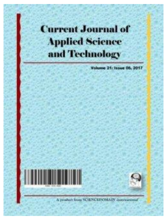


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# Effect of Different Shade Levels on Growth, Physiology and Biochemical Characteristics of Small Cardamom (*Elettaria cardamomum* Maton)

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author MA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SJA and KSK managed the analyses of the study and literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

*Elettaria cardamomum* was grown under shade levels (75% shade, 50% shade and open irradiance) to evaluate its photosynthetic characteristics, physiology and biochemical characters. The highest net photosynthetic rates and stomatal conductance were observed under 75% shade, followed in descending order by 50% and open condition. The highest quantum yield of photosystem II was observed under 50% shade. As shade level increased, Chl a,Chl b and total Chl contents also increased significantly. The total number of opened stomata generally displayed the best activity in leaves subjected to 75% shade. The highest total phenol and epicuticular wax contents were observed in open irradiance treatment and highest proline level was observed in plants subjected to the 50% shade treatment. The results indicate that increased plant height, chlorophyll and proline contents and higher quantum yield of Photosystem II and stomatal activity may play an essential role in shade adapting mechanism in small cardamom.

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Keywords: Shade; photosynthesis; stomatal behaviour; proline; phenolic content; epicuticular wax; small cardamom.

## 1. INTRODUCTION

Small cardamom (*Elettaria cardamomum*(L.) Maton, Zingiberaceae), a shade-loving herbaceous non-woody shrub of Indian origin. It is cultivated extensively in the high-altitude hilly areas of the Western Ghats of Kerala, Tamil Nadu and Karnataka states of peninsular India for its spicy and aromatic capsules. Cardamom has $C_3$ photosynthetic pathway [1].

The principle of shade regulation in cardamom has been in practice for decades. The complex tropical forest has been converted to a more open, simple and uniform system and hence leading to degradation of cardamom agroforestry system in India [1]. Reduced soil water content can decrease the yield of cardamom significantly during summer in the months of April and May. The number of flowers and capsules formed and the percentage of capsule set per plant were also reduced to 30% in summer and 80% in August or September. Synchronous soil and atmospheric warming of cardamom hills is evident which can adversely impact soil nutrient dynamics particularly major nutrients (nitrogen, phosphorus and potassium) leading to unavoidable yield reduction.

Light is a most important factor influencing plant growth, morphology, anatomy, various aspects of physiology, cellular biochemistry, flowering time and plant productivity [2,3,4]. In the light reactions of photosynthesis, light energy is used to produce ATP and NADPH, which are then used for carbon fixation and production of oxygen during the light-independent phase. Shading has a significant impact on plant photosynthesis. Normal plant growth needs optimal light irradiance because excessively high and low irradiance would result in photoinhibition and light deficiency respectively, resulting in restricted plant growth. Under high irradiance conditions, the photosynthetic apparatus absorbs excessive light energy, resulting in the inactivation or impairment of the chlorophyll-containing reaction centers of chloroplasts and consequent reduction of photosynthetic activity [5,6]. In contrast, under low irradiance conditions, insufficient ATP is produced to allow for carbon fixation and carbohydrate biosynthesis. This leads to a reduction in plant growth.

Therefore, an investigation is necessary to understand the physiology of cardamom yield under various shade level. Under the fast changing climate conditions of cardamom growing areas in Western Ghats, ecophysiological studies would be of immense use to manage and safeguard the cardamom agroforestry systems. The objectives of the present study were 1) to quantify the influence of different shade levels on photosynthetic characteristics, stomatal activity, and physiology of small cardamom, 2) to determine optimum light intensity required for plant growth, and 3) to understand cardamom plant's shade-adaptation mechanism. The present investigation may also help in establishing improved cultivation practices for cardamom and future crop improvement practices of this economically viable condiment.

## 2. MATERIALS AND METHODS

### 2.1 Plant Materials and Growth Conditions

Small cardamom plants (Variety: Appangala-1) were obtained from ICAR-Indian Institute of Spices Research, Regional station and were maintained in an open field, Appangala, Kodagu district, Karnataka (12°23'19"N 75°42'59"E), at an altitude of 920 meters above mean sea level. The observed average rainfall in experimental location was accounted to 2783mm with an average temperature of 20.5°C during 2016-2018. Plants were subjected to three different shade treatments for 18 months, starting from August, 2016. Treatments consisted of 75% and 50% shade levels and open condition (natural irradiance), and shades were created by using green colour commercial plastic shading nets (Prathu Agro company, Coimbatore, India). Per cent interception of light in the canopy was calculated (middle point of a slope) by comparison with a Photometer (Luxor, USA) placed in the open field situation. The measurement was made between mid-day and 2.00 pm as per the method suggested by [7].

Light interception = (Mean of light intensity at the middle of the canopy and ground level / Light intensity in the open) X 100

Each treatment involved seven replications. All plants were well-irrigated and protected from pathogens, pests and weed competition.

## 2.2 Observations on Plant Growth Characteristics

Plants were allowed to grow up to 18 months, after which observations on a number of shoots, leaf length and breadth and specific leaf weight were recorded.

## 2.3 Physiological Observations

i. **Photosynthetic Parameters:**

Photosynthetic parameters were recorded using a portable photosynthetic system (LCpro-SD Advanced Photosynthesis Measurement System, England). The parameters measured were net photosynthetic rate (Pn, µmol $m^{-2}$ $s^{-1}$), stomatal conductance ($g_s$, mol $m^{-2}$ $s^{-1}$), Photosynthetic photon flux density (PPFD, µmol $m^{-2}$ $s^{-1}$), intercellular $CO_2$ concentration (Ci, µmol $CO_2$ $mol^{-1}$) and transpiration rate (Tr, mmol$H_2O$ $m^{-2}$ $s^{-1}$). During the treatment period, data were recorded between 9:30 and 11:30 am. The measurements were recorded when both Pn and $g_s$ were stable. Five representative plants were randomly selected from each treatment to record the above parameters.

ii. **Chlorophyll fluorescence:**

Chlorophyll fluorescence, of the same leaves that were used for determination of photosynthetic parameters, was measured with a chlorophyll fluorometer (Os-30 p) in 10-15 minutes dark adapted leaves. The maximum PS II quantum yield (Fv/Fm) was determined in dark-adapted leaves between 9:30 and 11:30 am local time [8]. Gas exchange and chlorophyll fluorescence were analyzed on a typical sunny day. All measurements were performed on the attached fully expanded leaves of five plants per treatment.

iii. **Biochemical Assays:**

Total chlorophyll and carotenoid contents were estimated by adopting the method of Arnon [9] and expressed as mg $g^{-1}$ of fresh weight. The total phenolic content of the leaves extract was determined by the Folin–Ciocalteu method [10]. The total phenolic content was calculated from the calibration curve and expressed as µg $g^{-1}$ of fresh weight. Proline content of the leaf sample was estimated by the method of Bates [11] and expressed as µg $g^{-1}$ of fresh weight. Leaf epicuticular wax (EW) content was determined in leaves using the method described by Ebercon [12], and the content was expressed in µg $dm^{-2}$.

## 2.4 Statistical Analysis

Data was subjected to analysis of variance and Duncan's multiple range test was used to differentiate means as described by Duncan [13]. Values were considered at a significance level of 95% ($p<0.05$). Statistical analyses were performed using WASP-Web Agri Stat Package 2.0.

# 3. RESULTS AND DISCUSSION

Shade treatment significantly enhanced plant height in 75% shade (Fig. 1A); however, shade treatment had no significant effect on leaf length and width (Fig. 1B). Shade treatment significantly reduced specific leaf weight in 75% shade (Fig. 1C), a total number of tillers (Fig. 1D) but had no significant effect on the number of productive tillers (Fig. 1D) (Table 1). These observed results suggest that open treatment significantly reduced plant fitness, suggesting that high light intensity might not be a suitable habitat for small cardamom. This may explain why the main distribution habitats of small cardamom in the Western Ghats are in the shaded environment, rather than habitats with an open environment.

Stomata have a dramatic effect on photosynthesis [14]. The present results demonstrated that a number of opened stomata in plants grown under 75% shade treatment was greater than that of the plants grown under open condition (Fig. 2A). In the present study, high photon flux densities might limit photosynthesis through high irradiance and thermal damage resulting in stomatal closure. Stomatal pore features were significantly affected by irradiance. Plant stomata developed under high irradiance had better closing ability when stressed than plants grown under low irradiance, thus allowing them to retain more water [15].

**Table 1. The effects of different shade on growth characters of small cardamom**

| Treatments | Plant height (cm) | Leaf length (cm) | Leaf width (cm) | SLW (g $cm^{-2}$) | Total Tillers $plant^{-1}$ | Panicle bearing tillers $plant^{-1}$ |
|---|---|---|---|---|---|---|
| Open irradiance | 224.4$^{b}$ | 51.8$^{ns}$ | 8.61$^{ns}$ | 0.016$^{a}$ | 52.1$^{a}$ | 35.2$^{ns}$ |
| 50% shade | 227.6$^{b}$ | 53.1$^{ns}$ | 8.46$^{ns}$ | 0.015$^{b}$ | 44.0$^{b}$ | 31.2$^{ns}$ |
| 75% shade | 252.0$^{a}$ | 52.6$^{ns}$ | 8.69$^{ns}$ | 0.015$^{b}$ | 43.0$^{b}$ | 31.7$^{ns}$ |
| CV% | 8.477 | 6.07 | 5.44 | 4.125 | 14.16 | 19.37 |

*Values represent mean of seven replications. Same letter within each column indicate no significant differences among the treatments (P≤0.05).*

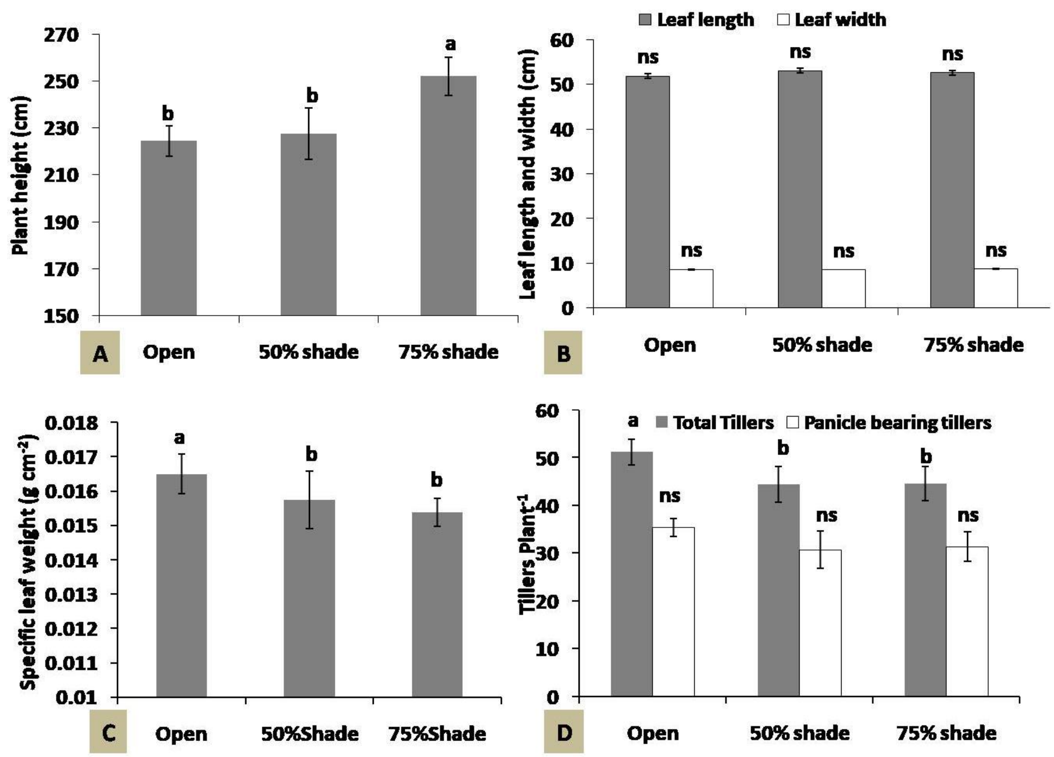


**Figure 1. Plant height (A), leaf length and width (B), specific leaf weight (C) and tillers plant$^{-1}$ (D).** The values represented mean ± SE, and different letters mark significant differences among shade treatments on the same day (P<0.05).

Leaf chlorophyll content is an important determinant of photosynthetic rate [16] and dry matter production [17]. Reduced rates of photosynthesis may be due to reduced levels of chlorophyll, particularly Chl a, which is more directly involved in determining photosynthetic activity [18,19]. A decrease in Chl a and Chl b contents may thus reflect the destruction of pigments by excessive irradiance under high irradiance open condition. We observed significant variation in chlorophyll content under different shade levels. Chl a, Chl b and total Chl contents increased and total phenol content decreased in 75% shade treatments (Figs. 3A and 3B and Table 2). The highest Chl a, Chl b, and total Chl contents were observed in plants grown under 75% shade and highest total phenol content was observed in plants grown in open condition. Shade significantly increased proline content and decreased epicuticular wax content (Fig. 3C and 3D). The highest proline was observed in 50% shade.

During daytime, the Photosynthetic Photon Flux Density (PPFD) ranged from 900 to 1700, 500 to 850 and 250 to 600 mmols $m^{-2}$ $sec^{-1}$ under open, 50% shade and 75% shade level respectively (Fig. 4). Net photosynthetic rate (Pn) varied significantly among shade treatments (Figs. 4 and 5A). The Pn value was highest in 75% shade treatment, followed (in descending order) by 50% shade treatment. Stomatal conductance ($g_s$) also varied significantly among various shade levels (Fig. 5B). Stomatal conductance ($g_s$) values of plants grown under open condition were lower and displayed a slight decrease in 50% shade. The highest $g_s$ values were observed under 75% shade. The intracellular carbon dioxide concentration (Ci) decreased significantly in 50% shade compared to other treatments and there was no significant difference in Ci between open and 75% shade treatment (Fig. 5C). The present study indicated that the Ci and Pn in leaves showed the negative relationship in open and 50% shade, while it showed positive relationship in 75% shade suggesting that contribution of Ci on Pn may vary in different shade levels [20] (Figs. 5A, 5C and Table 3). At the same time, $g_s$ decreased significantly in plants grown under open condition compared to other treatments (Fig. 5B). Under the high light environment, the observed reductions in gs, indicate that stomatal closure was due to light saturation and resulting in reduced water loss.

Transpiration rate (Tr) and leaf temperature were varied significantly among shade levels (Fig. 5D and 7A).The highest Tr and leaf temperature were observed in 75% shade and 50% shade treatments respectively. When net $CO_2$ assimilation became light saturated, transpiration constantly decreased with an increase in PPFD [21]. Thus, under light limitation (<300 mols $m^{-2}$ $sec^{-1}$) plants also exhibit a similar behavior of adaptation to escape from adverse climatic conditions as that in high light condition (>900 mols $m^{-2}$ $sec^{-1}$), by closing stomata due to water saturation, thereby adapting to a low light situation (Fig. 6).

**Table 2. The effects of different shade on biochemical characters of small cardamom**

| Treatments | Chl. 'a' (mg $g^{-1}$) | Chl. 'b' (mg $g^{-1}$) | Total chl. (mg $g^{-1}$) | Total phenol (mg $g^{-1}$) | Proline content (µg $g^{-1}$) | ECW (µg $cm^{-2}$) |
|---|---|---|---|---|---|---|
| Open irradiance | 0.345 $^c$ | 0.183 $^b$ | 0.566 $^b$ | 4.67 $^a$ | 1.97 $^b$ | 466.8 $^a$ |
| 50% shade | 0.448 $^b$ | 0.260 $^b$ | 0.772 $^b$ | 3.44 $^b$ | 12.2 $^a$ | 392.9 $^b$ |
| 75% shade | 0.527 $^a$ | 0.415 $^a$ | 1.08 $^a$ | 2.61 $^c$ | 9.55 $^a$ | 345.8 $^b$ |
| CV% | 11.57 | 18.09 | 21.78 | 12.38 | 34.67 | 10.63 |

*Values represent mean of seven replications. Same letter within each column indicate no significant differences among the treatments (P≤0.05)*

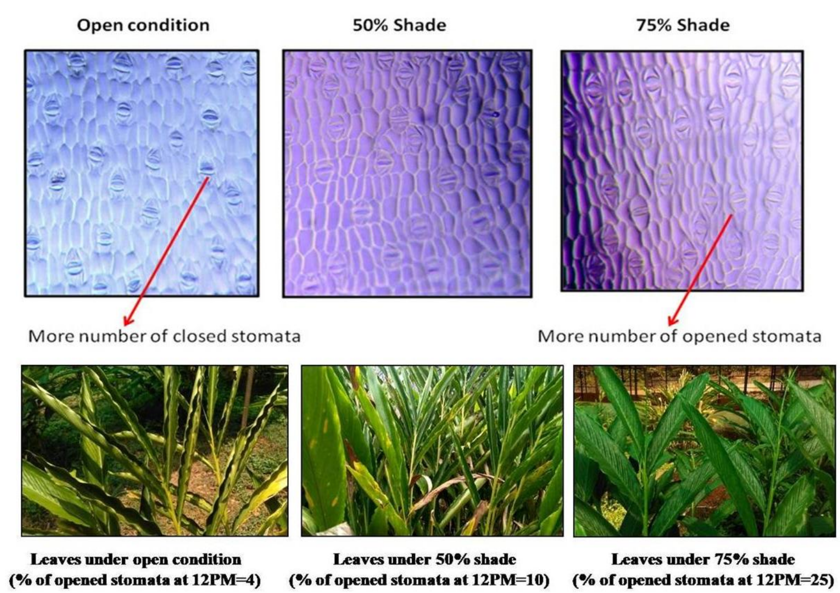


**Figure 2: Status of stomata under different shade level during mid day**

**Table 3. The effects of different shade on photosynthetic gas exchange of small cardamom**

| Treatments | Pn (µmol $CO_2$ $m^{-2}$ $s^{-1}$) | gs (mol $H_2O$ $m^{-2}$ $s^{-1}$ ) | Ci (µmol $mol^{-1}$) | Tr (mol $m^{-2}$ $s^{-1}$ ) | Leaf temperature (°C) | Chlorophyll fluorescence (Fv/Fm) |
|---|---|---|---|---|---|---|
| Open irradiance | 6.20 $^{b}$ | 0.089 $^{b}$ | 267.7 $^{a}$ | 2.04 $^{c}$ | 33.4 $^{c}$ | 0.649 $^{c}$ |
| 50% shade | 6.74 $^{b}$ | 0.099 $^{b}$ | 244.4 $^{b}$ | 3.41 $^{b}$ | 39.3 $^{a}$ | 0.760$^{a}$ |
| 75% shade | 8.56 $^{a}$ | 0.161 $^{a}$ | 267.1 $^{a}$ | 3.99 $^{a}$ | 36.7 $^{b}$ | 0.746 $^{b}$ |
| CV% | 14.81 | 15.97 | 5.11 | 15.43 | 5.16 | 4.45 |

*Values represent mean of seven replications. Same letter within each column indicate no significant differences among the treatments (P≤0.05).*

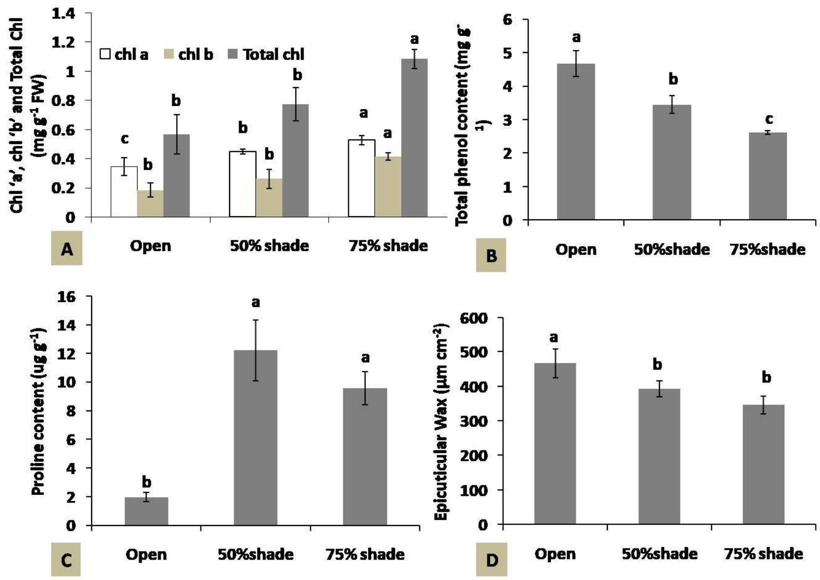


**Figure 3. Chlorophyll 'a', 'b' and total chlorophyll content (A), total phenol content (B), proline content (C) and epicuticular wax content (D).** The values represented mean ± SE, and different letters mark significant differences among shade treatments on the same day (P<0.05).

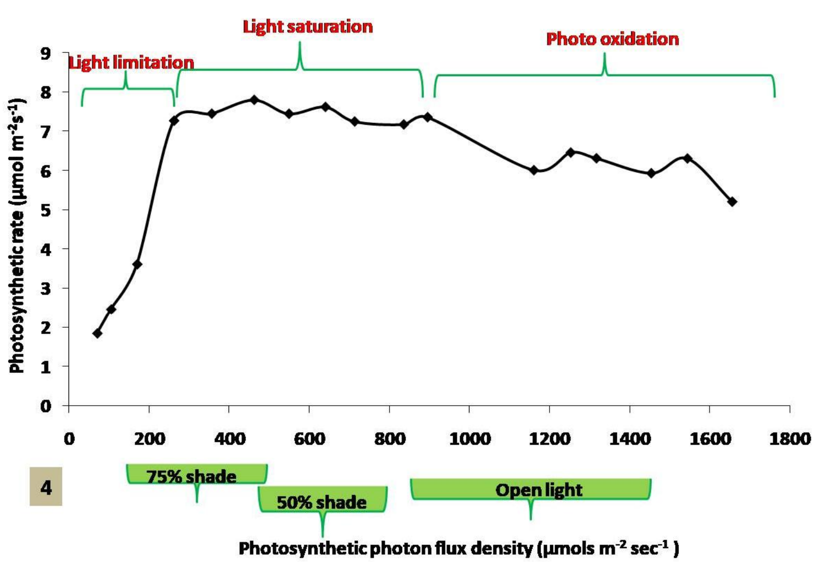


**Figure 4. Photosynthesis light responsive curve of small cardamom**

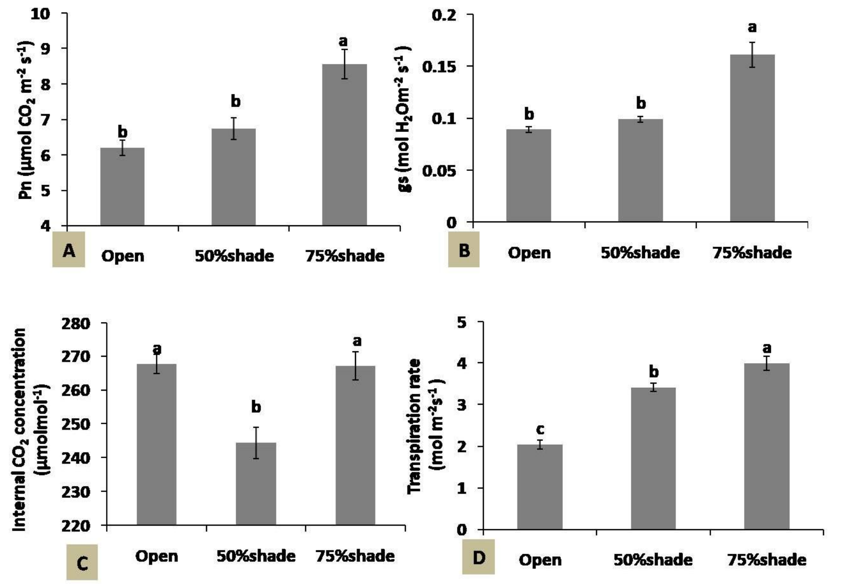


**Figure 5. Net photosynthetic rate (Pn) (A), stomatal conductance (gs) (B), intercellular $CO_2$ concentration (Ci) (C) and transpiration rate (Tr) (D).** The values represented mean ± SE, and different letters mark significant differences among shade treatments on the same day ($P<0.05$).

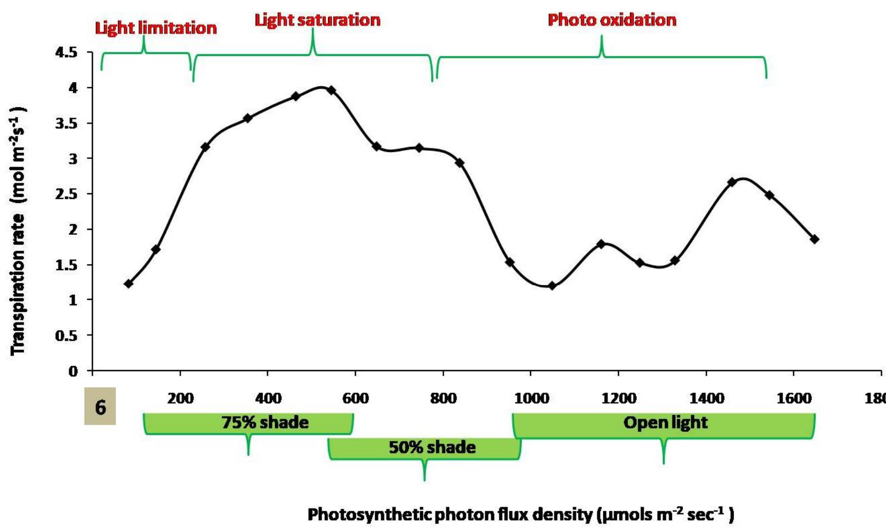


**Figure 6. Transpiration light responsive curve of small cardamom**

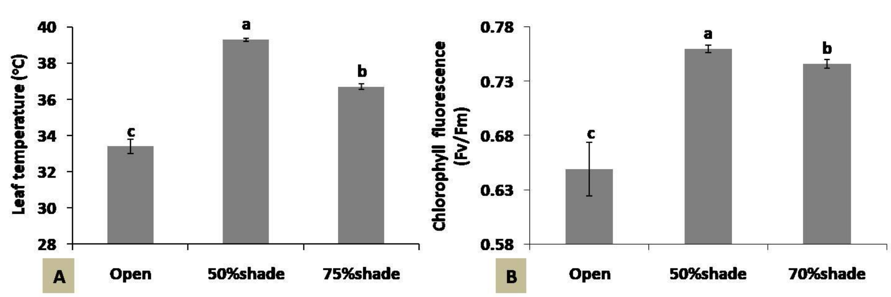


**Figure 7. Leaf temperature (A), Chlorophyll fluorescence (B).** The values represented mean ± SE, and different letters mark significant differences among shade treatments on the same day ($P<0.05$).

Chlorophyll fluorescence measurement is a mainstay of studies of photosynthetic regulation and plant responses to the environment because of its sensitivity, convenience, and nonintrusive characteristics [22,23]. In present study, the plants under open condition showed a significant reduction in maximum PSII efficiency (Fv/Fm) (Fig. 7B). Highest Fv/Fm was observed under 50% shade indicates that these plants were able to effectively reduce irradiance heat and efficiently utilise the energy absorbed by PSII antenna pigments [24,25].

## 4. CONCLUSIONS

The observed photosynthetic characteristics associated with light stress sensitivity in small cardamom, has contributed to an understanding of *E. cardamomum* species shade tolerance. The results clearly explained that shading is essential for its normal growth, although different degrees and durations of shading treatments significantly influence photosynthetic activity, chlorophyll and epicuticular wax content, chlorophyll fluorescence and biochemical traits. Plants under open condition (PPFD, 900 to 1600 mmol $m^{-2} s^{-1}$) suffer photoinhibition because of excess light exposure, whereas those grown under 50 to 75% shade (300 to 900 mmol $m^{-2} s^{-1}$) showed higher photosynthetic activity and when plants received PPFD less than 250 mmol $m^{-2} s^{-1}$, they suffered from light deficiency. This study indicated that small cardamom may adapt to shade conditions through increased plant height, chlorophyll and proline contents and higher Photosystem II and stomatal activity. This information will be of immense use for cardamom growing ecosystem as the present knowledge level on an ecological niche for cardamom is limited. The future line of research is to continue study reproductive biology and yield of small cardamom under different shade level to understand the response of small cardamom to shade.

## CONSENT

It is not applicable.

## ETHICAL APPROVAL

It is not applicable.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Murugan M, Shetty, PK, Ravi R and Subbiah, A. The Physiological Ecology of Cardamom (*Elettaria cardamomum* M) in Cardamom Agro Forestry System. International Journal of Environmental Research. Winter. 2009;3(1):35-44.
2. Dai YJ, Shen ZG, Liu Y, Wang LL, Hannaway D. Effects of shade treatments on the photosynthetic capacity, chlorophyll fluorescence, and chlorophyll content of *Tetrastigma hemsleyanum* Diels et Gilg. Environ Exp Bot. 2009;65:177–182.
3. Dai YJ, Shen ZG, Liu Y, Wang LL, Hannaway D. Effects of shade treatments on the photosynthetic capacity, chlorophyll fluorescence, and chlorophyll content of *Tetrastigma hemsleyanum* Diels et Gilg. Environ Exp Bot. 2009;65:177–182.
4. Deng YM, Li CC, Shao QS, Ye XQ, She JM. Differential responses of double petal and multi petal jasmine to shading: I. Photosynthetic characteristics and chloroplast ultrastructure. Plant Physiol Bioch. 2012;55:93–102.
5. Bertaminia M, Muthuchelianb K, Rubinigga M, Zorera R, Velascoa R. Low-night temperature increased the photoinhibition of photosynthesis in grapevine (*Vitisvinifera* L. cv. Riesling) leaves. Environ Exp Bot. 2006; 57:25–31.
6. Chen THH, Murata N. Glycine betaine protects plants against abiotic stress: Mechanisms and biotechnological applications. Plant Cell Environ. 2011;34:1–20.
7. Nelliat, EV, Bavappa KVA, Nair PKR. Multistoreyed cropping- a new direction in multiple cropping for coconut. World crops. 1974;26(6):223-226.
8. Strasser RJ, Srivastava A, Govindjee. Polyphasic chlorophyll a fluorescence transient in plants and cyanobacteria. Photochem. Photobiol. 1995;61:32-42.
9. Arnon DI. Copper enzymes in isolated chloroplasts, polyphenoxidase in *Beta vulgaris*. Plant Physiology. 1949;24:1-15.

10. Kaur C, Kapoor HC. Anti-oxidant activity and total phenolic content of some Asian vegetables Int. J. Food Sci. Technol. 2002; 37:53-161.
11. Bates LB, Waldren RP, Teare ID. Rapid determination of free proline for water stress studies. Plant and Soil. 1973;39:205- 207.
12. Ebercon A, Blum, A and Jordan' WR. A rapid colorimetric method for epicuticular wax content of sorghum leaves. Crop Sci.1977;17:179-180.
13. Duncan DB. Multiple range and multiple F tests. Biometrics. 1955;11:1-42.
14. Pan RZ, Wang XJ, Li NH. Plant Physiology. 5th ed. Higher Education Press, Beijing; 2008.
15. Taye Kufa, Jurgen Burkhardt. Stomatal characteristics in Arabica coffee germplasm accessions under contrasting environments at Jimma, Southwestern Ethiopia. International Journal of Botany. 2011;7:63-72.
16. Mao LZ, Lu HF, Wang Q, Cai MM. Comparative photosynthesis characteristics of *Calycanthus chinensis* and *Chimonanthus praecox*. Photosynthetica. 2007;45:601–605.
17. Ghosh PK, Bandyopadhyay KK, Manna MC, Mandal KG, Misra AK. Comparative effectiveness of cattle manure, poultry manure, phosphocompost and fertilizer-NPK on three cropping systems in vertisols of semi-arid tropics. II. Dry matter yield, nodulation, chlorophyll content and enzyme activity. Bioresource Technol. 2004;95:85–93.
18. Naidu RA, Krishnan M, Nayudu MV, Gnanam A. Studies on peanut green mosaic virus infected peanut (*Arachis hypogaea* L.) leaves. II. Chlorophyll protein complexes and polypeptide composition of thylakoid membranes. Physiol Plant Pathol. 1984;25: 191–198.
19. Sestak Z. Liminations for finding linear relationship between chlorophyll content and photosynthetic activity. Biol Plantarum. 1996;8:336–346.
20. Alagupalamuthirsolai M, Ankegowda SJ and Sharon Aravind. Factors determining the midday depression of photosynthesis in Small cardamom (*Elettaria cardamomum* maton) under summer climate. Multilogic in science. 2018;7:525-528.
21. Schapendonk AHCM, Dijkstra P, Groenwold J, Pot CS, Van de Geijn S. Carbon balance and water use efficiency of frequently cut *Lolium perenne* L. swards at elevated carbon dioxide. Global Change Biol. 1997; 3:207–216.
22. Schreiber U, Bilger W, Neubauer C. Chlorophyll florescence as a nonintrusive indicator for rapid assessment of in vivo photosynthesis. In: Schulze ED, Caldwell MM. (Eds.), Ecophysiology of Photosynthesis. Springer-Verlag, Berlin, 1995;49–70.
23. Rascher U, Liebig M, Lu¨ ttge U. Evaluation of instant light-response curves of chlorophyll fluorescence parameters obtained with a portable chlorophyll. Plant Cell Environ. 2008;23:1397–1405.
24. Guo HX, Liu WQ, Shi YC. Effects of different nitrogen forms on photosynthetic rate and the chlorophyll fluorescence induction kinetics of fluecured tobacco. Photosynthetica. 2006;44:140–142.
25. Shao Q, Wang H, Guo H, Zhou A, Huang Y. Effects of Shade Treatments on Photosynthetic Characteristics, Chloroplast Ultrastructure and Physiology of *Anoectochilus roxburghii*. PLoS ONE. 2014; 9(2):e85996.




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