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Critical limit of shade stress in lemongrass plant (*Cymbopogon nardus* L.)

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ABSTRACT

Lemongrass (Cymbopogon nardus L.) is well-known for its ability to thrive in sunlight. However, the capacity to tolerate shade when cultivated as an intercrop is unknown. Therefore, this study aimed to determine the tolerance limit of shade to the growth and production of lemongrass oil. A completely randomized design was used, with the treatment design varying by level of shade: control (without shade), 25%, 50%, and 75% shade. The parameters observed were light intensity, plant height, number of tillers, fresh weight of herbs, leaf thickness, leaf chlorophyll, and essential oil content. The results showed that 75% shade reduced light intensity by 75.38%, the number of tillers by 50.86%, fresh weight by 22.39%, leaf thickness by 31.91%, leaf chlorophyll by 54.96%, and essential oil content by 48%. The relationship pattern between shade and fresh weight of herbs was $Y = -0.00733X^2 + 0.3633X + 340.44$, with a correlation of 0.70 and a determinant of 83.70%. Meanwhile, the relationship pattern between shade and leaf chlorophyll content was $Y = -0{,}00029X^2 + 0.0093 + 47.26$, with a correlation of 0.9681 and a determinant of 98.3%. In conclusion, lemongrass planted as an intercrop can tolerate 25% shade, as evidenced by its growth indicators and essential oil production.

Keywords:
Citronella, Intercropping, Likes light, Shade plant

1. Introduction

Indonesia is globally recognized for its extensive plantation land. In 2024, rubber, oil palm, and coconut plantations were estimated to cover an area of 3.5 million, 15.5 million, and 3.3 million hectares, respectively [1]. These plantations have vast planting distances, which facilitates intercropping cultivation. A significant problem of plants cultivated as intercrops is the limited sunlight, which triggers light stress. Therefore, determining the critical limit of light stress is important to achieve high success.

One of the intercrops with high economic value is lemongrass (*Cymbopogon nardus* L.). In intercropping, more than one type of plant is planted on agricultural land. Lemongrass has essential oil content that is important for manufacturing perfumes, medicinal ingredients, and botanical pesticides [2]. It is also an ingredient in health drinks to make the body healthy [3].

Intercrops for cultivation purposes must be resistant to shade stress. The ability of plants to withstand shade stress varies according to the habitat and the need for light. A study by Begum et al. [4] showed that direct and indirect light affected the growth of *Kaempferia parviflora* plant. Danata et al. [5] and Danata et al. [6] stated that reduced light intensity due to shade impacted the stomata's opening and the lemongrass plant's photosynthesis rate, affecting growth and oil content. Irmawati et al. [7] stated that lemongrass tissue culture plantlets grow well with 3000 lux of light.

A study by Yang et al. [8] showed that the rate of photosynthesis and seed production of wheat plants decreased due to shade stress in the reproductive phase. Yi-bo et al. [9] also stated that shade stress in the reproductive phase will reduce the rate of photosynthesis and seed production of peanut plants. Nasser et al. [10] mentioned that water and shade stress in the flowering phase reduced corn yields. Additionally, Nasser et al. [11] stated that wheat plants also experienced the same problems when affected by water and shade stress.

A study by Yuan et al. [12] showed the shoot biomass of the two maize hybrids decreased significantly by shade stress treatment, for shade stress 7 d, the LC803 and LY336 were reduced by 56.7% and 44.4% compared with natural light. Ghorbel et al. [13] mentioned that shading treatment using a double-layer shading net produced the lowest chlorophyll content and the highest β-carotene content compared to other treatments. A study by Bebre et al. [14], in the a controlled pot experiment using European beech, Norway spruce, and Douglas fir seedlings and applying three different light availability showed that all seedlings allocated more growth to height than diameter as light availability decreased. Seedlings that achieved a higher average height in the previous year allocated less growth to height in the following year. Ribeiro et al. [15] shown that the patchouli plant grown in an environment with shading showed higher values for the leaf, stem, root ant total dry weights compared to full sun. Another study by Ekawati et al. [16] on *E. palmifolia* plants found that shading 75% gave the highest total flavonoid and anthocyanin content of E. palmifolia's bulb was 19.77% and 28.10% than no shading.

The study results show that plants have a critical limit of shade stress when growing and developing. The critical light limit value will guide the cultivation of lemongrass as an intercrop. Lemongrass generally thrives in sunlight, but it is necessary to determine the critical limit of shade stress the plant can tolerate. Before testing in the field, it is essential to test the resistance to light stress that lemongrass plants can tolerate on a small scale.

2. Methods

This study used a completely randomized environmental design, with a treatment design in the form of shade (N, %), namely N0 = Control (without shade, 100% light intensity), N1 = 75% light intensity (1 layer of shading net), N2 = 50% light intensity (2 layers of shading net), and N3 = 25% light intensity (3 layers of shading net).

Each treatment was repeated three times, creating 12 experimental plots. Each plot contained 20 polybags, 15 of which were used as observation samples, for a total of 240 polybags of the lemongrass plant.

A flat land topography was selected as the study location, and shade was 10 x 10 m. The height facing east was 2 m, and the one facing west was 2 m. Subsequently, an additional shade of approximately 0.5 m was given at each end facing east and west, with a decreasing position. Three types of shading treatments were used, namely 25% (1 layer of shading net), 50% (2 layers of shading net), and 75% (3 layers of shading net).

300 seedlings were taken from mature plants (at least 1 year old) with many shoots. Leaf tips were cut to a length of 30 cm from the base of the stem, which aimed to reduce transpiration and stimulate the growth of new shoots. The roots were cut and

left 5 cm long. Cutting the roots made it easier to plant in polybags. Seedlings were taken from Pemunduran Village, Kumpeh Sub-district, Muaro Jambi Regency, Jambi Province.

The media used was a layer of topsoil to which manure was added at a 2:1 ratio. It was prepared 1 week before planting to decompose organic matter and provide nutrients. Each 40 x 25 cm polybag contained 5 kg of soil.

Seedlings were selected based on the criteria of uniformity, normality, and freedom from pests and diseases. To facilitate planting, the media was made into holes using a ditch. The seedlings were maintained without shade for one month and then planted according to the treatment for three months, with four months of maintenance.

Fertilization was carried out after the plant had been maintained for one month. The NPK 16-16-16 compound fertilizer was used at a dose of 25 g per clump. Fertilization aims to help vegetative growth, as the elements N, P, and K are essential in the formation of plant cells, tissues, and organs.

Lemongrass plant maintenance was conducted by routinely watering twice a day with a volume of 400 mL, depending on the weather. Watering was not conducted during rain, and weeding was performed to protect the plant from weeds. Specifically, weeding was performed to clean the plant of weeds and remove dried lemongrass stems or leaves. This was carried out every two weeks or according to the condition of the existing weeds. Pest attacks on plant leaves were controlled with Sevin at the recommended dose.

2.1. Parameters

2.1.1. Light Intensity

Light intensity was measured using a tool called Li-COR 2000. The tool was activated, placed under shade, and left for a while to stabilize the numbers on the screen. This light intensity measurement was done daily during the study at 12.00 PM [17].

2.1.2. Number of Tillers

At the end of the study, the number of plant tillers was calculated by counting the number of stems in the plant clump [18]. When there were 20 stems in a plant clump, the number of tillers was 19 because the remaining stem was the parent plant.

2.1.3. Leaf Thickness

Leaf thickness measurements were carried out at the end of the study using a Dial Thickness Gauge [19]. Determine the most dominant offspring in a clump of lemongrass. From the offspring, 3 leaves are taken from the upper, middle and lower leaves. Leaf thickness measurement is measured in the middle of the leaf. The measurements were done immediately after the plant was harvested at the Basic Laboratory of Batanghari University, Jambi.

2.1.4. Leaf Chlorophyll Content

At the end of the study, leaf chlorophyll content was measured. Measurements were made in the field using a SPAD meter (Minolta 502) or chlorophyll meter, and the results were expressed in units. The SPAD meter was used because the leaf chlorophyll was positively correlated with the content determined destructively, while the destructive measurement was positively correlated with leaf N levels [20]. Determine 2 stems in each clump. Chlorophyll measurements are carried out on 3 leaves from the upper, middle and lower leaves. Chlorophyll measurements are carried out in the middle part of the leaf.

2.1.5. Essential Oil Content

The essential oil extraction using the Solvemn method described by Kurniawan et al. [21]. Several lemongrass leaves were taken and left for 3 days, 3 nights, and then compacted. About 100 grams of leaf and stems were taken and soaked in 90% ethanol up to 400 ml for 3 days and 3 nights. The ethanol liquid was placed into a three-necked flask containing a magnetic stirrer and extracted for 4 hours at a temperature of 80°C. The extraction results were filtered, and the filtrate was then distilled for approximately 2 hours at a temperature of 80°C. About 10, 15, 20, 25, and 30 grams of Sodium Bisulfite solution were added and stirred until homogeneous for approximately 2 minutes. The stirred solution was left until the upper and lower layers were formed. The lower layer was the remaining sediment from Sodium Bisulfite, and the upper layer was essential oil. Furthermore, the percentage of essential oil and water content was calculated.

2.2. Data Analysis

Two types of statistical test tools were used in data processing. First, data were analyzed statistically using an analysis of variance. The Duncan's Multiple Range Test (DMRT) further tests were performed at the 95% α level to obtain the best treatment. Second, orthogonal polynomial regression was used to determine the stress limit. Polynomial analysis was carried out twice, first with order one and continued with order 2. The equation selected had the highest correlation value from these two regression tests.

3. Results and Discussion

Analysis of variance results showed that shade treatment significantly affected the parameters of light intensity, number of tillers, fresh weight of herbs, leaf thickness, chlorophyll content, and essential oil content. The orthogonal polynomial regression analysis results indicate a quadratic pattern between shades with fresh weight of herbs and chlorophyll content. The effect of shade on the growth and production of essential oil in lemongrass plants is further explained.

3.1. Light Intensity, Number of Tillers, and Fresh Weight of Herbs

Shade significantly affected the light intensity received by the lemongrass plant, which then affected the number of tillers and fresh weight of herbs. DMRT further test results are presented in Table 1.

Table 1 shows that N0 had the highest light intensity value of 143,964 lux, significantly different from other treatments. N3 had the lowest light intensity value of 82,125 lux, with a decrease of 42.95%. Lemongrass is a C4 plant that requires full sunlight intensity. According to Bejia et al. [22], the reduction in light intensity caused by shade will affect plant growth. The observation results indicate that lemongrass responds to low light intensity based on several measurements of growth parameters. Light with a certain intensity is essential for plants as all metabolic processes require sunlight, specifically photosynthesis. Zumira et al. [23] explained that light intensity determines the temperature and water balance, closely related to the activity of photosynthesis and transpiration processes. Therefore, light intensity dramatically affects plant growth in areas such as stem elongation and leaf growth.

Table 1. Average light intensity, number of tillers, and fresh weight of herbs of lemongrass plant in various shade treatments

Shade Treatment	Parameters		
	Light Intensity (lux)	Number of Tillers	Fresh Weight of Herbs (g)
N_0 = 0%	143.96±4.31a	11.00±0.11a	337.00±0.31a
N_1 = 25%	123.59±3.70b	10.70±0.32ab	334.00±0.19a
N_2 = 50%	100.13±2.00c	8.30±0.16b	293.66±0.09b
N_3 = 75%	82.12±821.00d	7.30±0.07c	275.33±0.15b

Description: Numbers followed by the same lowercase letter are not significantly different in DMRT at a 5% α level.

Sunlight intensity affected the number of lemongrass plant tillers. Table 1 shows that N0 had 11 tillers, which was not significantly different from N1 but significantly different from N2 and N3. The results also showed that N3 had 7.3 tillers, not significantly different from N2. The number of tillers decreased by 33.63% when the lemongrass plant received 75% shade compared to without shade.

The high number of tillers in N0 cannot be separated from the plant's sunlight. When plants receive full sunlight according to their needs, the photosynthesis process will be maximized. This process produces photosynthate, transported to the growing point through the phloem tissue. Photosynthate is respired by cells to form energy for cell multiplication and development. The energy formed triggers the growth of new tillers and automatically becomes a sink that receives the photosynthate, leading to the flow toward the sink. This process stimulates the release and growth of tillers into mature plants.

The number of tillers decreased when the plant received light stress. Based on the results, the number of tillers in N3 was 7.3, while N0 was 11, indicating a decrease of 36.33% compared to N3. This data implies that the lemongrass plant has received light stress. Plants in light-stressed conditions tend to show different responses. For example, in lemongrass, light stress will reduce the number of tillers. The decreasing light intensity causes the rate of photosynthesis and photosynthate produced to be suboptimal. Photosynthate is the primary material for plants to grow and develop as it provides energy through the respiration process. According to Silveira et al. [24], The 65% and 78% reduction in Mombaca grass tiller population in areas with 30 and 60% shading, respectively, in comparison to full sun light exposure, was the main factor in the reduced productivity of the grasses managed in the agropastoral system. The decrease in the number of tillers in the lemongrass plant that received light stress was correlated with a reduction in the fresh weight. The treatment without shade produced a fresh weight of 337 g, while N1 (25% shade) produced 335 g. These two treatments were not significantly different. Plants in N3 treatment (75% shade) produced a fresh weight of 275.33 g, indicating a 22.39% reduction. The fresh weight accumulates in the number of stems in each plant clump. The polynomial regression test results between shade and fresh weight produced a quadratic pattern as in Figure 1.

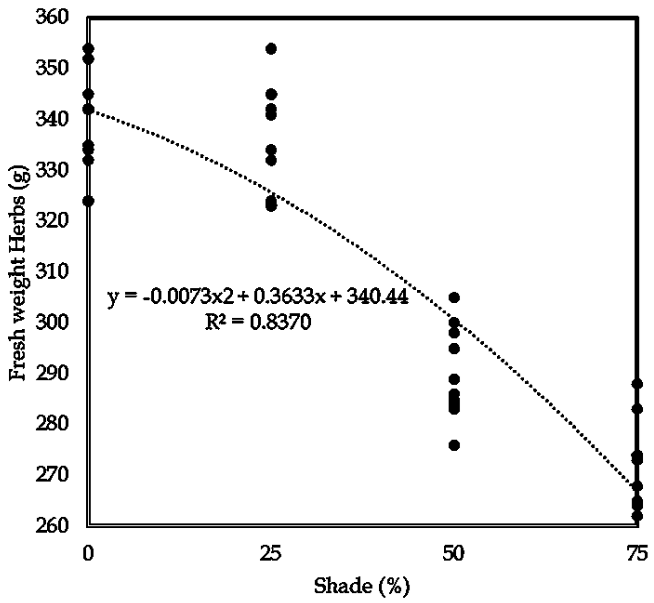

Figure 1. Relationship between shade percentage and fresh weight of herbs

The relationship pattern between shade and fresh weight produced the equation Y= -0.00733X^2 + 0.3633X + 340.44 with a substantial positive value (r= 0.70). Shade had an effect of 83.70% on the fresh weight of herbs (R2= 83.70%). This relationship pattern obtained a critical shade of 24.86% with a fresh weight of 336.83 g. When shade was increased to more than 24.86%, the fresh weight decreased until shade was 75%.

The decrease in the fresh weight of herbs can be attributed to the number of shoots that also reduced in the presence of shade. In general, fresh weight can indicate plant metabolic activity and is influenced by the content of tissue water, nutrients, and metabolic results that occur in plants due to a sufficient supply of sunlight [8]. The presence of shade caused a decrease in the intensity of light received and affected the fresh weight of lemongrass. A previous study by Ribeiro et al [15] showed that patchoulol and pogostol contents were higher under full sun, and, black net and Aluminet at 50% shading. The environment for patchouli cultivation can be improved by use shade nets, especially with Aluminet at 50% of shading. Another study added by Danata et al. [6] found that shade reduced the fresh weight of lemongrass by lowering the intensity of sunlight and the rate of photosynthesis. Fresh weight also reflects photosynthesis during the growth process, accounting for 90% of the total weight. Abdullah et al. [25] mentioned that regular watering and appropriate sunlight intensity will make leaf growth and thickness more optimal while increasing the photosynthesis rate. The products from photosynthesis are used to make stem, leaf, and root cells, which contribute to the fresh weight.

3.2. Leaf Thickness, Chlorophyll Content, and Essential Oil Content

Shade affected leaf thickness, the amount of chlorophyll in the leaf, and the essential oil content. DMRT test at 5% α level showed that the plant could tolerate 25% shade.

Table 2. Average leaf thickness, chlorophyll content, and essential oil content of lemongrass plant at various percentages of shade

Shade Treatment	Parameter		
	Leaf Thickness (mm)	Leaf Chlorophyll (SPAD)	Essential oil (%)
N_0 = 0%	31.66±0.63a	47.00±0.97a	1.30±0.64a
N_1 = 25%	29.33±0.87b	46.00±1.31a	1.20±0.66a
N_2 = 50%	24.66±0.98c	38.66±1.27b	0.87±0.04b
N_3 = 75%	24.00±0.98c	30.33±2.21c	0.67±0.02c

Description: Numbers followed by the same lowercase letter are not significantly different in the DMRT at the 5% α level.

Lemongrass plants without shade had a leaf thickness of 31.66 mm and significantly differed from other shade treatments. At 75% shade, leaf thickness was 24 mm. causing a reduction of 31.91%. The decrease in leaf thickness was caused by reduced light intensity. Low light intensity causes the leaf to become pale due to decreased chlorophyll. According to Miao et al. [26], factors that affect leaf thickness include water availability, nutrients, and light intensity. The amount of sunlight exposure influences each part's different leaf thicknesses. When light received is reduced, the leaf will be thinner, but when light is optimal, the leaf becomes thicker, and the color fades. This is because chlorophyll of the leaf functions in the process of photosynthesis.

The decrease in light intensity impacts the reduction in leaf chlorophyll (Table 2). Leaf without shade had a chlorophyll content of 47 SPAD units, which decreased to 46 SPAD units when shaded by 25% but was not significantly different based on the DMRT test. At 75% shade, chlorophyll content decreased to 30.33 SPAD units or 56.66%. The relationship pattern between shade and leaf chlorophyll content produced the equation $Y = -0{,}00029X^2 + 0.0093 + 47.26$ with a substantially positive value of $r = 0.96$. Shade had a 98.30% effect on leaf chlorophyll content (R^2 = 93.30%). This relationship pattern obtained a critical shade of 1.60% with chlorophyll content of 47.27 SPAD units (Figure 2).

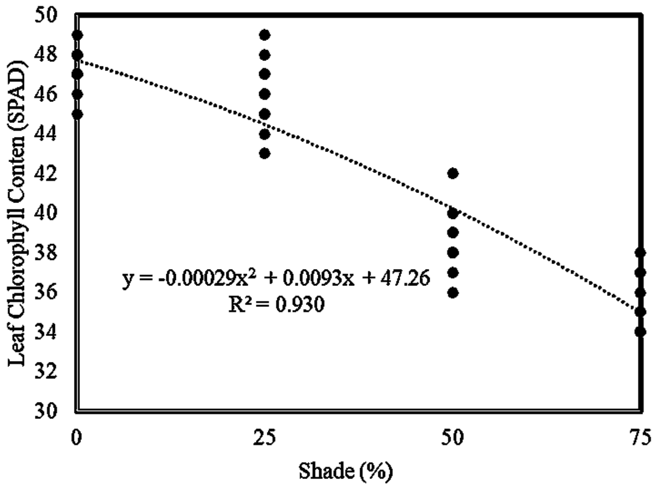

Figure 2. The relationship between shade and chlorophyll content of lemongrass leaf

In N0 treatment (without shade), the highest leaf chlorophyll content value was 47 SPAD Units. In the N3 treatment (75% shade), the leaf chlorophyll content was 30.33 SPAD Units, indicating that chlorophyll content decreased with increasing shade. This is because, in N3 treatment (75% shade), light intensity decreased by 42.95% due to light stress. Chlorophyll in the leaf functions to absorb sunlight. The more light is exposed to the plant, the greater the chlorophyll content. Chlorophyll is a green leaf substance that can absorb light to reflect the yellowish-green color. The content parameters can be compared with the color of the leaf in the N0 treatment. When leaf color is brighter, the sunlight is not blocked by shade, making chlorophyll content function properly and reflecting a paler color, such as apple green. In other words, the lighter received, the more significant chlorophyll contained in the leaf. Li et al. [27] and Dewi et al. [28] stated that factors influencing the formation of chlorophyll include plant genetics, light, and elements N, Mg, and Fe, which act as catalysts in the synthesis process.

The results showed that the higher the percentage of shade, the lower the chlorophyll content. This is because chlorophyll requires light intensity, and when chlorophyll content decreases, it affects leaf color. The more shaded the plant, the darker the leaf color because chlorophyll is not used in photosynthesis.

Shade reduces chlorophyll content by lowering the intensity of sunlight and limiting the rate of photosynthesis. Leaves in unshaded conditions generally had a higher chlorophyll content. Therefore, chlorophyll concentration is significantly affected by differences in light intensity. Increasing the chlorophyll content enhanced the plant's ability to capture sunlight, further accelerating the photosynthesis rate [29].

As shown in Table 2, shade ultimately affected essential oil yield. Plants without shade had an essential oil content of 1.3%, which was not significantly different from the N1 treatment of 1.2%. There was a decrease in essential oil content of 48% when the lemongrass plant received 75% shade. According to A'yun et al. [30], several factors affect lemongrass essential oil, including climate, soil fertility, plant age, and distillation methods. The fairly hot environmental conditions of the study land caused high levels of essential oil yields because lemongrass is a C4 plant that requires full sunlight and is also resistant to drought stress. These stress conditions can increase essential oil production with sufficient P and K elements [31]. Stress conditions in the form of high environmental temperatures cause lemongrass to produce secondary metabolites as a form of self-defense system, namely aromatic compounds [32]. Previous studies have reported by Sheikh et al. [33]; Kumar et al. [34] and Kumar et al. [35], that the essential oil yield is influenced by plant growth, number of shoots, and dry biomass production of the plant. This was in line with the previous analysis stating that plants without shade had the highest number of shoots and the most significant storage weight. Danata et al. [5] and Danata et al. [6] also mentioned that the highest oil yield was obtained in the treatment without shade, decreased at 25% shade, then decreased drastically at 50% and 75% shade.

Shade conditions affect the lemongrass plant's growth, yield, physiological responses, and essential oil quality. The higher the percentage of shade, the lower the essential oil content. Previous analysis showed that shade treatment affected the essential oil content, such as linalool and eugenol because the typical basil flavor increased in total light and decreased in shade conditions [36,37]. Another *Eucalyptus citriodora* Hook plant analysis reported that a higher shade percentage led to thicker stem growth, broader petals, and more branches. In this analysis, changes in thickness and chlorophyll content of lemongrass leaf affected the rate of photosynthesis, causing an impact on the growth and production of essential oil.

4. Conclusion

In conclusion, shade affected all parameters tested in this analysis, including light intensity, number of tillers, fresh weight of herbs, leaf thickness, chlorophyll, and essential oil content. The shade of 75% caused a reduction in light intensity, number of tillers, fresh weight, leaf thickness, chlorophyll, and essential oil. The regression test results showed that the lemongrass plant could still tolerate light stress in the 25% shade treatment, and then when shade was increased, the plant would be stressed by light, and all components of growth would decrease. The critical limit of light stress for lemongrass planted as intercrops was 25% with growth indicators and essential oil production. Lemongrass can grow and produce well as an intercrop with a minimum light intensity of 75%.

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References

1. Direktorat Jendral Perkebunan. Statistik perkebunan unggulan nasional 2020-2024. 2024.
2. Mumba AS, Rante CS. Pest control of aphids (Aphis gossypii) on pepper plants (Capsicum annum L.) using an extract of citronella (Cymbopogan nardus L.). J Agroekoteknologi Terap. 2020;1(2):35–8.
3. Afdhol MK, Hidayat F, Erfando T, Lestari FA, Hakim M, Syawaldriyansah RR. Pemanfaatan daun serai wangi sebagai bahan baku pembuatan minyak atsiri untuk peningkatan ekonomi masyarakat desa. Din J Pengabdi Kpd Masy. 2022;6(3):564–9.
4. Begum T, Gogoi R, Sarma N, Pandey SK, Lal M. Direct sunlight and partial shading alter the quality, quantity, biochemical activities of Kaempferia parviflora Wall., ex Baker rhizome essential oil: A high industrially important species. Ind Crops Prod. 2022;180:114765.
5. Danata NH, Aini N, Udayana C, Setiawan A, Kurnianingrum F. Growth, yield and transpiration rate of Cymbopogon nardus L. at different shade levels. In: The 1st International Conference on Agricultural, Neutraceutical and Food Science (ICANFS) 2022. 2022. p. 150–5.
6. Danata NH, Aini N, Udayana C, Setiawan A, Yamika WSD, Prambudi R. Diversity characterization of three varieties of Cymbopogon nardus under different shade conditions. Biodiversitas. 2023;24(6):3574–82.
7. Irmawati D, Rahayu ES. Development of photomyxotrophic culture protocol of lemongrass through sucrose concentration increase and light intensity decrease. Biosaintifika. 2023;15(2):212–9.
8. Yang H, Dong B, Wang Y, Qiao Y, Shi C, Jin L, et al. Photosynthetic base of reduced

grain yield by shading stress during the early reproductive stage of two wheat cultivars. Sci Rep. 2020;10:14353.
9. Yi-bo W, Rui-dong H, Yu-fei Z. Effects of shading stress during the reproductive stages on photosynthetic physiology and yield characteristics of peanut (Arachis hypogaea Linn.). J Integr Agric. 2021;20(5):1250–65.
10. Nasser MA, Negyan Z, Ejaz I, Faroog M. Physiological mechanisms of grain yield loss under combined drought and shading stress at the post-silking stage in maize. J Soil Sci Plant Nutr. 2023;23:1125–1137.
11. Naseer MA, Hussain S, Mukhtar A, Rui Q, Ru G, Ahmad H, et al. Chlorophyll fluorescence, physiology, and yield of winter wheat under different irrigation and shade durations during the grain-filling stage. Front Plant Sci. 2024;15:1396929.
12. Yuan L, Liu J, Cai Z, Wang H, Fu J, Zhang H, et al. Shade stress on maize seedlings biomass production and photosynthetic traits. Ciência Rural. 2022;52(3):e20201022.
13. Ghorbel M, Brini F, Brestic M, Landi M. Interplay between low light and hormone-mediated signaling pathways in shade avoidance regulation in plants. Plant Stress. 2023;9:100178.
14. Bebre I, Riebl H, Annighöfer P. Seedling growth and biomass production under different light availability levels and competition types. Forests. 2021;12:1376.
15. Ribeiro AS, Tostes WN, Bertolucci SKV, Coelho AD, Carvalho AA de, Pinto JEBP. Light intensities alter growth and essential oil of patchouli under shade nets. Ciência Rural. 2022;52(5):e20210118.
16. Ekawati R, Saputri LH. Chlorophyll components, total flavonoid, anthocyanin content and yield of Eleutherine palmifolia L. (Merr) on different shading levels. In: IOP Conference Series: Earth and Environmental Science. 2022. p. 012004.
17. Zhang M, Chen W, Jing M, Gao Y, Wang Z. Canopy structure, light intensity, temperature and photosynthetic performance of winter wheat under different irrigation conditions. Plants. 2023;12(19):3482.
18. Altendorf KR, DeHaan LR, Heineck GC, Zhang X, Anderson JA. Floret site utilization and reproductive tiller number are primary components of grain yield in intermediate wheatgrass spaced plants. Crop Sci. 2021;61(2):1073–88.
19. Pérez-Bueno ML, Illescas-Miranda J, Martín-Forero AF, de Marcos A, Barón M, Fenoll C, et al. An extremely low stomatal density mutant overcomes cooling limitations at supra-optimal temperature by adjusting stomatal size and leaf thickness. Front Plant Sci. 2022;13:919299.
20. Benati JA, Nava G, Mayer NA. Spad index for diagnosis of nitrogen status in 'Esmeralda' peach. Rev Bras Frutic. 2021;43(1):e-093.
21. Kurniawan E, Sari N, Sulhatun. Ekstraksi sereh wangi menjadi minyak atsiri. J Teknol Kim Unimal. 2020;9(2):43–53.
22. Bejia T, Semahegn Z. Effects of increased temperature on photosynthesis of C3 and $4 plants. J Nat Sci Res. 2022;13(11):19–25.
23. Zumira A, Salsabila A, Nurzeha F, Supriatno B, Anggraeni S. Desain kegiatan praktikum pengaruh intensitas cahaya terhadap laju proses fotosintesis bermuatan literasi kuantitatif. J Basicedu. 2022;6(4):7474–85.
24. Silveira Junior O, Lima ICS, Rodrigues MOD, Rodrigues MOD, André TB, Santos AC. Effect of shading on agronomic and structural characteristics of mombaça grass in agroforestry system in the Cerrado-Amazon Ecotone. J Anim Plant Sci. 2024;34(4):936–45.

25. Abdullah, Masthura. Sistem pemberian nutrisi dan penyiraman tanaman otomatis berdasarkan real time clock dan tingkat kelembaban tanah berbasis mikrokontroler ATMEGA32. FISITEK J Ilmu Fis dan Teknol. 2018;2(2):33–41.
26. Miao C, Yang S, Xu J, Wang H, Zhang Y, Cui J, et al. Effects of light intensity on growth and quality of lettuce and spinach cultivars in a plant factory. Plants. 2023;12(18):3337.
27. Li J, Cao X, Jia X, Liu L, Cao H, Qin W, et al. Iron deficiency leads to chlorosis through impacting chlorophyll synthesis and nitrogen metabolism in Areca catechu L. Front Plant Sci. 2021;12:710093.
28. Dewi S, Zainuddin DU, Angka AW. Response of garlic varieties growth towards the use of biological fertilizer. Anjoro Int J Agric Bus. 2022;3(2):51–5.
29. Zainal A, Hasbullah F, Akhir N, Hervani D. Pengaruh intensitas cahaya terhadap pertumbuhan dan kandungan klorofil daun tanaman talas putih (Xanthosoma sp). J Pertan Agros. 2022;24(2):514–25.
30. A’yun Q, Hermana B, Kalsum U. Analisis rendemen minyak atsiri seraiwangi (Cymbopogon nardus (L.) pada beberapa vaietas. J Pertan Presisi (Journal Precis Agric. 2020;4(2):160–73.
31. Wahyudi A. Sistem produksi minyak serai wangi berkelanjutan. Perspektif. 2021;20(2):94–105.
32. Chetouani M, Chetouani M, Arabi M, Bidi H, Hassani Y. Water stress effect on the quality and quantity of lemongrass essential oils in glass greenhouses: Juvenile and adult stages. E3S Web Conf. 2024;527:03005.
33. Sheikh R, Islam MA, Sharmin A, Biswas R, Kumar J. Sustainable agroforestry practice in Jessore District of Bangladesh. Eur J Agric Food Sci. 2021;3(1):1–10.
34. Kumar S, Prasad R, Kumar V, Krishna AK. Organic source on productivity of pomegranate–lemongrass-based agroforestry system in central India. Agrofor Syst. 2021;95:615–24.
35. Kumar V, Singh N, Singh V, Sharma R, Singh A, Kumar R, et al. Impact of different soil types of bundelkhand region of India on vegetative growth and oil yield of lemongrass (Cymbopogon flexuosus) cv. Krishna. Med Plants-International J Phytomedicines Relat Ind. 2021;13(4):622–6.
36. Mwithiga G, Maina S, Muturi P, Josiah G. Lemongrass (Cymbopogon flexuosus) growth rate, essential oil yield and composition as influenced by different soil conditioners under two watering regimes. Hellyon. 2024;10(4):e25540.
37. Mwithiga G, Maina S, Muturi P, Gitari J. Lemongrass (Cymbopogon flexuosus) agronomic traits, oil yield and oil quality under different agro-ecological zones. J Agric Food Res. 2022;10:100422.