Low Light Intensity Increases Xanthorrhizol Content and the Growth of Java turmeric (*Curcuma xanthorrhiza*)

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Abstract. Java turmeric (*Curcuma xanthorrhiza* Roxb.) is a medicinal herb whose rhizomes contain xanthorrhizol, a bioactive compound with significant pharmacological properties. Environmental factors, including light intensity, can influence the accumulation of bioactive compounds in plants. This study investigated the effect of shade on the growth, biomass, and xanthorrhizol content of Java turmeric by cultivating plants under four levels of sunlight intensity using shade nets: 0%, 25%, 50%, and 75%. The results indicated that shading did not significantly affect fresh rhizome weight or xanthorrhizol content, demonstrating that Java turmeric can maintain its yield and bioactive compound production under reduced light conditions. Plants grown under 75% shade exhibited higher chlorophyll a, chlorophyll b, and total chlorophyll, as well as a 64% increase in carotene content compared to unshaded plants, suggesting physiological adaptation to low light by enhancing photosynthetic pigments. Shade treatments had no significant effect on overall plant growth, anatomical traits, or biomass accumulation. These findings indicate that Java turmeric can tolerate and adapt to low-light environments without compromising yield, highlighting its potential for intercropping under shaded conditions, such as under tree canopies or plantation crops.

1 Introduction

Curcuma xanthorrhiza Roxb, a member of the Zingiberaceae family, is a medicinal plant native to Indonesia and commonly known as Java turmeric. This plant is widely cultivated in Indonesia and other Southeast Asian countries, including Malaysia, Thailand, Vietnam, and the Philippines. It has long been used in traditional medicine to treat migraines, constipation, and inflammatory conditions [1]. This plant is characterized by branched rhizomes with a dark yellow to reddish-brown exterior and an orange to orange-red interior, and grows in shrublands and teak forests in moist, fertile, humus-rich soils up to an altitude of 750 m [2]. The essential oil of C. xanthorrhiza contains xanthorrhizol, a bisabolene-type sesquiterpenoid unique to this species among the Curcuma genus [7,8,9], and is responsible for many of its pharmacological properties, including anti-inflammatory, antioxidant, antimicrobial, anticancer, antihyperglycemic, antihypertensive, and hepatoprotective effects [3,4,5,6]. The production of secondary metabolites, such as xanthorrhizol, is highly complex and influenced by internal factors, including genes and enzymes, as well as external environmental conditions, including light, temperature, water availability, and soil characteristics [10,11]. Light intensity, in particular, plays a vital role in regulating the synthesis and accumulation of bioactive compounds, as shown in studies on ginger and other medicinal plants where shading affects the yield and composition of essential oils [12,13,14]. According to the study, at 20% and 40% shading levels, the yield of dried ginger was higher, and the essential oil content tended to increase with increasing shading [15]. The concentrations of camphene, sabinene, b-pinene, borneol, bornyl acetate, and Z-jasmone were higher in *Flourensia cernua* plants grown in the shade than in plants exposed to full light. The development

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of medicinal plants can be seen in the synthesis of their main active ingredients, where the concentration of these ingredients is the most critical factor in determining the plant's economic value. With increasing land-use pressure and potential for intercropping in plantation areas, Java turmeric is often grown in shaded conditions. Yet, limited research has examined how light intensity affects xanthorrhizol content, growth, and biomass accumulation in this species. Addressing this knowledge gap is crucial for optimizing cultivation practices and enhancing the medicinal and economic value of Java turmeric. Therefore, this study aims to evaluate the effect of shading on xanthorrhizol content, plant growth, and biomass of C. xanthorrhiza.

2 Materials and Methods

This study was conducted at the Cikabayan Research Station (6°33′ S, 106°42′ E) from July 2021 to April 2022.

The materials used in this study were curcuma derived from seedlings having a height of 20-30 cm, shade net (25%, 50%, and 75%), manure, and inorganic fertilizers: other materials were inorganic fertilizers in the form of urea (contains 45% nitrogen), SP 36 (contains 36% phosphorus), KCl (contains 60% potassium), along with standard chemicals for pigment and active compound analysis. Key equipment included planting tools, thermometer, lux meter, digital scales, meters, HPLC, GC-MS, and spectrophotometer.

The experiment utilized a randomized complete block design (RCBD) with four shading treatments: full light (0% shade, N0), 25% (N1), 50% (N2), and 75% (N3) shade netting. Each treatment was replicated three times (a total of 12 plots), and each plot contained six sample plants. Soil was minimally tilled before making plots (80 cm × 80 cm spacing, 10 cm planting hole depth). Basal fertilization included 20 t ha^{-1} manure, 92 kg ha^{-1} nitrogen, 72 kg ha^{-1} phosphorus, and 120 kg ha^{-1} potassium. Standard cultivation practices were followed, including watering, weeding, and pest and disease control. Plants were harvested at eight months after planting.

Observed Variables. Morphological and agronomic traits: plant height (cm), number of leaves, number of tillers, fresh and dry weights (shoot, root, rhizome). Physiological traits: pigment contents (chlorophyll-a, chlorophyll-b, total chlorophyll, anthocyanin, betacarotene), stomata density, and xanthorrhizol content ($mg \cdot g^{-1}$). Xanthorrhizol content was measured by HPLC using a C18 column (150 × 4.6 mm, 5 µm), with methanol: water (80:20) as the mobile phase and detection at 280 nm. Retention time for the target compound was approximately 9.6 minutes. Chlorophyll and anthocyanin analysis followed a standard protocol: leaf samples (0.02 g) were extracted with acetone, centrifuged, and the supernatant was measured spectrophotometrically at specific wavelengths. Concentrations were calculated using established formulas (Sims and Gamon, 2002). Stomata density was determined by applying clear nail polish to the lower leaf surface, removing the dried imprint with transparent tape, and viewing under a microscope at various magnifications. Light intensity was recorded during the growth phase using a lux meter at various plot points. Growth variables (height, leaf number) were measured regularly, while yield and physiological parameters (fresh/dry weight, rhizome traits, pigment contents, leaf area via ImageJ software) were assessed at harvest.

All data were subjected to analysis of variance (ANOVA), and group means were compared using Duncan's test at a significance level of $p < 0.05$. Data processing was performed using SPSS software.

3 Result and Discussion

3.1 Effect of shading on the active compound xanthorrhizol.

Shading density did not significantly affect the fresh or dry weight of Java ginger rhizomes (Table 1), nor did it affect xanthorrhizol content substantially (Figure 1). This indicates strong shade tolerance, with plants adapting well even under 75% shade. Therefore, Java turmeric can be successfully grown under a variety of shade conditions without significant yield loss or reduction in key active compounds. This is consistent with previous research showing that cultivation under coffee canopies (50–70% light transmission) maintains optimal rhizome production and curcumin and antioxidant levels. Java turmeric shade tolerance is consistent with findings for other Curcuma species and shade-adapted medicinal plants [19].

Table 1. Effect of shade on fresh weight and dry weight of rhizomes at 32 WAP

Shade density (%)	fresh weight rhizome (g)	dry weight rhizome (g)
0	628.0 ± 491 a	80.62 ± 59.8 a
25	866.0 ± 426 a	117.12 ± 50.15 a
50	443.8 ± 216 a	61.34 ± 30.24 a
75	157.8 ± 105.8 a	17.66 ± 12.74 a

Note: means followed by the same letter in the same column are not significantly different based on the Duncan test at α = 5%. The mean value is followed by the standard deviation value

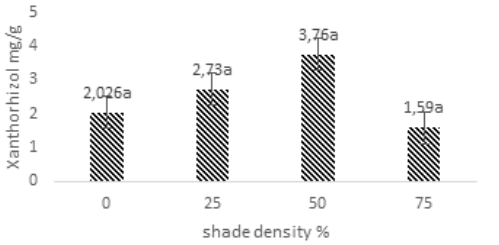

Figure 1. Effect of shade on the bioactive content of xanthrrizhol (mg g-1) at 32 WAP

3.2 Effect of Shading on plant growth

Growth variables—including plant height, leaf number, tiller number, and leaf area—were unaffected by increasing shade levels (Table 2). These results indicate that Java turmeric possesses physiological mechanisms that allow it to maintain growth under reduced light. At a shade density of 75%, plants can still provide the exact yield as unshaded plants. Plants grown at low light intensities can experience etiolation, caused by the accumulation of auxin in the apical shoots, which is not degraded by low light conditions because shading increases the height of ginger plants due to auxin activity [20]. Another study showed that ginger plants increased in height and leaf number by 60% in shade compared to unshaded areas; this increase was caused by reduced light transmission and increased relative humidity and air temperature. Plant adaptation to shade can occur through (1) increased leaf area as a means of reducing metabolite use and (2) reduced transmitted and reflected light.

3.3 Effect of Shading on Plant Biomass

No significant differences were observed in the fresh or dry weight of shoots and roots between shade treatments (Table 3); plant biomass was determined from the growth of ginger plants. Other studies have shown that the yields of ginger under 50% and 30% shade are higher than under 70% shade. In another study of ginger plants grown under coconut trees,

the fresh weight, dry weight, and oil content of ginger rhizomes differed significantly when harvested at different ages. Environmental conditions such as light availability and plant age influence phytochemical composition and yield.

3.4 The effect of shading on the anatomy and physiology of Java turmeric leaves.

Shading significantly increased chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid content (Table 4), illustrating a key adaptation mechanism: increased pigment synthesis to enhance photosynthetic efficiency under low-

Table 2. Effect of shade on plant height, number of leaves, number of tillers, and leaf area of java turmeric plants at 32 WAP

Shade density (%)	plant height (cm)	number of leaves	number of tillers	leaf area (cm-2)
0	92.56 ± 39.69 a	9.11 ± 0.76 a	2.11 ± 1.34 a	3969 ± 2689 a
25	115.22 ± 16.03 a	10.11 ± 0.84 a	0.89 ± 0.69 a	4570 ± 1204 a
50	129.89 ± 32.55 a	9.11 ± 0.19 a	0.66 ± 0.66 a	3753 ± 2086 a
75	119.78 ± 21.45 a	9.22 ± 0.84 a	0.44 ± 0.38 a	3165 ± 1099 a

Note: means followed by the same letter in the same column are not significantly different based on the Duncan test at α = 5%. The mean value is followed by the

Table 3. Effect of shade on plant biomass of java turmeric plants at 32 WAP

Shade density (%)	shoot fresh weight (g)	root fresh weight (g)	shoot dry weight (g)	root dry weight (g)
0	497.8 ± 606.41 a	41.17 ± 34.56 a	61.41 ± 39.38 a	11.89 ± 5.98 a
25	690.5 ± 166.04 a	77.33 ± 13.53 a	101.96 ± 13.48 a	16.92 ± 1.28 a
50	418.3 ± 105.20 a	65.83 ± 41.75 a	60.79 ± 13.96 a	28.50 ± 14.52 a
75	517.7 ± 281.05 a	42.50 ± 22.45 a	57.49 ± 35.22 a	12.24 ± 8.86 a

Note: means followed by the same letter in the same column are not significantly different based on the Duncan test at α = 5%. The mean value is followed by the standard deviation value

light conditions. However, the chlorophyll a/b ratio, anthocyanin content, stomata number, and stomata density were not significantly affected. High chlorophyll levels allow for more effective light absorption, a characteristic of shade-tolerant species. According to [24], plants adapt or avoid shade stress by increasing the efficiency of light capture per unit area of photosynthesis with higher levels of shade provided by increasing the amount of chlorophyll per unit area of leaves and the chlorophyll b/a ratio. Research on giving shade to land spinach plants shows that shade reduces the chlorophyll content of land spinach plants. A two-layer shade net (light intensity = 370.6 lux) produces the lowest chlorophyll content but the highest β-carotene. The results of research show that moderate shade conditions will reduce the amount of light reaching the leaf surface, resulting in a reduction in light by 50%; rice leaves have more than 0% chlorophyll. Rrice with increased chlorophyll content in shade conditions can be used as an indicator of shade-tolerant rice.

Curcuma exhibits strong adaptability to low-light conditions, as evidenced by increased levels of chlorophyll a, chlorophyll b, total chlorophyll, and carotene under higher shade conditions, particularly at 75% density. This physiological response allows the plant to thrive without significant reductions in growth, fresh rhizome weight, or xanthorrhizol yield, thus confirming its suitability for cultivation in shaded systems. Overall, shade did not negatively

Table 4. Effect of shade on anthocyanin, carotene, number of stomata, and density of stomata of java turmeric at 32 WAP

Shade density (%)	Anthocyanin (mg g-1)	Carotene	Number of stomata	Density of stomata
0	0.080 ± 0.03 a	0.28 ± 0.09 b	21.20 ± 4.9 a	108.28 ± 25.94 a
25	0.13 ± 0.08 a	0.39 ± 0.03 ab	23.90 ± 3.2 a	121.88 ± 16.44 a
50	0.113 ± 0,03 a	0.39 ± 0.03 ab	24.23 ± 0.23 a	123.58 ± 1.13 a
75	0.212 ± 0.09 a	0.46 ± 0.07 a	20.53 ± 0.53 a	104.87 ± 2.83 a

Note: means followed by the same letter in the same column are not significantly different based on the Duncan test at α = 5%. The mean value is followed by the standard deviation value

impact plant anatomy, biomass, or key growth parameters, demonstrating curcuma's ability to maintain productivity and quality in light-limited environments.

4 Conclusion

Java turmeric plants demonstrated strong adaptability to low light conditions, as shading up to 75% did not significantly affect rhizome fresh weight, growth, biomass, or xanthorrhizol content. Under shaded conditions, the plants increased chlorophyll a, chlorophyll b, and carotene content, indicating a physiological adjustment to reduced light intensity. These findings suggest that Java turmeric can be effectively cultivated in shaded environments without compromising yield or key compound production.

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