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Microclimate modification through green shade nets enhances growth, yield, and water productivity of *Chrysanthemum indicum* L. under semi-tropical conditions

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Abstract
The adoption of sustainable horticulture techniques has been shown to intensify ornamental flower production within a limited area, particularly under adverse climatic conditions. The primary objective of this research was to evaluate the potential of 50% green shade nets in comparison to the open field to enhance the agronomic traits and water use efficiency (WUE) of *Chrysanthemum indicum* L. During the period from October 2024 to February 2025, a well-controlled experiment was conducted in Bengaluru city of India (semi-tropical climate). The study design involved a randomized block with six replications. The findings indicated that plants grown under green shade nets exhibited a 23.6% increase in plant height, reaching 60.2 cm, as opposed to 48.7 cm in the open field. In addition, the green shade nets treatment resulted in a 47.1% increase in the number of branches per plant. The leaf area index (LAI) was 50.7% higher under green shade nets, at 3.24 compared to 2.15 in the open field. Flower yield parameters such as number of flowers per plant were higher by 45.3 flowers per plant under green shade nets (45.3) than open condition (29.7), indicating an increase of 52.5%. The green shade nets treatment also improved flower quality, with flower diameter being 5.8 cm and the fresh flower weight (single flower) of 10.2 g, compared to 4.9 cm and 8.4 g, respectively, in the open field. Cumulatively, these advantages led to a significant increase in total yield by 50.6%, with green shade nets achieving 12.95 t ha^{-1} compared to the 8.60 t ha^{-1} in open field. Microclimate data showed that the maximum temperatures were 2.4 °C lower and relative humidity 6-8% higher during the hottest part of the day under shade nets than in the open field. Photosynthetically active radiation (PAR) was reduced by about 50% under the green shade nets. Water use efficiency (WUE) was recorded to be 3.37 kg m^{-3} in green shade net as against 1.92 kg m^{-3} in open field, signifying a 75.5% enhancement. Statistical analysis indicated that there were strong positive associations between flower yield and LAI ($r = 0.82$) and number of branches ($r = 0.79$), and a strong negative correlation between flower yield and the mean maximum temperature ($r = -0.71$). In conclusion, the application of 50% green shade nets emerges as an effective and promising technique for the sustainable intensification of chrysanthemum cultivation in semi-tropical regions, offering concurrent advantages in terms of growth, yield, quality, and water productivity.

Keywords: *Chrysanthemum indicum*, shade net cultivation, microclimate modification, water use efficiency, protected cultivation, ornamental horticulture, semi-tropical climate

1. Introduction

Chrysanthemum is one of the most commercially important ornamental crops, second only to roses in the global cut flower trade (Wang *et al*., 2019; Pan *et al*., 2025) [20, 15]. The genus Chrysanthemum is a dicot plant of the Compositae family consisting of approximately 200 species. *Chrysanthemum indicum* L. (Syn. *Chrysanthemum morifolium* Ramat) is extensively cultivated in India and across the world because of its wide use as an ornamental, the popular chrysanthemum flower extract as a nutraceutical, and source of a variety of bioactive compounds used in traditional medicine preparations (Kentelky *et al*., 2021) [9]. This plant species produces medicinally important flavonoids, essential oils, and other important therapeutic compounds. Thus, Chrysanthemum has been the subject of considerable interest in phytochemical and pharmacological studies (Liang *et al*., 2007) [11]. Chrysanthemum cultivation covers a total area of about 15,000 hectares in India and is concentrated in Karnataka, Tamil Nadu, West Bengal, Maharashtra, and Delhi. It is a highly profitable crop for small and marginal farmers (Pathania *et al*., 2024) [15]. The world chrysanthemum exports from China have been increasing rapidly in recent years, with substantial growth from 2015 to 2024, as reported by a recent market report (Pan *et al*., 2025) [15]. China is the leading exporter of cut chrysanthemum and medicinal chrysanthemum, which can have a direct impact on the global supply and influence the competitive landscape for other countries involved in chrysanthemum production and export.

Chrysanthemum cultivation, particularly in the open fields in semi-tropical regions of Karnataka and other areas with similar agroclimatic conditions, encounters a variety of environmental factors that can impede production and affect profitability. These environmental factors that pose challenges for open field cultivation include excessive solar radiation and high temperature stress, especially during pre-monsoon and post-monsoon seasons, erratic moisture supply and availability, and high evapotranspiration. High-temperature stress, particularly during the pre-monsoon and post-monsoon periods, can cause physiological stress on plants, leading to reduced photosynthesis, hastened senescence, increased flower drop, and consequently, lower yield and poor quality (Kumari *et al*., 2023) [10]. Furthermore, these conditions also result in increased transpiration, reduced relative humidity, and the potential for heat stress, which collectively reduce plant vigor and marketable yield (Yadav *et al*., 2023) [21]. In Karnataka, maximum temperatures often exceed 32 °C during the flowering and fruiting stages, while relative humidity can fall below 40% during dry spells, both of which are far from ideal for the growth of chrysanthemums.

One of the strategies to address these issues is the adoption of protected cultivation practices such as the use of shade net systems. Shade nets provide a practical and cost-effective solution for creating a more favorable microclimate for plant growth while moderating the adverse effects of extreme environmental conditions. Shade nets work by intercepting and diffusing a fraction of the incident solar radiation, thereby reducing the radiant heat load on the plants, decreasing canopy temperature, lowering water stress, and overall creating a more conducive environment for growth and development (Stamps, 2009; Díaz-Pérez, 2013) [19, 1]. In comparison to conventional greenhouses, shade net structures present numerous benefits, including a lower initial investment cost, ease of installation and maintenance, better air circulation, and a lower disease incidence compared to completely enclosed systems (Singh and Sharma, 2024) [18]. A recent review article published in 2024 has highlighted that shade net technology has become very popular among vegetable growers for production in bright, sunny, hostile, and summery habitats by ameliorating the crop microenvironment, increasing plant growth, reducing plant diseases and physiological disorders, and extending the harvesting period (Kabir *et al*., 2024) [7]. Furthermore, the agriculture nets market size has been observed to reach USD 10.6 billion in 2024 and is anticipated to register a compound annual growth rate (CAGR) of 5.4% to hit USD 17.9 billion by 2034 (Future Market Insights, 2025) [3]. In this context, the use of photoselective shade nets has emerged as an innovative technique in the realm of protected cultivation. Photoselective shade nets are distinct from conventional nets in that they include chromatic pigments, light dispersive, and reflective components within the netting material, intended to filter specific spectral components of solar radiation while converting direct light into diffused light (Shahak *et al*., 2008; Ilić *et al*., 2017) [16, 5]. The responses of ornamentals to colored shade nets have been found to be significantly different from those observed under commonly used black nets of the same shading coefficient, and these effects can be ascribed to their influence on vegetative vigor, plant dwarfing, branching, leaf variegation, and changes in the timing of flowering (Oren-Shamir *et al*., 2001; Stamps, 2009) [14, 19]. In a study published in 2024 on the effects of planting dates and fertilizer management on the growth, yield, and soil health of chrysanthemum (Pathania *et al*., 2024) [15], the authors reported that appropriate planting dates combined with adequate fertilization improved chrysanthemum plant height (79.44 cm), flower diameter (7.83 cm), vase life (14.90 days), and soil health parameters. A review published in April 2025 on the effect of temperature on edible chrysanthemum growth and yield has shown that moderate day/night temperature of around 25/20 °C promoted the optimal growth with the highest yield and supported the maximum net photosynthetic rate, while the maximum water use efficiency was observed at cooler temperatures (Huang *et al*., 2025) [4].

Studies on the cultivation of chrysanthemum under shade nets have reported promising findings from different locations. In a study in Brazil, the use of shade net cultivation improved cut flower stem length, flower diameter, and vase life compared to open field production (Fornaciari *et al*., 2020) [2]. In a study on chrysanthemum grown under shade nets in the Northwest Himalayan mid hills of India, the authors reported that chrysanthemum cultivars under shade net exhibited better growth and prolonged the flowering period than the plants grown in the open (Singh *et al*., 2017) [17]. The results of a study on the effects of colored shade nets on water use efficiency and irrigation requirements of chrysanthemum revealed that a green shade net improved water use efficiency by around 28% and reduced irrigation requirement without significant yield loss (Manjunatha *et al*., 2023) [12]. In another study on the effects of different levels of white, blue, and green shade nets on chrysanthemum growth and yield in the Netherlands, the authors reported that shade nets lower the extreme temperatures during the day and night, reducing plant water stress. Shade nets also increase the concentrations of photosynthetic pigments and result in an overall improvement in plant vigor (Ilić and Fallik, 2017) [5].

On the other hand, there are certain limitations in the existing literature that need to be addressed. First, most of the previous studies have been conducted on *Chrysanthemum morifolium* cultivars rather than C. indicum, which is gaining importance in the production of traditional medicine and specialty markets. Second, the research has primarily been focused on temperate or high-altitude areas, where the temperature and radiation are not the same as those found in low-elevation tropical and semi-tropical conditions. Third, limited studies have been done to quantify water use efficiency under shade nets using precise irrigation management and monitoring systems. Fourth, little information is available on the specific microclimate alterations caused by shade nets and their direct link with growth and yield parameters in chrysanthemum cultivation.

The study site in Bengaluru, located at an elevation of about 920 meters, is in southern Karnataka, experiences a typical semi-tropical climate with distinct seasonal changes. This makes the site particularly relevant and suitable for the proposed study on the effects of shade nets on *Chrysanthemum indicum*. The region endures moderate temperatures, with occasional heat stress during the summer months, receives variable rainfall distribution, and faces water scarcity, which calls for the need for better irrigation efficiency. These local conditions, coupled with the existing research gaps, necessitate this investigation. The primary objective of this research was to evaluate the performance of *Chrysanthemum indicum* under 50% green shade net and an open cultivation system during the October 2024 to February 2025 growing season. The specific aims of the study were as follows: (1) to determine the differences in vegetative growth parameters including plant height, branching patterns, and leaf area development between shade net and open field systems; (2) to assess the modifications in the microclimate in terms of temperature, relative humidity, and light intensity under the shade net; (3) to evaluate the flower production, yield components, and quality attributes under both cultivation systems; and (4) to determine the irrigation water requirement and calculate water use efficiency to determine the sustainability and water conservation potential of shade net cultivation for chrysanthemum production in semi-tropical climates.

2. Materials and Methods

2.1 Experimental Site and Climatic Characterization

A field experiment was carried out at the research farm of the Department of Agricultural Engineering, Reva University, Bengaluru, Karnataka (13.02°N latitude, 77.60°E longitude and 920 m above mean sea level), during October 2024- February 2025, which coincides with the best chrysanthemum growing and flowering time for the region. The area has a semi-tropical climate with moderate temperature, well-defined wet and dry seasons, and uneven distribution of rainfall. The long-term average rainfall for the location is 970 mm per year, with average maximum temperature between 28 °C and 35 °C and average minimum temperature between 15 °C and 22 °C during the time of experiment.

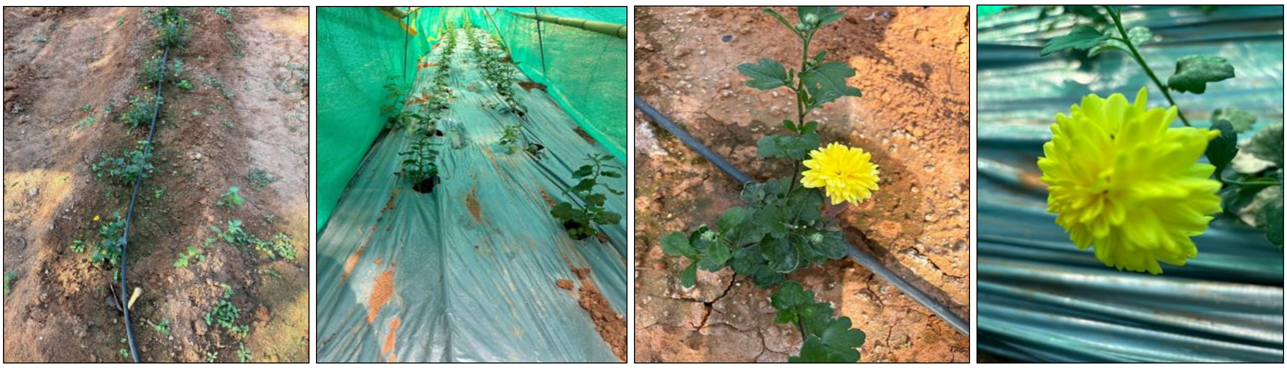
A soil sample was collected from different spots of the field at 0-30 cm depth and analyzed for different chemical properties in the soil laboratory, following standard methods given by Jackson (1973) [6]. The soil texture was analyzed by the hydrometer method, and it was found to be red sandy loam with sand, silt, and clay in 65, 20 and 15% proportion, respectively. Soil pH measured by a glass electrode pH meter in 1: 2.5 soil-water suspension was 6.5, while the organic carbon (Walkley-Black method) was 0.65% and categorized as medium in the soil. The available nitrogen (N), phosphorus (P), and potassium (K) (alkaline permanganate method, Olsen method and neutral normal ammonium acetate extraction respectively) were 245, 32, and 198 kg ha^{-1}, respectively, in the soil and categorized as medium. The soil was well-drained with bulk density (BD) and field capacity (FC) of 1.42 g cm^{-3} and about 22% (v/v), respectively.

2.2 Experimental Design and Treatment Details

Experimental design: The experiment was based on the Randomized Block Design (RBD) with two treatments and six replications, in which total twelve plots were available. The treatments were T1: Cultivation under 50% green shade net and T2: Conventional open cultivation as the control treatment. Each plot consisted of one raised bed with a size of 4 m × 2 m, i.e. a plot size of 8 m2. The raised beds were constructed with a height of 15 cm above the ground level to provide good drainage condition. Drainage is important to avoid water logging during excessive rainfalls or irrigation.

Shade net used was prepared from HDPE with UV stabilization and knitted type of shade net was used with a shade percentage of 50%. The selected shade net had a shade factor of 50% that means 50% of the solar radiation reaches the plants, whereas the rest is absorbed by the net. These specifications are supported by other recent studies which found that UV stabilization property in the shade net material is an emerging trend these days to provide better durability and protection under solar radiation (Agriplast, 2024) [1]. The shade net structure was supported by using GI pipes of 4-m height with horizontal wires tied at the height of 2.5 m above ground level. Shade net material was tied to the support structure using plastic cables for proper tension.

Planting arrangement: The plant spacing was arranged in a rectangular system of 30 cm × 30 cm which makes the total plant population to be 111,000 plants ha^{-1}. Each plot had 10 rows with 20 cm distance between rows. The adjacent plots were separated by the buffer row of 50 cm width and one-meter wide buffer was given at the edge of the whole experimental area as shown in Figure 1.



Open filed condition **Green shade net** **Open filed condition** **AGreen shade net**

Fig 1: Experimental design and treatment details

2.3 Plant Material and Cultural Practices

The plant material used was *Chrysanthemum indicum* L., a local genotype which is well adapted to the Bengaluru agroclimatic zone, and widely grown by farmers in the study area. The propagation was done through vegetative means using the terminal cuttings of length 5-7 cm with 3-4 nodes which is the standard commercial propagation method ensuring genetic uniformity (Kentelky *et al*., 2021) [9]. The cuttings were induced to root by dipping the basal end in the rooting hormone having indole-3-butyric acid (IBA) at 2000 ppm concentration for 10 seconds. This treatment was found to stimulate rapid and uniform rooting in stem cuttings. The rooted cuttings were raised under nursery conditions for hardening of 10-12 days before transplanting, which was done in the first week of October 2024.

Nutrient application was based on the soil test recommendations and the nutrient requirement of the crop. The basal application was done by incorporation of well-decomposed farmyard manure @ 25 t ha^{-1} during bed preparation. An inorganic fertilizer was applied @ 100: 50:50 kg ha^{-1} of N:P_2O_5:K_2O (Pathania *et al*., 2024) [15]. The complete dose of phosphorus and potassium was applied as basal, while nitrogen was applied in three equal splits at 15, 35 and 55 days after transplanting (DAT). This is to match the nutrient uptake of the crop to the nutrient supply and to reduce the nitrogen losses.

The drip irrigation systems were installed in both the treatments so as to facilitate precise water application and to measure the water applied, as per modern irrigation efficiency practices (Jin *et al*., 2024) [6]. The drip laterals with inline emitters of 30 cm spacing were laid on either side of each row along the bed centre, and the emitters were placed such that they were next to each plant. The frequency of irrigation was based on the crop evapotranspiration (ETc) demand calculated using the Penman-Monteith equation under local conditions. Irrigation was applied to meet about 80% of the evapotranspiration requirement to avoid excess soil moisture in the root zone. The water meters which were installed at the inlet of each treatment blocks were used to measure the total amount of irrigation water applied during the crop season.

Mulching using black polyethylene of 25 microns thickness was done, which covered the soil surface. Weeds were controlled by manual weeding if necessary. Pest and disease incidence was controlled as per the principles of integrated pest management (IPM) with regular monitoring of the crops for the incidence of pests. Pinching was done at 15 DAT by removing the apical growing point to induce the axillary buds to grow into lateral branches, thereby increasing flower production. Staking was done by using bamboo poles when the plants were about 30 cm in height to support the plants from lodging.

2.4 Data Collection and Measurements

2.4.1 Microclimate Monitoring

Microclimate parameters were measured during the growing season with automatic data logger systems. Temperature and humidity sensors recorded maximum, minimum and mean air temperature and relative humidity at 50 cm height above the ground surface on an hourly basis (representing mid-canopy zone). Light intensity was measured with quantum sensors, measuring PAR (photosynthetically active radiation) in the 400-700 nm range. Sensor data were recorded automatically in data loggers and downloaded every week.

2.4.2 Growth and Vegetative Parameters

Measurements of vegetative growth were taken at three growth stages, namely, 60, 90 and 120 DAT. From each plot, five plants were randomly selected and tagged for identification. Height of the plant was measured using a measuring tape from the soil surface to the tip of the main stem and was recorded to the nearest centimetre. Branch number was assessed by counting all the primary and secondary branches of the main stem having a minimum length of 5 cm. Leaf area index (LAI) or ratio of leaf area to unit ground surface area, was estimated non-destructively, using a canopy analyzer that measures light interception, as per the standard procedure (Pathania *et al*., 2024) [15].

2.4.3 Flowering and Yield Parameters

Flowering observations were taken from first visible flower buds through to harvest maturity. At commercial harvest maturity, detailed yield assessments were made. Total flowers per plant were counted on all tagged plants. Ten flowers per plot were randomly selected for flower diameter measurements with a digital caliper. Individual flower fresh weight was determined by harvesting ten representative flowers per plot and immediately weighing on a precision balance. Yield per plant was calculated by multiplying total flowers per plant by the average flower fresh weight. Per-plant yield was multiplied by the plant population (111,000 plants ha^{-1}) to estimate yield on a per-hectare basis (t ha^{-1}).

2.4.4 Water Use and Water Use Efficiency

The amount of total irrigation water applied to each treatment was recorded using water meters located at the inlet to the irrigation system. Total irrigation during the growing season was calculated as the sum of individual irrigations. Total irrigation amount was expressed as depth equivalent (mm) by dividing the total volume applied by the plot area. Water use efficiency (WUE) was calculated using equation 1: Irrigation water use efficiency (IWUE) can be defined as the mass of flowers produced per unit volume of irrigation water applied, and its higher values mean better water use (Kazemi *et al*., 2019) [8].

$$\text{Water use efficiency (WUE)} = \frac{\text{Total crop yield (kg ha}^{-1}\text{)}}{\text{Total amount of water applied (m}^3\text{ ha}^{-1}\text{)}} \quad (1)$$

2.5 Statistical Analysis

All the data were statistically analyzed by analysis of variance (ANOVA) under general linear model procedure using the randomized block design. The model consisted of treatment as a fixed factor and replication as a random factor. Treatment means were separated using least significant difference (LSD) test at 5% probability when treatment effects were significant ($P<0.05$). Pearson correlation coefficient was also calculated to analyze the relationships among microclimate, growth, and yield parameters, and significant at 5 and 1% probability. All the analyses were performed with the help of standard statistical software (SPSS 22.0). Data are presented as treatment means with standard error (S.E m±) and LSD values.

3. Results and Discussion

3.1 Microclimate Modifications Under Shade Net

The use of 50% green shade net significantly altered the microclimate experienced by the chrysanthemum plants during the growing season from October 2024 to February 2025, as summarized in Table 1. The maximum daytime air temperature under the shade net averaged at 29.8 °C, compared to 32.2 °C in the open field, showing a reduction of 2.4 °C. This reduction in temperature can be particularly beneficial during the flowering stage, as high temperatures can lead to faster flower senescence and lower flower quality (Huang *et al*., 2025) [4]. The minimum night-time temperatures recorded were slightly higher under the shade net, averaging at 18.6 °C compared to 17.8 °C in the open field, a difference of 0.8 °C, aligning with observations by Shahak *et al*. (2008) [16] and Ilic *et al*. (2017) [5].

Table 1: Microclimate parameters under green shade net and open field conditions during October 2024 to February 2025

Parameter	Green Shade Net	Open Field	Difference
Maximum temperature (°C)	29.8	32.2	-2.4
Minimum temperature (°C)	18.6	17.8	+0.8
Mean temperature (°C)	24.2	25.0	-0.8
Relative humidity (%)	62.4	55.8	+6.6
PAR (μmol m^{-2} s^{-1})	485	965	-480
Light reduction (%)	-	-	49.7

Note: Values represent seasonal averages across the experimental period.

A trend of higher relative humidity was also recorded during the entire experimental period in the shade net (Table 1). The mean day time relative humidity was recorded as 62.4% in the shade net, while it was 55.8% in open field, with an increase in relative humidity in the shade net treatment of 6.6%. The higher relative humidity can offer a number of physiological benefits to chrysanthemum such as minimization of transpiration water stress, increase in stomatal conductance to allow more CO_2 uptake for photosynthetic activity, and prevention of flower desiccation during development. These factors also coincide with the findings of a study that states that the use of shade nets can minimize hot temperatures and reduce water needs of crops, and improving irrigation water use efficiency (Kabir *et al.*, 2024) [7].

The photosynthetically active radiation was noted to be 965 μmol m^{-2} s^{-1} in the open field, whereas, under the 50% shade net, the PAR was 485 μmol m^{-2} s^{-1}. This translates to a 49.7% reduction in PAR due to the shade net (Table 1). While this is a drastic reduction in the light intensity in the shade net treatment, this is not an issue in terms of chrysanthemum production as it was previously shown that chrysanthemum could be produced in between 30 and 50% shade (Yadav *et al.*, 2023) [21]. The factors of lower irradiance, along with the temperature and humidity, created a more conducive environment for the physiological processes to take place and aid in the resulting growth and yield, as will be discussed below.

3.2 Vegetative Growth Performance

The application of shade net significantly increased vegetative growth parameters including plant height compared to open field conditions (Table 2). At 90 DAT, the plant height under shade net was 60.2 cm, which was 23.6% higher than the 48.7 cm recorded in open field condition (P<0.05). The greater plant height observed under the shade net can be attributed to the shade avoidance syndrome, a phenomenon where plants exhibit increased stem elongation in response to shade (Stamps, 2009) [19]. However, in this case, the moderate shade level provided by the net appears to have allowed for healthy stem elongation without leading to excessive etiolation. The taller stature of plants under shade net is also indicative of reduced heat stress and better water status, as temperature stress can limit cell expansion and consequently reduce internode elongation (Huang *et al.*, 2025) [4].

Table 2: Vegetative growth parameters of *C. indicum* under green shade net and open field conditions

Parameter	Green Shade Net	Open Field	S.E m±	LSD (5%)
Plant height at 90 DAP (cm)	60.2	48.7	1.35	4.02
Branches per plant (No.)	17.8	12.1	0.95	2.85
Leaf Area Index (LAI)	3.24	2.15	0.14	0.42

Note: Measurements averaged across six replications; DAP = Days After Planting.

Branch number per plant was significantly higher under shade net, with 17.8 branches compared to 12.1 branches in the open field, a 47.1% increase (Table 2). The increase in branch number is likely the result of the pinching operation, as well as the microclimate conditions created by the shade net, which may have encouraged axillary bud break and lateral shoot growth. Studies on chrysanthemum have shown that moderate shade and optimal temperature conditions can influence cytokinin to auxin ratios in plant tissues, leading to increased lateral bud activation and branching (Kentelky *et al.*, 2021; Pathania *et al.*, 2024) [9, 15]. The higher branch number under the shade net provides more flowering sites, potentially contributing to increased flower production.

Leaf area index (LAI) also showed significant improvement under shade net, with a value of 3.24 compared to 2.15 in the open field, an increase of 50.7% (Table 2). The increased LAI is a result of both higher leaf number (due to increased branching) and the greater leaf area of individual leaves under the shade net treatment. Shade-grown plants often have larger, thinner leaves with a higher specific leaf area to adapt to low radiation conditions and make the most of the light available (Stamps, 2009) [19]. The increased LAI under the shade net is especially important, as it indicates an increased photosynthetic capacity of the whole canopy. This is supported by the strong positive correlation between LAI and flower yield (r = 0.82, see Section 3.4) which underscores the functional relevance of this vegetative trait. The growth improvements under the shade net in this study are in line with results observed for various ornamental plants under photoselective nets (Oren-Shamir *et al.*, 2001; Shahak *et al.*, 2008) [14, 16].

3.3 Flowering and Yield Performance

Flowering and yield parameters were significantly (P<0.05) higher under shade net cultivation than under open field conditions (Table 3). The mean number of flowers per plant under shade net was 45.3 which was 52.5% (P<0.05) more than the 29.7 flowers per plant in open field. This significant increase in the number of flowers was due to an increase in the number of branches per plant (each branch with a number of flower buds) in addition to improved physiological status that promoted the initiation of flower buds and lowered bud abortion rate. It is well known that high temperature stress during reproductive stage development may lead to flower bud abortion and reduced flower set in chrysanthemum (Huang *et al.*, 2025) [4] and the 2.4 °C reduction in temperature under shade net clearly ameliorated this stress.

Table 3: Flowering and yield parameters of *C. indicum* under green shade net and open field conditions

Parameter	Green Shade Net	Open Field	S.E m±	LSD (5%)
Flowers per plant (No.)	45.3	29.7	2.10	6.30
Flower diameter (cm)	5.8	4.9	0.18	0.54
Flower fresh weight (g)	10.2	8.4	0.28	0.84
Yield per plant (g)	462	249	14.7	44.1
Yield (t ha^{-1})	12.95	8.60	0.42	1.25

Note: Measurements averaged across six replications.

Flower quality attributes also recorded appreciable improvements under the shade net treatment (Table 3). The average flower diameter recorded was 5.8 cm under shade net treatment and 4.9 cm under open field condition which is an improvement of 18.4%. Similarly, individual flower fresh weight was 10.2 g under shade net treatment and 8.4 g under open field condition which is an improvement of 21.4%. Improvement in quality parameters indicated more availability of resources for flower development under the enhanced microclimate conditions. The improved relative humidity under shade net condition was an important factor for the improved cell turgor and expansion in developing flowers (Fornaciari *et al*., 2020; Singh *et al*., 2017) [2, 17]. In addition, less heat stress under shade net could allow longer flower development period for the formation of larger and fully developed flowers (Fornaciari *et al*., 2020) [2]. The concurrent improvements in flower number and individual flower quality resulted in a significant increase in yield (Table 3). The per plant yield under shade net was 462 g, whereas, it was 249 g under open field condition, an improvement of 85.5%. On a per hectare basis, the yield was estimated to be 12.95 t ha^{-1} and 8.60 t ha^{-1} under shade net and open field condition, respectively, which is a 50.6% improvement in yield. The extent of the yield improvement was comparable to other reports on chrysanthemum under shade net treatment (Manjunatha *et al*., 2023) [12]. The economic impact of this yield gain could be substantial for the growers as the increased production can recoup the investment in shade net and provide additional revenue, especially in premium markets where high-quality flowers are in demand (Pathania *et al*., 2024) [15].

3.4 Water Use Efficiency and Irrigation Requirements

Water use patterns and efficiencies also differed significantly between the two systems (Table 4). The total irrigation water used during the growing season under shade net and open field was 384.0 and 448.0 mm, respectively, with a reduction of 14.3% in irrigation requirement under shade net. The water saving under shade net over open field was mainly because of reduction in evapotranspiration under shade net, as affected by the lesser temperature, higher humidity and radiation reduction. The application of shade net significantly reduced atmospheric evaporative demand and the crop could meet the water status of the tissues under lower irrigation input. The water requirement results were consistent with a recent study, which showed that shade nets significantly reduce crop water requirements by 15-30%, with no or little negative effect on yield (Kabir *et al*., 2024; Manjunatha *et al*., 2023) [7, 12].

Table 4: Irrigation water applied and water use efficiency under green shade net and open field conditions

Treatment	Irrigation Applied (mm)	Yield (kg ha^{-1})	WUE (kg m^{-3})	WUE Improvement (%)
Green Shade Net	384.0	12,950	3.37	75.5
Open Field	448.0	8,600	1.92	-

Note: WUE = Water Use Efficiency; Values represent totals across the entire growing season.

The efficiency of water use, expressed as yield per unit irrigation water applied (WUE), showed a remarkable enhancement under shade net cultivation (Table 4). The WUE in shade net was 3.37 kg m^{-3}, while the open field recorded a WUE of 1.92 kg m^{-3}, indicating a significant increase of 75.5%. This dramatic improvement in WUE is primarily attributed to a synergistic reduction in irrigation requirement (-14.3%) and an upsurge in production (+50.6%) under shade net. The higher WUE under shade net implies that farmers can achieve higher production with less water under conditions of limited or costly irrigation water, enhancing not just the economic but also the environmental sustainability of chrysanthemum production. This aspect of WUE aligns with recent work on other ornamental crops, especially under deficit irrigation and protected cultivation systems (Kazemi *et al*., 2019; Jin *et al*., 2024) [8, 6].

The linkages between modified microclimate and production were further strengthened through correlation analysis (Figure 2). Flower yield had a strong positive correlation with LAI (r = 0.82, *P*<0.01) and branch number (r = 0.79, *P*<0.01), suggesting a direct pathway from vegetative vigor to reproductive output. On the other hand, a significant negative correlation was observed between yield and mean maximum temperature (r = -0.71, *P*<0.01), highlighting heat stress as a key yield-limiting factor under open field conditions. Thus, these correlations not only support the impact of shade net on chrysanthemum production but also provide mechanistic insights into the benefits: by alleviating temperature stress, enhancing relative humidity, and fostering vegetative growth, shade nets create a microclimate that is highly conducive for chrysanthemum flowering and yield formation.

	LAI	Branches	Max Temp	Yield
LAI	1.00	0.76**	-0.64*	0.82**
Branches	0.76**	1.00	-0.58*	0.79**
Max Temperature	-0.64*	-0.58*	1.00	-0.71**
Yield	0.82**	0.79**	-0.71**	1.00

* Significant at P < 0.05; ** Significant at P < 0.01

Fig 2: Correlation matrix showing relationships between microclimate parameters and yield components

3.5 Economic and Environmental Implications
The economic viability and agronomic rationale for employing a 50% green shade net under Bengaluru conditions for C. indicum cultivation is compelling. Although the initial capital investment in shade net infrastructure (nets, support structures, installation) is an added cost compared to open field cultivation, this cost can be amortized over the 3-5-year lifespan of UV-stabilized shade nets (Agriplast, 2024) [1]. The 50.6% yield increase directly translates to improved gross returns, especially when factoring in the premium prices that larger, high-quality flowers fetch in commercial markets. Furthermore, the 75.5% enhancement in water use efficiency offers ongoing operational cost savings through reduced irrigation needs, particularly valuable in the context of rising water costs and scarcity in many production regions (Kabir *et al*., 2024) [7].

The environmental sustainability benefits of shade net cultivation extend beyond water conservation. The reduced irrigation requirement (14.3% less water) also contributes to conservation of scarce water resources and reduced energy consumption for water pumping and distribution. The improved microclimate under shade nets also resulted in lower incidence of heat stress-related physiological disorders, potentially reducing the need for chemical interventions to manage stress-induced pest and disease problems. These environmental benefits align with global trends toward sustainable intensification of agricultural production, where increased productivity is achieved through ecological optimization rather than increased external inputs (Singh and Sharma, 2024) [18].

4. Conclusion
Optimal cultivation of *Chrysanthemum indicum* L. with the help of 50% green shade net instead of open field conditions in the month October 2024 to February 2025 was conducted in Bengaluru and it was clearly found that the use of shade net resulted in significant ($p <0.05$) improvement in various performance indicators. Highlights of the investigation are as follows:

- Temperature (day time), relative humidity and photosynthetically active radiation were decreased by 2.4 °C, 6.6% and 51%, respectively with the 50% green shade net compared to those in open field condition, which resulted in alleviated stress condition for chrysanthemum during its entire growth period.
- Plant height, branch number and leaf area index were increased by 23.6% (60.2 cm vs 48.7 cm), 47.1% (17.8 vs 12.1) and 50.7% (3.24 vs 2.15), respectively under shade net compared to open field condition, which supported the good flowering and yield performance.
- Flower number per plant, flower diameter and single flower fresh weight were significantly increased by 52.5% (45.3 vs 29.7), 18.4% (5.8 cm vs 4.9 cm) and 21.4% (10.2 g vs 8.4 g), respectively due to the deployment of shade net. Correspondingly, total flower yield was also enhanced by 50.6% (12.95 t ha^{-1} vs 8.60 t ha^{-1}), when shade net was used compared to open field condition.
- Shade net deployment decreased irrigation water (14.3%, 384.0 mm vs 448.0 mm) and at the same time increased yield. Water use efficiency was improved by 75.5% (3.37 kg m^{-3} vs 1.92 kg m^{-3}) with shade net use in comparison to open field condition.
- Linear correlation analysis among flower yield with leaf area index ($r = 0.82$), branch number ($r = 0.79$) and maximum temperature ($r = -0.71$) indicated that the temperature stress was the limiting factor for flower yield in open field and the positive correlation with leaf area index and branch number indicated the mechanism of improving flower yield with the shade net in comparison to open field.

Results of this experiment, under semi-tropical Bengaluru conditions, indicates that 50% green shade net cultivation is an economically feasible and practically implementable cultivation practice, suitable for sustainable intensification of C. indicum production, with concurrent positive effects on growth, yield, quality, and water use efficiency (WUE). The introduction of shade net cultivation technology in commercial farming practices in Bengaluru and similar agroclimatic zones, can be an important step towards improving the profitability and net income of growers, by not only increasing yield and enabling better quality flowers that fetch premium market prices, but also by reducing the irrigation water requirements, thereby, improving water management efficiency.

Moreover, the beneficial effects of this practice could also help address future challenges of climate change including greater frequency of extreme temperatures and water shortage for open field production of ornamentals. Additionally, future studies on this subject may be focused on (1) cost-benefit and economic analysis of the shade net practice; (2) effects of different shade percentages, such as 30%, 40%, 60%, and 75% shade; (3) effects of coloured shade nets, e.g., red, blue, pearl, which could offer additional spectral modification as against mere reduction of light intensity; (4) postharvest quality aspects such as vase life, flower senescence traits, and storage potential; (5) soil health, microbial activity, and other indicators of sustainability under shade net cultivation; and (6) integrated management practices such as mulching, fertigation, and precision irrigation management in conjunction with shade net. To summarize, this study offers a strong scientific basis to conclude that 50% green shade net cultivation significantly improves the performance, resource use efficiency, and marketability of C. indicum crop, under semi-tropical growing conditions of Bengaluru and similar regions, and is an easy to access and adopt technology for smallholder and commercial growers to increase chrysanthemum production.

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Conflict of Interest Statement
The author declares no conflict of interest.

Data Availability Statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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References

1. Agriplast. Protect your crops with shade nets solutions. Agriplast Tech India Private Limited; 2024. Available from: https://www.agriplast.co.in/blogs/protect-your-crops-with-

shade-nets-solutions
Díaz-Pérez JC. Bell pepper (*Capsicum annuum* L.) crop as affected by shade level: Microenvironment, plant growth, leaf gas exchange, and leaf mineral nutrient concentration. HortScience. 2013;48(2):175–182.

2. Fornaciari V, Gonçalves DC, Lovo M, De Oliveira EC, Amaro de Sales R. Production of cut chrysanthemum under different shading screens in Espírito Santo, Brazil. International Journal of Agronomy & Agricultural Research (IJAAR). 2020;16(3):45–54.
3. Future Market Insights. Agriculture Nets Market Size, Trends 2025 to 2035. Market Analysis Report; 2025.
4. Huang YL, Chen LD, Fu BJ, Huang ZL, Gong J. Impact of temperature on growth, photosynthetic efficiency, yield, and functional components of bud-leaves and flowers in edible chrysanthemum (*Chrysanthemum morifolium* Ramat). Horticulturae. 2025;11(5):448. DOI:10.3390/horticulturae11050448
5. Ilić ZS, Fallik E. Light quality manipulation improves vegetable quality at harvest and postharvest: A review. Environmental and Experimental Botany. 2017;139:79–90.
Ilić ZS, Milenković L, Šunić L, Fallik E. Effect of coloured shade-nets on plant leaf parameters and tomato fruit quality. Journal of the Science of Food and Agriculture. 2018;98(8):2567–2574.
6. Jackson ML. Soil Chemical Analysis. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
Jin EJ, Choi MS, Lee H, Bae EJ, Kim DH, Yoon JH. Smart automatic irrigation enhances sap flow, growth and water use efficiency in containerized *Prunus* × *yedoensis* Matsum. seedling. Plants. 2024;13(23):3270. DOI:10.3390/plants13233270
7. Kabir MY, Díaz-Pérez JC, Nambeesan SU. Shade nets improve vegetable performance. Scientia Horticulturae. 2024;337:113487. DOI:10.1016/j.scienta.2024.113487
8. Kazemi F, Jozay M, Salahshoor F, van Etten E, Rezaie S. Effects of various irrigation regimes on water use efficiency and visual quality of some ornamental herbaceous plants in the field. Agricultural Water Management. 2019;212:78–87.
9. Kentelky E, Szekely-Varga Z, Bálint J, Balog A. Enhance growth and flower quality of *Chrysanthemum indicum* L. with application of plant growth retardants. Horticulturae. 2021;7(12):532. DOI:10.3390/horticulturae7120532
10. Kumari S, Damodaran T, Dutt K, Kumari S, Debnath P, Shukla A, *et al*. Flowering time, photoperiod, shade and temperature response in chrysanthemum cultivars. Journal of Applied Horticulture. 2023;25(3):224–229.
11. Liang YN, Guo QS, Zhang ZY, Wang TY, Wang T. Effects of climate factors on quality of *Chrysanthemum morifolium* originated from Wenxian County. China Journal of Chinese Materia Medica. 2007;23:2474–2477.
12. Manjunatha MK, Maheshwara Babu B, Srinivasa Reddy GV, Rajkumar R, Ramesh G. Effect of environmental parameters on chrysanthemum under different colour low tunnel shade nets and mulches. Ecology, Environment & Conservation. 2023;29(Suppl.):S492–S499. DOI:10.53550/EEC.2023.v29i06s.077
13. News Market. Agriculture Nets Market to Surpass USD 17.9 Billion by 2034. Market Analysis Report. October 2025.
14. Oren-Shamir M, Gussakovsky EE, Shpiegel E, Nissim-Levi A, Ratner K, Ovadia R, *et al*. Coloured shade nets can improve the yield and quality of green decorative branches of *Pittosporum variegatum*. Journal of Horticultural Science and Biotechnology. 2001;76(3):353–361.
15. Pan B, Du Y, Chen Q, Wang Y, Chen L, Li H, *et al*. China's chrysanthemum in the global market: evaluating the international competitiveness and influencing factors. Frontiers in Sustainable Food Systems. 2025;9:1521709. DOI:10.3389/fsufs.2025.1521709
Pathania S, Dhiman SR, Kashyap B, Bhardwaj SK, Sharma N, Razdan VK. Influence of planting dates and fertilizer modules on yield of chrysanthemum and soil health. BMC Plant Biology. 2024;24:510. DOI:10.1186/s12870-024-05241-y
16. Shahak Y, Gal E, Offir Y, Ben-Yakir D. Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. Acta Horticulturae. 2008;797:75–80. DOI:10.17660/ActaHortic.2008.797.8
17. Singh AK, Singh DK, Singh AK, Kumar R. Evaluation of different chrysanthemums under shade net house in mid hills of Northwest Himalaya. International Journal of Pure and Applied Bioscience. 2017;5(1):980–985. DOI:10.18782/2320-7051.2486
18. Singh MC, Sharma KK, editors. Protected Cultivation: Structural Design, Crop Management Modeling and Automation. 1st ed. Apple Academic Press; 2024. DOI:10.1201/9781003402596
19. Stamps RH. Use of colored shade netting in horticulture. HortScience. 2009;44(2):239–242. DOI:10.21273/HORTSCI.44.2.239
20. Wang H, Jiang J, Chen S, Qi X, Peng H, Li P, *et al*. Current achievements and future prospects in the genetic breeding of chrysanthemum: a review. Horticulture Research. 2019;6:109. DOI:10.1038/s41438-019-0193-8
21. Yadav K, Damodaran T, Dutt K, Kumari S, Debnath P, Shukla A, *et al*. Photoperiod and temperature response in chrysanthemum: Flowering time and quality attributes. Journal of Applied Horticulture. 2023;25(3):238–242.