate irrigation system to increase patchouli productivity sustainably, especially in Aceh.

2. MATERIALS AND METHODS

2.1. Location and Materials

The research was conducted from March to November 2022, at the Experimental Garden of the Faculty of Agriculture, Universitas Syiah Kuala, Banda Aceh, with an altitude of 5 m above sea level and coordinates 5°33'59.02" N and 95°22'24.04" E.

The tools used were solarimeter tubes, umbrometers, thermometers, hygrometers, meters, analytical scales, measuring cups, ovens, and plastic pots with iron stands, and funnels. The materials used in this study were Aceh patchouli seedlings of the Tapak Tuan and Sidikalang varieties, paranet with a percentage of 30% and 60%, soil, manure, insecticides, fungicides, and inorganic fertilizers (urea, SP36, KCL).

2.2. Research Design

The design used in the study was a nested design with two treatment factors, namely differences in shade levels and differences in variety types. The first factor consists of three levels, namely conditions without shade (N0), 30% paranet shade (N1), and 60% (N2). The second factor consists of two levels, namely Aceh patchouli variety Tapak Tuan (V1) and Aceh patchouli variety Sidikalang (V2). Based on the two treatment factors, 6 treatment combinations were obtained with 8 replications so that there were a total of 48 observation units. Three plants were used for each destructive sampling at the ages of 1, 2, 3, 4, and 5 months after planting. This study lasted for 6 months with the stages presented in Figure 1.

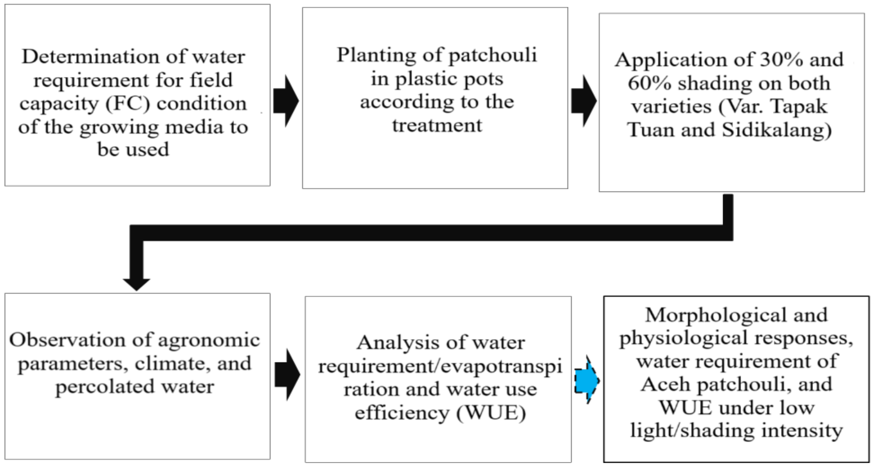

Figure 1. Research flow diagram

Figure 2. Planting distance between pots applied in the study (100 cm x 150 cm).

2.3. Preparation of Seedlings and Planting Media

The patchouli plants used were the result of shoot cuttings with a diameter of 0.8-1.0 cm with a length of 15-20 cm, and were 1.5 months old or had shoots and leaves. The seedlings were then transferred to large plastic pots (diameter 50 cm and height 45 cm), and adjusted to shade treatment until they were 6 months old. Patchouli plants were planted in soil media that had been mixed with manure (2:1) and inorganic fertilizers with doses of 128.8 kg N/ha, 25 kg P_2O_5/ha, 84 kg K_2O/ha, and 42 kg MgO/ha (Nasruddin *et al*., 2016). The distance between pots was 100 cm × 150 cm (Figure 2). During maintenance, insecticide, and fungicide spraying was carried out.

2.4. Shade Application

The shading used in this study was shading using paranet with a density of 30% and 60%. The higher the percentage value of the paranet, the denser the paranet nets, so that the solar radiation transmitted is smaller. The paranet shade was installed at a height of 150 cm above the patchouli plant so that the paranet shadow hit the patchouli plant efficiently and facilitated plant measurement and maintenance. To ensure the percentage of radiation intensity received under the paranet, a solarimeter was placed in conditions without shade and under 30% and 60% paranet shade.

In each treatment, an ombrometer, thermometer, and hygrometer were installed, each to measure rainfall, air temperature, and air humidity. Maintenance activities include watering, soil loosening and weed control. Watering was carried out every day at 07:00 WIB, with an amount of around 1000 ml obtained from the results of the planting media calibration. Weed control was done by cutting all plants growing in the planting medium. Cutting was done right on the surface of the soil so that there is no transpiration from other plants other than the patchouli plant.

2.5. Determination of Irrigation Water and Field Capacity

Determination of irrigation water and field capacity follows Fanggidae & Impron (2018). Determination of irrigation water is done to determine the water content of field capacity which is done by providing a certain amount of water evenly and slowly to the planting medium until percolation occurs (Figure 3). Water supply is stopped when percolation occurs or gravity water stops. The results of the pre-study showed that the average amount of water needed for percolation to occur was 650 ml. The amount of water needed for percolation to occur indicates that the soil water content has met the field capacity. Irrigation water was provided every day (morning at 08:00 WIB) during the research period. The amount of irrigation water provided exceeded the field capacity, which was 1000 mL (1 L). The surface area of the soil in the pot is 452.6 cm^2.

2.5.1. Plant Water Requirements

Calculation of plant water requirements aims to determine the effect of treatment (shade and different patchouli varieties). Plant water requirements can be determined through the evapotranspiration value approach (Fanggidae & Impron, 2018; Hartfield & Dold, 2019). Plant water requirements were calculated using the following equation:

$$ET\ (ml)\ = Irrigation\ - Percolation \quad (1)$$

$$ET\ (mm) = \frac{ET\ (cm^3)}{Surface\ area\ (cm^2)} \quad (2)$$

Total water usage or total *ET* for patchouli plant was calculated from 2 WAP to 12 WAP using the following equation:

$$ET\ Total\ = ET1 + ET2 + ET3 + \cdots + ETn \quad (3)$$

2.5.2. Irrigation Water Use Efficiency

Water use efficiency (WUE) values was measured 5 times by destructively harvesting plants at the ages of 4, 8, and 12 WAP. WUE describes the ratio of harvest yield (*Y*) and water uptake (*WU*), calculated as follows (Bai *et al*., 2016):

$$WUE = \frac{Y}{WU} \quad (4)$$

2.4.5. Biomass Measurement

Biomass measurement in this study was only the final biomass by following the procedure carried out by Fanggidae & Impron (2018). Biomass measurements were carried out at 4 WAP, 8 WAP, and 12 WAP. Plants whose biomass was measured were randomly selected in each treatment group. Plants were dried in an oven at 80°C for 24 hours. After 24 hours, the patchouli plant biomass was weighed using an analytical balance.

Figure 3. Mechanism for determining field capacity in the planting media used.

2.3. Data Analysis

The research data were analyzed using ANOVA and if there were differences between groups, it was continued with the DMRT test at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1. Climatological Conditions

The climate conditions at the location during the study were relatively diverse. This can be seen from the fluctuations in rainfall, air temperature and humidity as well as the duration of exposure. The distribution of rainfall during the study is presented in Figure 4 with a total intensity reaching 646 mm or with an average monthly rainfall intensity of 170 mm/month. The average air temperature during the study was 27.4 °C with the lowest minimum temperature of 20.4 °C and the highest maximum temperature of 36.5 °C.

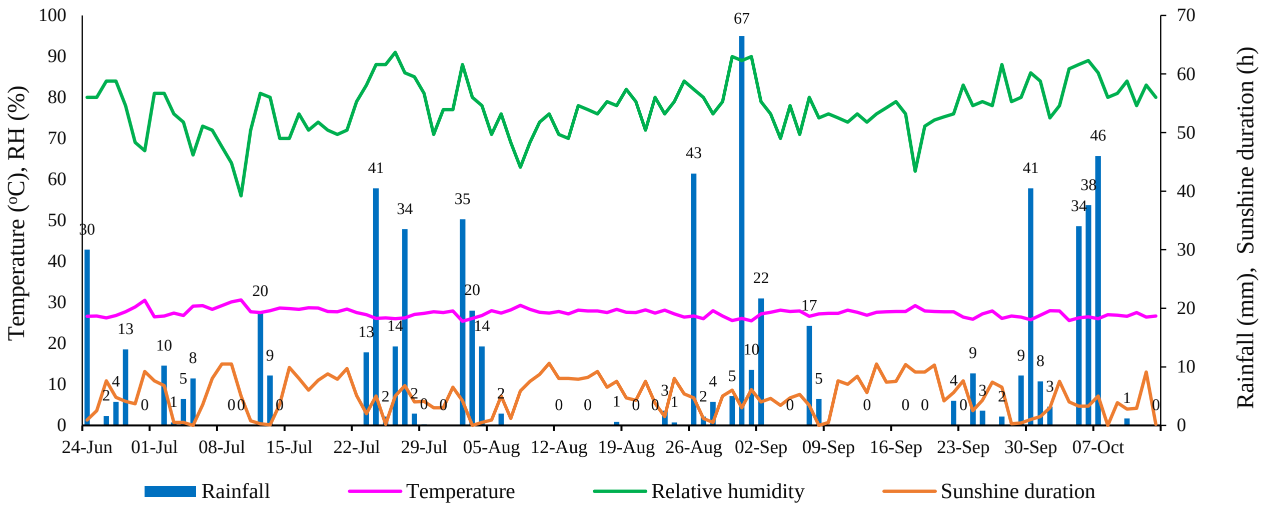

Figure 4. Climatological conditions during the study

The average air humidity (RH) was 77.5% with the highest humidity of 91% and the lowest of 56%. The duration of solar radiation exposure during the study varied greatly, with the longest being 10.6 hours and the lowest being 0 hours, with an average of 5 hours. This study took place in the Aceh Province which is included in the 10 patchouli production center areas with a planting area of 1,018 ha and 147 tons (Dirjenbun, 2024). Aceh Province as a patchouli production center proves that the climate in this region is suitable for patchouli cultivation.

3.2. Effect of Shade on Water Requirements of Patchouli

The total water use of patchouli plants is the amount of consumptive water use expressed as the total water lost through the evapotranspiration (ET) process. Total water use is determined by adding up the daily ET values that occur. ET value is a measure of plant water requirements, which includes evaporation of water vapor from the soil and transpiration from plants (Allen *et al*., 1998). According to Suliman *et al*. (2024), in addition to hydrometeorological factors, soil conditions are the most important indicators in controlling ET.

Figures 5 and 6 respectively show the distribution and evapotranspiration values of Aceh patchouli plants at several levels of shade and varieties. Table 1 shows the total evapotranspiration and water requirements used by Aceh patchouli plants at several levels of shade and varieties. Based on the data in Table 1, it is known that the water requirement per plant in the group without shade reaches 73.55 mm (equivalent to 33.29 L of water), at a shade level of 30% it is 72.47 mm (equivalent to 32.80 L of water) and at 60% shade only 67.29 mm (equivalent to 30.44 L of water). When compared to the water requirements of patchouli plants without shade, the needs of plants under 30% shade require 1.5% less water, while patchouli under 60% shade require 9% less water than patchouli without shade.

The results of the nested design analysis showed that there was at least 1 pair of shade levels that were significantly different from the average evapotranspiration value (mm) with a p value of 0.018 ($p < 0.05$). The results of further tests using the Tukey test showed that the average evapotranspiration of patchouli plants planted without shade was significantly different from the average evapotranspiration of patchouli plants planted under 60% shade with a p value

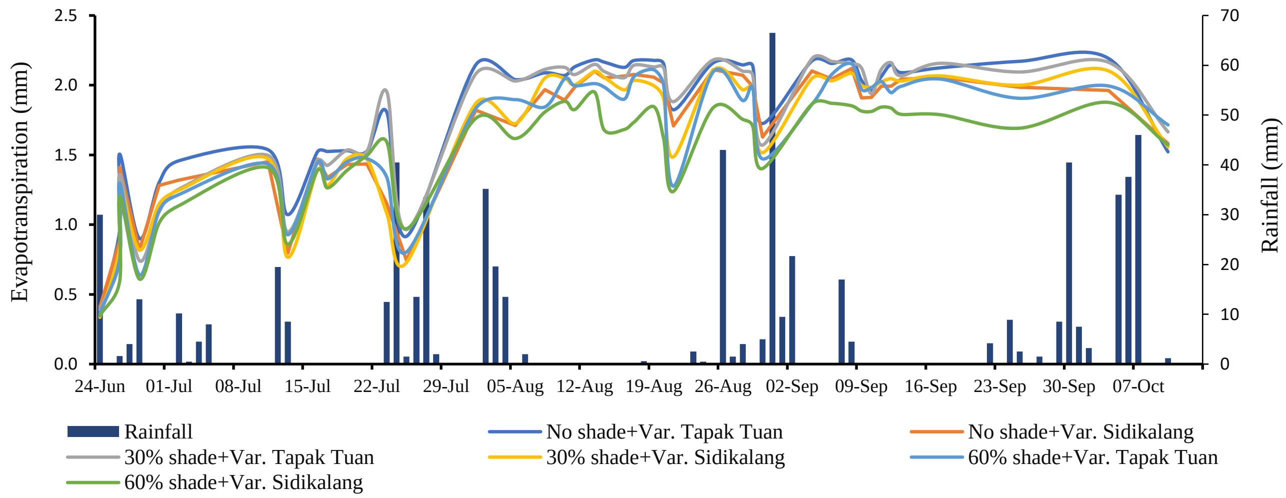

Figure 5. Distribution of evapotranspiration of Aceh patchouli plants at several levels of shade and varieties.

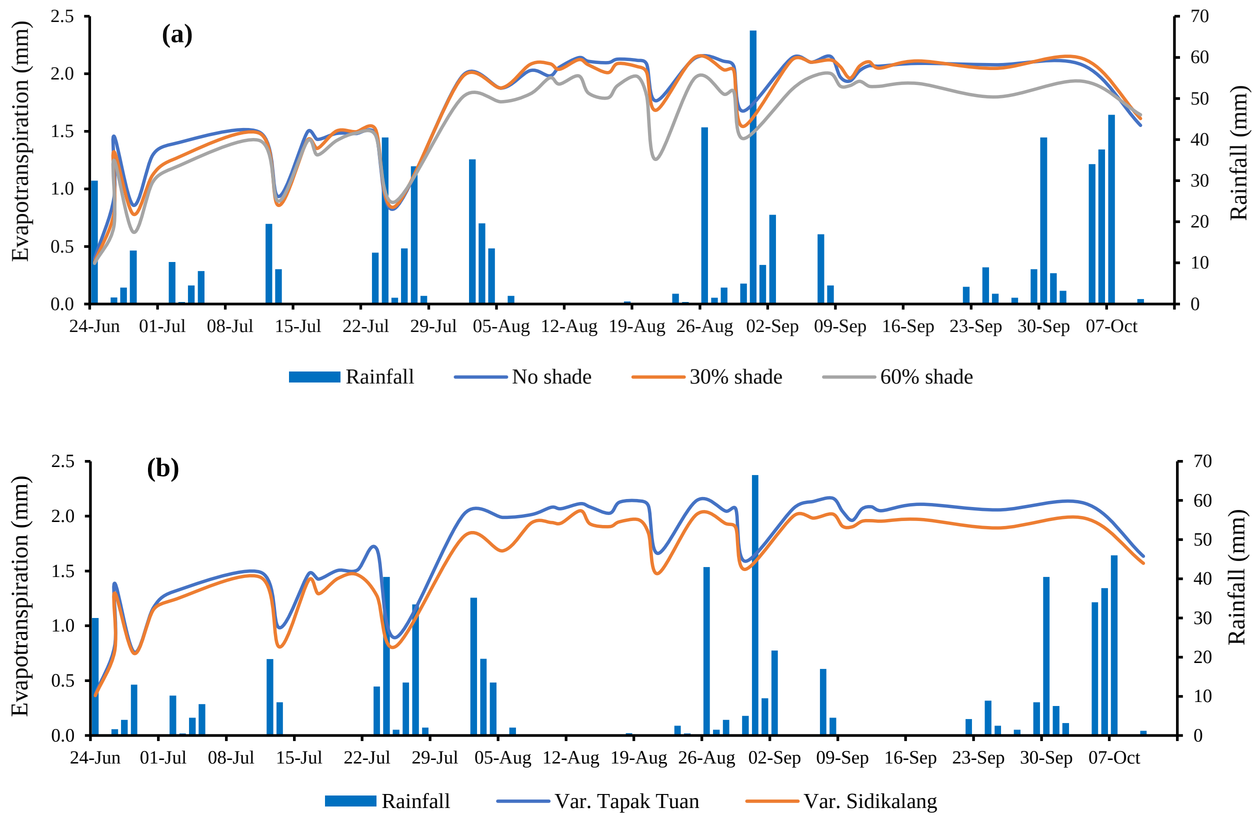

Figure 6. Comparison of evapotranspiration of Aceh patchouli plants based on: (a) shade levels, and (b) varieties

Table 1. Total evapotranspiration and water requirements used by Aceh patchouli plants at several levels of shade.

Parameter	No Shade	30% Shade	60% Shade
Total evapotranspiration (mm)	73.55^{a}	72.47^{ab}	67.27^{b}
Total water requirement used (L/plant)	33.29^{a}	32.80^{ab}	30.44^{b}

Note: Plot surface area 452.6 cm^2. Means followed by the same superscript letter in the same row are not significantly different ($p > 0.05$).

of 0.014 ($p < 0.05$). The average evapotranspiration in the 30% shade group was not significantly different ($p > 0.05$) from the group without shade (p value 0.180) and also 60% shade (p value 0.540). Providing 30% shade has not been able to provide an effect on the evapotranspiration value, in contrast to 60% shade which showed its effect. Providing 60% shade is thought to be able to maintain sufficient groundwater for patchouli plant performance, as seen from the patchouli plant biomass obtained (Figure 6a).

The results of the study showed that patchouli plants that were given shade required less water than those without shade, so that providing shade can be an effort to adapt to increasingly extreme climate change, especially drought. Plant growth cannot be separated from the condition of the roots and shoots of the plant. Root and shoot growth is more influenced by the availability of groundwater than the photosynthesis process (Khalil *et al*., 2020). Therefore, maintaining the availability of water for plants is the main key to maintaining plant growth (Brendel, 2021; Peng *et al*., 2021; Chen *et al*., 2022; Gul *et al*., 2023). The availability of groundwater is currently a serious problem due to global warming which causes increase earth's surface temperature, resulting in changes in the evapotranspiration process and plant water needs. The amount of groundwater can be stimulated, one of which is by providing shade (Tams *et al*., 2022).

Table 2 shows the evapotranspiration value and water requirement of patchouli plants based on their varieties. The amount of water required by the Tapak Tuan variety of patchouli based on the evapotranspiration rate is 73.56 mm (or equivalent to 33.29 L), while the Sidikalang variety is 68.63 mm (or equivalent to 31.06 L) during its growth (12 WAP). Based on the percentage, the Sidikalang variety is 7% more water efficient than the Tapak Tuan variety.

Table 2. Total evapotranspiration and water requirement used by Aceh patchouli plants in different varieties

Parameter	Tapak Tuan Variety	Sidikalang Variety
Total evapotranspiration (mm)	73.56[a]	68.63[a]
Total water requirement used (L/plant)	33.29[a]	31.06[a]

Note: Plot surface area 452.6 cm^2. Means followed by the same superscript letter in the same row are not significantly different ($p > 0.05$).

The results of statistical analysis showed that there was no significant difference between patchouli varieties (Tapak Tuan variety and Sidikalang variety) in the level of shade (without shade, 30%, 60%) on the average evapotranspiration value (mm) ($p > 0.05$). The variety factor in this study did not show its effect on the level of water requirements of patchouli plants. However, many studies have shown that plant genetic factors are one of the factors that influence sensitivity to evapotranspiration (Tamang *et al*., 2022; Ruggiero *et al*., 2017; Ehdaie & Waines, 1997). The data in Table 2 show a tendency that the Sidikalang variety has a lower evapotranspiration rate. In previous studies, it was found that the Sidikalang variety has a smaller number and size of leaves than the Tapak Tuan variety (Dwifandi *et al*., 2024). The small leaf size results in a slower rate of transpiration from the leaf surface. Genetic factors play a role for plants to show their response to various stimuli or exposures, both positive and negative responses. Currently, genetic engineering efforts are developing to produce plants that are resistant to current environmental conditions that are drought tolerant (Basu *et al*., 2016; Cao *et al*., 2017; Mahmood *et al*., 2019) and tolerant of waterlogging (Ahmed *et al*., 2013; Pan *et al*., 2021; Tong *et al*., 2021; Belliappa *et al*., 2024).

3.3. Effect of Shade on Water Use Efficiency of Patchouli Plant

The water use efficiency value of patchouli plants under 60% shade is significantly higher than without shade and 30% shade ($p < 0.05$). The highest water use efficiency value is found in patchouli plants under 60% shade (1.71 g/L) then without shade (1.38 g/L) and 30% shade (1.34 g/L). The water use efficiency of Aceh patchouli plants at several levels of shade and varieties is presented in Figure 7. The results of statistical analysis showed that there was no significant difference between the levels of shade (without shade, 30%, 60%) on the average WUE value with a p value of 0.134 and there was also no significant difference between the types of varieties (Tapak Tuan and Sidikalang) in the level of shade (without shade, 30%, 60%) on the average WUE value with a p value of 0.097. However, there is a tendency for the use of shade to have an impact on increasing the efficiency of water use of patchouli plants. Providing shade reduces the intensity of solar radiation which has an impact on decreasing air temperature and increasing air humidity so that the rate of evapotranspiration decreases. In this study, it can be seen that the higher the percentage of shade used, the lower the rate of evapotranspiration.

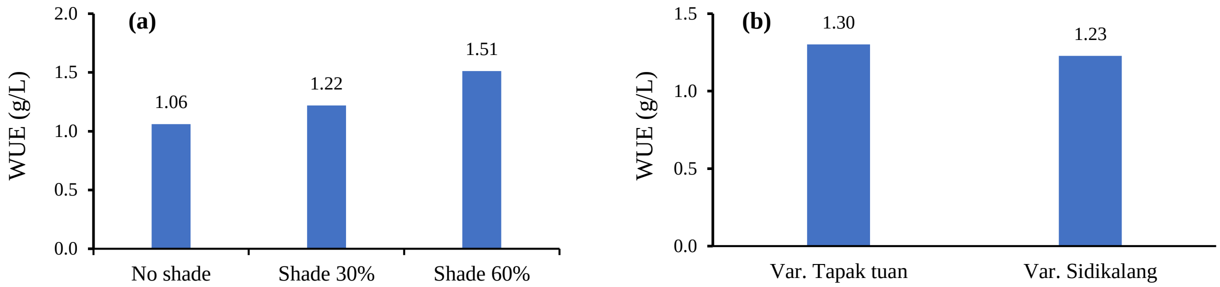

Figure 7. Comparison of water use efficiency (WUE) of Aceh patchouli based on: (a) shade levels, and (b) varieties.

The Tapak Tuan patchouli variety showed a better level of water use efficiency compared to the Sidikalang variety, although it was not significantly different ($p > 0.05$) with each water use efficiency (WUE) value of 1.46 g/L and 1.48 g/L. This is thought to be influenced by the greater number of leaves of the Tapak Tuan variety compared to the Sidikalang variety as reported by Dwifandi *et al*. (2024). The large number of leaves can act as an internal canopy to prevent solar radiation from entering the soil which can cause evaporation (Medrano *et al*., 2015).

3.4. Total Biomass

The biomass measured in this study was the biomass of dry plants. Figure 8a shows the amount of patchouli biomass at several levels of shade. The use of shade has not been able to significantly increase the total biomass of patchouli plants ($p < 0.05$). During the growth period of the plant, the climate conditions, especially rainfall, which also indicates the level of cloudiness during the planting period, are relatively high, as shown in Figure 4. The average rainfall during the growth period of patchouli plants reached 170 mm/month. This causes the biomass of patchouli plants under shade to be no different from those planted without shade. However, there is a tendency for the biomass of patchouli plants that are shaded to be higher than those that are not shaded. The same pattern is also shown in the variety factor (Figure 8b), however, there is a strong tendency that the Tapak Tuan variety (43.30 g) has a relatively higher biomass compared to the Sidikalang variety (41.59 g).

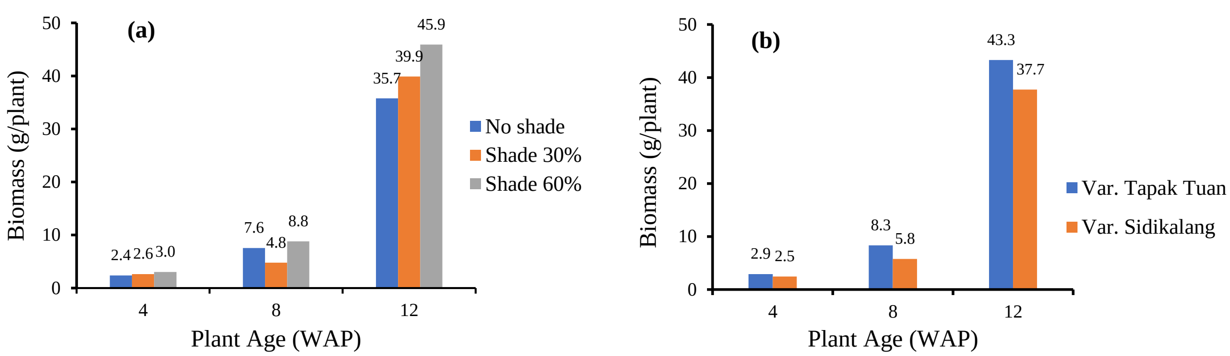

Figure 8. Development of biomass yield of Aceh patchouli based on: (a) shade levels, and (b) varieties

The results of statistical analysis showed that the provision of shade of either 30% or 60% did not significantly affect ($p>0.05$) the biomass of patchouli plants at the age of 4 WAP (p value 5.14), 8 WAP (p value 5.14), or 12 WAP (p value 3.89), compared to no shade. In this study, the shade factor did not affect the dry biomass of patchouli plants in 3 age groups. This is suspected because the soil water content in the 3 treatment groups was relatively the same, although the group without shade had a significantly higher evapotranspiration rate than the 60% shade group. The same pattern was also shown by the influence of the patchouli plant variety factor which did not show a significant difference between groups ($p > 0.05$). At the age of 4 WAP and 8 WAP, the same p-value was obtained, namely 4.76. At the age of 12 WAP, the p-value was obtained as 3.49. The Tapak Tuan and Sidikalang varieties were thought to be less responsive to groundwater loss in this study. Both varieties have good adaptation to changes in groundwater levels due to the evapotranspiration process that occurs when shaded or not. The microclimate conditions between groups are thought not to experience significant changes so that plants are able to carry out metabolism (photosynthesis and respiration) more optimally. However, this study did not measure the levels of photosynthesis and respiration of patchouli plants.

The results of this study differ from the study conducted by Setiawan & Sukamto (2016), which showed that patchouli planted under shade had a significantly higher dry weight than without shade. Shading can reduce the rate of evapotranspiration so that the availability of groundwater is better maintained which has a positive impact on plant growth. Chandel *et al*. (2024) stated that the processes of photosynthesis and respiration play an important role in plant growth and development. The same pattern was shown in the study conducted by Chandel *et al*. (2024) on *Ocimum gratissimum* L. plants showed that the biomass of *O. gratissimum* grown in a greenhouse had a higher fresh biomass than that grown in open fields. Plant biomass is also influenced by soil organic carbon content (Li *et al*., 2019; Yang *et al*., 2017) and carbon content from soil bacteria (Yang *et al*., 2017). In this study, all groups were planted in the same planting medium so that it is assumed that the organic carbon content and carbon from bacterial biomass in the medium of the three groups are also the same and have an impact on relatively the same dry biomass.

4. CONCLUSION

The use of shade in patchouli cultivation can reduce the amount of water needed during growth. The water requirement for each treatment is without shade 33.29 L/plant, 30% shade 32.80 L/plant (reduced by 1.5%) and 60% shade 30.30 L/plant (reduced by 9%). The water requirement of the Tapak Tuan patchouli variety is higher (33.30 L/plant) than the Sidikalang variety (30.96 L/plant). The use of shade can increase the efficiency of water use in patchouli plants. The efficiency of water use in patchouli shade increases with increasing percentage of shade level. There is no difference in the level of water use efficiency between the Tapak Tuan and Sidikang varieties.

Further research is recommended to explore the effect of a combination of light intensity and other environmental factors such as temperature, air humidity, and type of planting media on the efficiency of water use and secondary metabolite results of patchouli plants. In addition, testing various patchouli varieties can provide more comprehensive information regarding the response of genotypes to environmental stress conditions.

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