PHOTO-THERMAL MANIPULATIONS FOR DELAYED BUD OPENING IN NERIUM (*NERIUM OLEANDER*)

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Abstract. Nerium is a versatile flowering plant requiring less labor and low input for commercial cultivations. The growers harvest the mature flower buds from late at night to early in the morning hours with the use of a headlight as the flowers exhibit full bloom in the morning. With this background, investigation was done under different conditions of lighting and water spraying in the form of fog in nerium variety 'pink' at Samakuttapatti village, Panamarathupatti Block, Salem district, Tamil Nadu, India. The plant height (268.00 cm) was maximum in the plants exposed with 450-495 nm of blue light for 6 h + water spray (fog) 15 min. for every 1 h. Inflorescence with the highest number of flower buds (9.25) and flower yield (230.80 g plant^{-1}) were recorded in water spray (Fog) 15 min. for every 1 h which highly favored for harvesting between 5.30 A.M. and 7.30 A.M. or preferably in the previous day evening. The same treatment exerted the highest benefit cost ratio (2.83). The Principal Component analysis showed strong association with Percentage of unopened flower buds (POUP), Single flower bud weight (SFBW), Number of flower buds per inflorescence (NFB) and Total number of inflorescence plant^{-1}.
Keywords: *lighting system, water spray, fog, principal component analysis, unopened flower buds*

Introduction

The flowering shrub nerium (*Nerium oleander* L.) is one of the significant plants belongs to Apocynaceae family. It is commonly known as 'Arali' in Tamil, 'Kaner' in Hindi, 'Raktakarabi' in Bengali, 'Kabirei' in Manipuri and 'Kananpar' in Mizo. This crop thrives in tropical and subtropical climates and bears blossoms constantly throughout the year. It is one of the well-known sclerophyllous plant that can able to endure the extended durations of heat and dryness. It can withstand both drought and flooding, but cannot resist the protracted period of frost. Nerium bears flowers round the year in clusters of five lobed flowers. Because of its beautiful and profuse flowering habit and good shelf life period, nerium is commercially grown under South Indian conditions (*Fig. 1*). The flowers are used for garland making as its spiritually valued for

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worshipping in temples. In India, commercial cultivation of nerium is confined to Tamil Nadu with an area of 2,303 ha contributing 5.3% in total flower cultivation (Anonymous, 2023). Owing to its continuous demand especially during the festive seasons, the area of cultivation is increasing due its versatile adoptability, less labor and low input requirement for commercial cultivations. Although the area and demand is markedly increasing, the main problem associated with cultivation is harvesting of flower buds. With the use of a headlight, the growers harvest the mature flower buds from late night to early in the morning hours as the flowers exhibit full bloom in the morning. During the phase of harvesting, farmers face snake, scorpion and reptile bites causing ill effects to the farming fraternity.

Different photoreceptors are used to regulate or to change the growth of plants more specifically the different properties of light such as quality, quantity, intensity, direction and light duration all play an important role in flowering of crop plants. For instance, length of the stem, color of the leaf and flowering are greatly affected by intensity of light. Blue light influences the synthesis of chlorophyll during photosynthesis and regulates stomatal opening and the photo-morphogenetic response via cryptochrome and phytochrome systems. In addition to the above, blue light plays an important role in the promotion of vegetative characters more especially on height of the plant, area of leaf, and yield of flower and ornamental crops. Plants respond well to varying light stimuli and modify their physiological and metabolic process accordingly Jones (2018), Sadhu Prabhakaran et al. (2021a), Velmurugan et al. (2022) and Spall and Lopez (2023). In addition to light, temperature is another vital fundamental environmental component that regulates plant growth, development, and flower production in horticultural crops. Any short-term variation in temperature for a few days can also result with a dramatic impact on flower production of crop plants (Hatfield and Prueger, 2015).

One of the remarkable studies of Andrews (1929) revealed that in Crocus, the flower buds would reach full maturity but the flowers cannot open at low temperatures. The flowers of some Crocus plants opened even with temperature variations of 0.5°C. Warm night time (WN) conditions caused Arabidopsis plants to flower earlier than constant warm (CW) conditions (Thines et al., 2014). In these conditions, the experiment was carried out to manipulate the time of harvesting of nerium buds involving different colored light emitting diodes (LED) and water spray to circumvent the drudgery faced by the nerium farmers.

Materials and methods

Experimental area

The field problem-based investigation was carried out at a progressive nerium grower field at Samakuttapatti village, Panamarathupatti Block, Salem district, Tamil Nadu, India. The experimental field was located at the Latitude of 11’34” N, longitude of 78’14” E and altitude of 261 m above mean sea level. Well established three years old plants were used for the study. ‘Local Pink’, the commercially cultivated nerium variety was chosen for imposing the treatments.

Experimental condition

The soil texture of the experimental field is sandy loam with pH (8.04), EC (0.28 d Sm^{-1}), organic carbon (0.41%), available nitrogen (214.10 mg/kg), available

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phosphorous (19.9 mg/kg) and available potassium (312.7 mg/kg). Well established three years old plants were used for the study. Nerium variety 'local pink' was selected for imposing the treatments. The plants were planted at the spacing of three meters between the rows and two meters between the plants in the row. At the time of treatment application, the entire experimental field was kept free from weeds. The plants were irrigated as and when required and manured with FYM @ 10 t/ha during January and again in August. Biofertilizers *viz.*, *Azospirillum* and *Phosphobacteria* were applied @ 2 kg/ha along with the FYM. The plants were irrigated once in 10-15 days depending on the weather conditions. Spraying of Dimethoate or Proponofos @ 2 ml/lit of water was recommended for the control of leaf eating caterpillars. The intercultural operations such as fertilization and need based plant protection measures were followed as recommended in the Horticultural Crop Production Guide (2013). The weather parameters of the experimental location was sourced from NASA Power Global Meteorology, Surface Solar Energy and Climatology and furnished in *Figure 2*.

Figure 1. *Promising nerium growing areas of Tamil Nadu*

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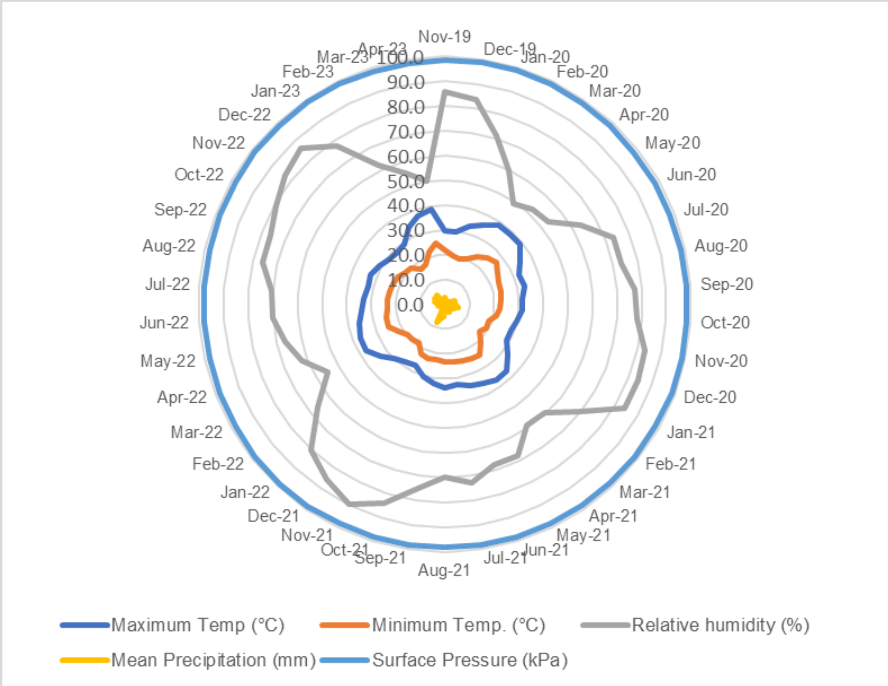

Figure 2. *Weather conditions during the experimental period*

Treatment details

Experiment was systemized with three replications in Randomized Block Design (RBD). The treatments were imposed to twenty plants in a plot. LED lights were hang down vertically above the canopy level by using GI wire support at the distance of 1.25 m above the canopy level to ensure complete light coverage of plants. Similarly, the foggers was also installed/positioned vertically at the plant canopy level for uniform coverage of fog to the entire experimental plot. The treatments was imposed during night time from 10.00 P.M. to early morning 4.00 A.M. and the treatment schedule includes 450-495 nm of Blue light (T_1), 620-750 nm of Red light (T_2), 450-500 nm of White light (T_3), Blue light + fogging (water spray) @ 15 min h^{-1} (T_4), Red light + fogging (water spray) @ 15 min h^{-1} (T_5), White light + fogging (water spray) @ 15 min h^{-1} (T_6), fogging alone @ 15 min h^{-1} (T_7) and traditional farmers practices i.e. without any lighting and fogging treatment as control (T_8). The motor for water spray (foggers) and switching (ON/OFF) were operated with automated controller unit attached with cyclic timers (Manufacturer: RMG Automation) with starter. The motor will be switched ON for the programmed period (15 min for every 1 h) and then automatically gets switched OFF for the rest of programmed period (45 min). This sequence will repeat in a cyclic pattern from 10.00 PM to early morning 4.00 AM. However, the LED lights (Manufacturer: Omtronics led lighting solutions, Coimbatore) will be continuously switched ON from 10.00 PM to early morning 4.00 AM. The treatments on lighting and water spraying (fogging) was installed (1st fortnight of September, 2019) and test run done for fine tuning of treatments to ensure the proper illumination of light as well as water spray for complete coverage within the plot. The period of experiment was started during November, 2019 and completed on April, 2022 and validation was done up to April, 2023. The calibration and acclimation period was more than one month prior to the recording of observations.

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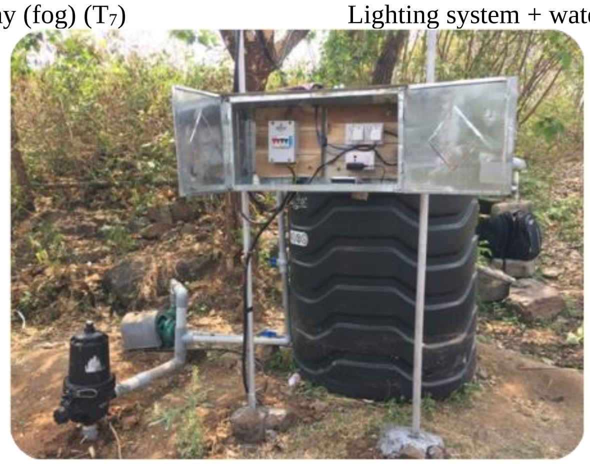
Blue LED light (T_1)

Red LED light (T_2)

White LED light (T_3)

Water spray (fog) (T_7)

Lighting system + water spray (Day view)



Automated controller unit (ON/OFF) for lighting and fogging system

Details of observations

After the calibration/acclimation period, the observations were recorded i.e. period of start of the experiment at regular intervals. The observations on growth parameters viz., height of the plant, spread of the plant in directions from East to West and North to South, number of primary branches plant^{-1}, length of internodes was recorded at monthly intervals. The flower yield parameters such as days required for flower bud initiation, number of inflorescences plant^{-1}, number of flower buds inflorescence^{-1}, percentage of opened flowers and unopened matured flower buds inflorescence^{-1}, flower opening time, single flower bud weight, hundred flower bud weight, flower yield, flower bud length, flower diameter and shelf life were studied on daily basis. In addition to the above, physiological parameters viz., leaf area and total chlorophyll was also recorded during the phase of evaluation at monthly intervals. Leaf area was computed on the graphical method and expressed in cm^2. The total chlorophyll content in nerium leaves were assessed following the methods suggested by Arnon (1949) and Yoshida et

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al. (1971) and the mean values were expressed in mgg^{-1} of fresh weight of sample. The anthocyanin content was measured in Spectrophotometer at 525 nm and the OD values were expressed in µgg^{-1} as suggested by Swain and Hillis (1959).

Statistical analysis

The observations recorded were statistical analyzed with five percent (0.05) probability and the results were interpreted based on the methods of Gomez and Gomez (1984). The cost economics of nerium was worked out for an area of one acre (4000 m^2) and expressed in USD. The ratio of gross income and gross cost is computed and expressed as BC ratio. Principal Component Analysis was determined to assess the extent of variation among the treatments using R.4.2.2 version (R Core Team. 2022). PCA involves a number of statistical procedures, including determining the mean, covariance matrix, eigen vectors, and eigen values; choosing components; creating feature vectors; and generating a new set of data for interpretation.

Results and discussion

The findings of the two years pooled data revealed that there was a remarkable divergence among the different LED lighting and fogging treatments with respect to growth and yield parameters.

Growth parameters of nerium

Light is primary energy source for photosynthesis and activates the bio-molecular signals for photo-morphogenesis and other physiological processes in plants. The vegetative growth and flowering are highly influenced by the spectrum of light. The three parameters viz., quality of light, quantity and duration of lights play a vital role in plant growth. The tallest plants (268.00 cm) were observed when the were plants illuminated exposed with 450-495 nm of Blue light + fogging (water spray) @ 15 min h^{-1}. The spread of the plants in direction from North to South (142.75 cm) and East to West (136.75 cm) was noticed in plants receiving 450-495 nm of Blue light (*Table 1*). This may be due to the result of photons emitted from the blue lights could have prompted the photosynthetic activities of nerium. In addition to the above blue light significantly influences the phototropism, photo-morphogenesis and photosynthetic functioning of leaves. Blue light controls the loss of water in plants through the opening of stomata and enhances the CO_2 uptake in plants. This could have resulted in more plant height of nerium. The conclusions of the current investigation are consistent with the reports of Sadhu Prabhakaran et al. (2021b) in nerium.

Significantly, greater number of primary branches plant^{-1} (10.65) was noticed in plants exposed with Red light + fogging (water spray) @ 15 min h^{-1}. The distance between the nodes i.e. intermodal length was maximum (9.35 cm) when the plants were illuminated to 620-750 nm of Red light. The Red light promotes the division and elongation of cells which in turn has the profound influence on auxiliary bud initiation. This could might be the basis for the maximum count of primary branches. The meristematic activity of the plant cells are triggered by red light. The finding of Heo et al. (2011) in ageratum seedlings, Sadhu Prabhakaran et al. (2021b) in nerium and Spall and Lopez (2022) in Marigold confines that light illumination has improved growth of plants, which is in accordance with the present findings of nerium variety ‘pink’.

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Table 1. *Effect of different light and fogging system on growth and flower yield parameters of nerium (pooled mean data of 2 years)*

Treatments	Plant height (cm)	Number of primary branches plant^{-1}	Plant spread N-S (cm)	Plant spread E-W (cm)	Internodal length (cm)	Days required for flower bud initiation to flower opening (days)	Total number of inflorescences plant^{-1}	Percentage of opened flower buds	Percentage of unopened flower buds
450-495 nm of Blue light (T_1)	200.00^{c}	9.75^{a}	142.75^{a}	136.75^{a}	7.70^{b}	8.55^{ab}	16.75^{c}	25.15 (30.10)^{a}	74.85 (59.90)^{a}
620-750 nm of Red light (T_2)	204.50^{de}	8.50^{abc}	118.00^{d}	108.00^{de}	9.35^{a}	8.95^{a}	13.55^{d}	28.10 (32.01)^{a}	71.90 (57.99)^{a}
450-500 nm of White light (T_3)	221.00^{cde}	7.15^{bc}	132.50^{bc}	118.00^{bcd}	7.40^{bc}	7.65^{bc}	16.00^{d}	24.35 (29.57)^{a}	75.65 (60.43)^{a}
Blue light + fogging (water spray) @ 15 min h^{-1} (T_4)	268.00^{a}	6.65^{bc}	128.75^{bcd}	106.50^{de}	7.70^{b}	6.75^{cd}	20.00^{b}	8.25 (16.69)^{bc}	91.75 (73.31)^{b}
Red light + fogging (water spray) @ 15 min h^{-1} (T_5)	232.00^{bc}	10.65^{a}	118.00^{d}	100.00^{e}	6.25^{c}	7.45^{c}	23.95^{a}	9.15 (17.61)^{bc}	90.85 (72.39)^{b}
White light + fogging (water spray) @ 15 min h^{-1} (T_6)	220.50^{cde}	6.50^{c}	133.50^{abc}	121.25^{bc}	7.65^{b}	6.00^{d}	18.50^{bc}	9.95 (18.39)^{b}	90.05 (71.61)^{b}
Fogging alone @ 15 min h^{-1} (T_7)	253.50^{b}	8.90^{ab}	137.50^{ab}	125.00^{ab}	7.45^{bc}	6.70^{cd}	24.40^{a}	6.95 (15.29)^{c}	93.05 (74.71)^{b}
Control (T_8)	227.75^{cd}	10.50^{a}	124.00^{cd}	110.75^{cde}	6.75^{bc}	8.50^{ab}	16.55^{cd}	29.25 (32.24)^{a}	70.75 (57.26)^{a}
SEd	12.24	1.14	5.01	6.22	0.55	0.49	1.54	0.49 (1.42)	0.64 (4.05)
CD (p = 0.05)	24.52	2.29	10.03	12.46	1.12	0.97	3.07	0.98 (3.04)	1.27 (8.68)

Figures in parenthesis arc sine transformed values
Means having the same letter are not statistically different at $p \geq 0.05$

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Yield parameters of nerium

Light influences the plant's growth throughout all phases, namely germination, stem growth, root and leaf development, phototropism, chlorophyll accumulation, development of branches and flowering. The number of days required for flower bud initiation differed greatly amongst the treatments and the data was presented in *Table 2*. Exposing the 'local pink' variety of nerium plants with 450-500 nm of White light + fogging (water spray) @ 15 min h^{-1} requires shorter (6.00) number of days for initiation of flower buds. The number of inflorescence $plant^{-1}$ (24.40) was found to be maximum by spraying the water in the form of fog @ 15 min h^{-1}. It is evident from the data that the highest percent (93.05) of unopened flower buds was noted by spraying the water in the form of fog @ 15 min h^{-1}. The lowest percent (70.75) of unopened flower buds was noted in the plants control plots without any treatments, which was found to equivalent (71.90) with the plants illuminated with 620-750 nm of Red light. The spraying the water in the form of fog @ 15 min h^{-1} (T_7) i.e. without any illumination of LED lights had pronounced effect and overwhelmed the other treatments in terms on the number of flower buds $inflorescence^{-1}$ (9.25), flower length (3.70 cm), and flower yield (230.80 g $plant^{-1}$). However, exposure of nerium plants with Blue light + fogging (water spray) @ 15 min h^{-1} exerted the best in terms of flower length (3.70 cm) and Red light + fogging (water spray) @ 15 min h^{-1} showed best performance in terms of flower diameter (3.18 cm). Flower opening was primarily influenced by external factors viz., light, relative humidity, temperature and internal rhythm, besides the balance of sugar substances and polysaccharides degradation.

Table 2. *Effect of different light and fogging system on flower yield, physiological and biochemical parameters of nerium (pooled mean data of 2 years)*

Treatments	Number of flower buds $inflorescence^{-1}$	Single flower bud weight (mg)	Flower length (cm)	Flower diameter (cm)	Flower yield (g $plant^{-1}$)	Shelf life (days)	Leaf area (cm^2)	Total chlorophyll (mg g^{-1})	Anthocyanin content (µgg^{-1})	
									Opened flowers	Unopened flower buds
T_1	5.50^{e}	192.00^{d}	2.55^{b}	2.60^{b}	183.40^{cd}	2.5	48.15^{b}	2.85	0.81^{ab}	0.78^{ab}
T_2	7.85^{cd}	203.95^{c}	3.20^{ab}	2.84^{ab}	195.10^{bc}	2.0	49.32^{a}	3.09	0.79^{ab}	0.75^{abc}
T_3	7.90^{bcd}	203.80^{c}	3.15^{ab}	2.99^{ab}	203.60^{d}	1.5	45.55^{ab}	3.66	0.76^{b}	0.70^{c}
T_4	8.65^{abc}	225.95^{a}	3.70^{a}	3.10^{ab}	205.55^{b}	2.8	41.22^{c}	3.92	0.85^{a}	0.82^{a}
T_5	9.20^{ab}	208.25^{c}	2.90^{ab}	3.18^{ab}	210.55^{ab}	2.9	44.07^{bc}	3.79	0.77^{b}	0.72^{bc}
T_6	7.00^{d}	$213.70b^{bc}$	2.80^{ab}	2.80^{ab}	207.50^{b}	2.7	42.64^{c}	4.23	0.75^{b}	0.69^{c}
T_7	9.25^{a}	223.30^{ab}	3.70^{a}	3.83^{a}	230.80^{a}	3.1	46.46^{ab}	3.51	0.64^{c}	0.61^{d}
T_8	6.25^{de}	182.40^{d}	2.55^{b}	2.46^{b}	168.00^{d}	2.0	45.34^{ab}	2.84	0.59^{c}	0.55^{d}
SEd	0.65	5.80	0.47	0.51	9.23	NS	2.04	NS	0.02	0.03
CD (p = 0.05)	1.33	11.63	0.96	1.03	18.49		4.09		0.06	0.07

Means having the same letter are not statistically different at $p \geq 0.05$

Water relations in plants had a profound influence on the opening of flowers. The low water potential drastically affects the flower opening and quality of flowers. Under normal situations, the flowers remain in a turgid condition which in turn favors the higher yield of flower buds. The opening of the flower was also hastened by the increased relative humidity, which was proved by Harrp et al. (2020). Further, thermoregulation also plays substantial role in the opening of flowers. The pattern of

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occurrence of floral humidity varies according to the plant species and specifically the floral humidity was promising at the center of the flower rather than the distal ends. The raise in temperature during the morning is more sufficient for blooming of the flowers of Tulipa and Crocus. It has also been reported that even by the rise of 0.5°C in Crocus resulted in the opening of flowers; however, it was 1.0°C for Tulipa flowers (Pfeffer, 1873; Andrews, 1929). The interpretation of Hou et al. (2022) reported that existence of high or low temperature coupled with low relative humidity had more impact on the opening of flowers, while illumination intensity had no discernible effect. The results of the present investigation is in consonant with Liu et al. (2023). The heat stress has profound influence on flower opening, opening of the spikelet, dehiscence of anthers, viability of pollens and elongation of pollen tube etc. Therefore, the fogging system (water spraying) has the ability to reduce the environmental temperature to the extent of one to two degree Celsius in open field conditions. With respect to the time of flower opening, the treatment receiving water spray in the form of fog has extended the time of harvest in the morning hours for at least 2–3 h and also highly suited for harvesting in the previous day evening. The illumination of nerium plants with different LED lights and water spray did not show any exemplary results on shelf life of flowers.

Physiological parameters of nerium

The maximum leaf area (49.32 cm^2) and minimum leaf area (41.22 cm^2) was registered with the exposure of nerium plants to 620-750 nm of Red light and Blue light + fogging (water spray) @ 15 min h^{-1} for 6 h respectively. The leaf area in plants regulates interception of light, which in turn reflects on the productivity of plants. Similar research findings were reported in Rosa × hybrida with more leaf area and enhanced levels of soluble carbohydrates (Terfa et al., 2012). The other findings of Zheng and Van Labeke (2017) also proved that spectrum of Blue light has greater influence on leaf area of ornamental plants. The total chlorophyll content was found to be maximum (4.23 mg g^{-1}) under illumination with White light + fogging (water spray) @ 15 min h^{-1} (T_6) when compared to traditional farmers practices (2.84 mg g^{-1}) i.e. without any lighting and fogging treatment as control (T_8). The warm white light greatly influences the synthesis of chlorophyll in Spinach which was subsequently confirmed the positive impact on accumulation of assimilates in leaves. This is in corroboration with the reports Burattini et al. (2017).

The influence of several LED lights and a fogging system on nerium flowers showed marked increase in the anthocyanin levels. The anthocyanin content in opened flowers was highest (0.85 μgg^{-1}) in 450-495 nm Blue light + fogging (water spray) @ 15 min h^{-1} and lowest (0.59 μgg^{-1}) in farmers practices i.e. without any lighting and fogging treatment as control. For unopened flower buds, it is evident from the data that the same trend was followed by the illumination of distinct LED lighting and fogging systems (*Table 2*). Anthocyanins that conglomerated in plants do not influence chloroplast photosynthetic processes. Anthocyanin production is a genetically manipulated phytochrome-mediated process that requires a photosynthetic rate (Meng et al., 2004). Light is a significant factor in anthocyanin production. Anthocyanin biosynthesis is greatly influenced by the intensity of light or exposure to light (Giusti and Wrolstad, 2001). In chrysanthemum, Rutland (1968) reported that night temperature influenced anthocyanin content more than the day temperature. In the present study, it was evident that water spray as fog during night time might have reduced the temperature and maintained the biosynthesis of anthocyanin. A analogous trend was also opined by Ryu et al. (2012).

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Bud opening of nerium

The effect of different lighting and fogging system influenced the time of bud opening of nerium (*Table 3*). The monthly average data on time of opening showed that flowering opening time ranged from 6.00 AM (450-500 nm of White light) to 8.10 AM (fogging alone @ 15 min h^{-1}) during November to December month i.e. during the winter months with low environmental temperature. Whereas during summer i.e. May-June the same treatments exhibit the early time of flower opening from 4.45 AM to 6.10 AM. From the results it clearly demarcates that temperature play a major role in opening of flower buds. Zhang et al. (2022) also opined that number of flowers during winter season is more than that of autumn and summer season and the underlying environmental conditions critically influence the molecular regulatory networks related to flowering of crops. This is in agreement with the findings of Liu et al. (2023) and stated that stress condition with high temperature influence the opening of spikelet, dehiscence of anthers, etc.

Table 3. *Effect of different light and fogging system on on time of flower opening of nerium (mean data of 2 years)*

Treatment	1st Bi- month (Nov-Dec)	2nd Bi-month (Jan-Feb)	3rd Bi-month (Mar-April)	4th Bi-month (May-June)	5th Bi-month (July-Aug)	6th Bi-month (Sep-Oct)
T1	6.05 AM	5.50 AM	5.05 AM	4.50 AM	5.10 AM	5.25AM
T2	6.20 AM	5.55 AM	5.00 AM	4.45 AM	4.55 AM	5.15 AM
T3	6.00 AM	5.50 AM	5.10 AM	5.00 AM	5.15 AM	5.20 AM
T4	7.25 AM	6.40 AM	5.20 AM	5.25 AM	5.15 AM	7.10 AM
T5	7.00 AM	7.15 AM	6.15 AM	5.40 AM	6.05 AM	7.00 AM
T6	7.35 AM	7.10 AM	6.25 AM	5.50 AM	6.15 AM	6.50 AM
T7	8.10 AM	7.55 AM	7.30 AM	6.10 AM	7.35 AM	7.50 AM
T8	7.15 AM	6.10 AM	6.00 AM	5.50 AM	6.20 AM	5.45 AM

Economics of nerium

From the farmer's perspective, cost economics plays a critical role in any crop production with the ultimate aim of supporting the grower to make more profit with less input. The economic analysis for cultivation of nerium pink cultivar plants for one acre was calculated for the treatments individually. *Table 4* revealed that the highest gross income (USD 4753.90) and net returns (USD 3096.70) with benefit cost ratio (2.87) was noticed in the plant provided with water spray in the form of fog 15 min h^{-1}. The minimum gross income, net returns and cost benefit ratio of USD 1843.35, USD 889.38 and 1.93 was registered in control i.e. farmers practice without treatmental effects respectively. This could be due to the reason water spray as fog could have resulted with bolder and lengthier flower buds which are highly preferred for veni making and other floral preparations. In addition to the above, wages paid for harvesting of the buds during the mid night time is comparatively higher than the wages paid during the day time. The quality of flowers mainly determines the market price which in turn decided the profitability of the crop. The findings of the present experiment is in concurrence with the results of Gamanagatti and Patil (2018), Dhawan et al. (2021) and Runkl (2023) in various horticultural crop including chrysanthemum and carnation. In total, it could be observed that during the night time, the fogging (water spray) @ 15 min h^{-1} significantly influenced the growth, flower yield, quality and net return of nerium (*Nerium oleander* L.) crop as preferred by the progressive growers.

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Table 4. *Effect of different light and fogging system on cost economics of nerium*

Treatment	Gross income (USD)	Gross cost (USD)	Net returns (USD)	BC ratio
T_1	2740.07	1651.09	1088.98	1.66
T_2	2910.31	1651.09	1259.23	1.76
T_3	2403.98	1651.09	752.89	1.46
T_4	3290.43	2207.56	1082.87	1.49
T_5	3200.17	2207.56	992.61	1.45
T_6	2930.86	2207.56	723.30	1.33
T_7	4753.90	1657.20	3096.70	2.87
T_8	1843.35	953.96	889.38	1.93

$1 USD = ₹81.7644 as on 30.04.2023

Principal component analysis

Analysis and interpretation is cumbersome to differentiate the effect of various lighting system on flower opening of nerium. Hence, the PCA was carried out to compress as an exploratory statistical process to convert highly correlated variables with the uncorrelated ones. PCA uses the orthogonal conversion to avoid the problem of multicollinearity. Multicollinearity between the variables of independent nature will end up with less reliability and statistical inferences. PCA with Eigen values greater than one were chosen and the first four explained (89.09%) the overall variation. The PC 1 contributed 37.56% of variance and PC 2 contributed 26.60%, while PC3 and PC 4 contributed 13.85% and 11.08% of variance respectively. From the above, four Principal Components a cumulative total of 89.09% of variation was obtained (*Table 5*). A similar kind of trend was expressed by Deepika et al. (2022) in Castor with four components totaling more than 70% of variance.

Table 5. *Eigen values, variance and cumulative percentage of variance for 10 principle components*

PC	Eigen value (λ)	Percentage of variance (%)	Cumulative percentage of variance (%)
PC 1	5.2579	37.56	37.56
PC 2	3.7238	26.60	64.16
PC 3	1.9389	13.85	78.00
PC 4	1.5516	11.08	89.09
PC 5	0.6821	4.87	93.96
PC 6	0.3515	2.51	96.47
PC 7	0.1863	1.33	97.80
PC 8	0.1489	1.06	98.86
PC 9	0.0919	0.66	99.52
PC 10	0.0319	0.23	99.75
PC 11	0.0242	0.17	99.92
PC 12	0.0104	0.07	100.00
PC 13	0.0006	0.00	100.00

The Eigen values are ordered from the largest to smallest in the Scree polt. A sharp curve followed by a bend and finally a straight line is the perfect pattern of expression. The first four possible components in the steep curve before the first point where the line trend

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begins which has contributed 89.09% of cumulative variance. The Principal Component where interrupted by examining the coefficient of direction and magnitude of variables in original form. The PC 1 has more positive association with Percentage of unopened flower buds (POUP), Single flower bud weight (SFBW), Number of flower buds per inflorescence (NFB), Total number of inflorescence plant^{-1} (TI) and negative association with Percentage of opened flower buds (POP) and Days taken from flower bud initiation to flower opening (DIFO). The second Principal component has more positive association with Flower diameter (FD) and largely negatively associated with Flower length (FL) and Flower yield (FY) (*Table 6*). A Scree plot (*Fig. 3*) was created using ten dimensions, the X axis and the percentage of explained variation in the Y axis. According to Eigen values, the first four Principal Component explained 89.09% of overall variation.

Table 6. *Contribution of original variables in the principal components*

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
PH	0.290	-0.277	-0.203	-0.158	-0.133	-0.307	0.730	0.160	-0.142	0.136
NPB	-0.168	0.149	-0.207	-0.551	0.510	0.214	0.068	0.192	-0.357	-0.354
PSNS	0.045	-0.288	0.558	-0.158	0.087	-0.259	0.046	0.038	0.109	-0.340
PSEW	-0.079	-0.255	0.569	-0.132	0.290	-0.113	-0.132	0.000	-0.123	0.269
IL	-0.045	-0.243	-0.051	0.558	0.568	0.340	0.256	0.213	0.135	0.118
DIFO	-0.318	-0.199	-0.285	-0.134	0.231	-0.163	0.051	-0.750	0.210	0.085
TI	0.344	0.118	0.008	-0.388	0.232	0.088	0.054	0.060	0.711	0.191
POP	-0.418	-0.036	-0.079	0.096	0.035	-0.327	0.024	0.235	0.150	-0.069
POUP	0.418	0.036	0.079	-0.096	-0.035	0.327	-0.024	-0.235	-0.150	0.069
NFB	0.320	0.161	-0.282	0.096	0.281	-0.524	-0.432	0.238	0.046	0.034
SFBW	0.391	0.005	0.045	0.310	0.169	-0.008	0.003	-0.305	-0.045	-0.497
FL	0.173	-0.443	-0.211	-0.001	0.041	-0.166	-0.110	-0.068	-0.072	-0.280
FD	0.080	0.451	0.170	0.116	0.297	-0.323	0.213	-0.243	-0.347	0.319
FY	0.128	-0.461	-0.173	-0.110	0.036	0.103	-0.356	0.041	-0.288	0.415

PH-Plant height, NPB-Number of primary branches, PS NS-Plant spread N-S, PS EW-Plant spread E-W, IL-Internodal length, DIFO-Days taken from flower bud initiation to flower opening, TI-Total number of inflorescence plant^{-1}, POP-Percentage of opened flower buds, POUP-Percentage of unopened flower buds, NFB-Number of flower buds per inflorescence, SFBW-Single flower bud weight, FL-Flower length, FD-Flower diameter, FY-Flower yield, SL-Shelf life, LA-Leaf area, TC-Total chlorophyll

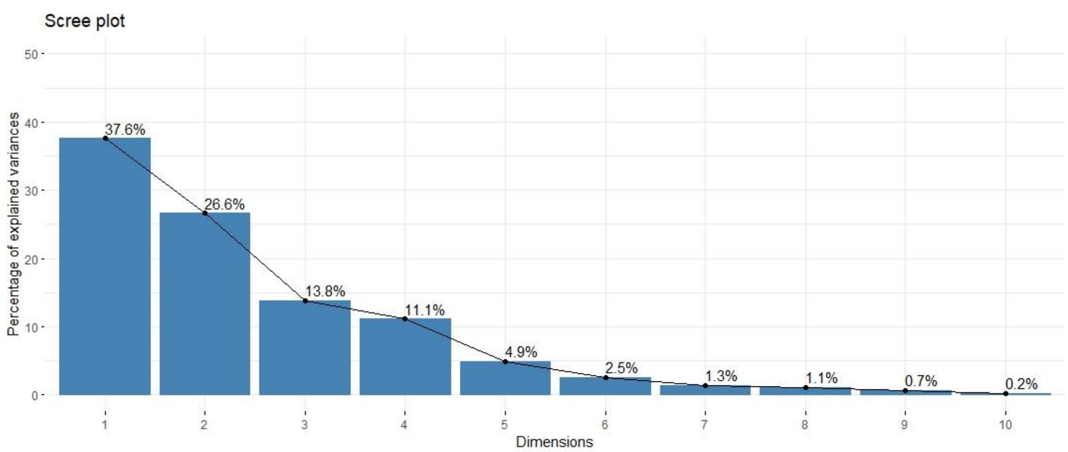

Figure 3. *Depicting the ten dimensions scree plot with explained variables in percentage*

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Figure 4 shows that PCA Biplot displaying the projection of traits on the first two Principal components *viz.*, Percentage of unopened flower buds (POUP), Single flower bud weight (SFBW), Number of flower buds per inflorescence (NFB) and Total number of inflorescence plant^{-1} (TI) and had more positive association with PC1. The Percentage of opened flower buds (POP) and Days taken from flower bud initiation to flower opening (DIFO) had more negative association with PC2. The realistic character relationship among the traits was portrayed by Biplot ordination in two or more dimension (Corovello, 1970). The results of the present investigation affirmed that PCA has more and strong association with Percentage of unopened flower buds (POUP), Single flower bud weight (SFBW), Number of flower buds per inflorescence (NFB) and Total number of inflorescence plant^{-1} (TI) and this was demonstrated by the fact that the angle of vectors between these traits was less than 90° (*Fig. 5*). Further the above information is evident with the findings of Piedade et al. (2019) and Yamanura and Mohan Kumar, 2020).

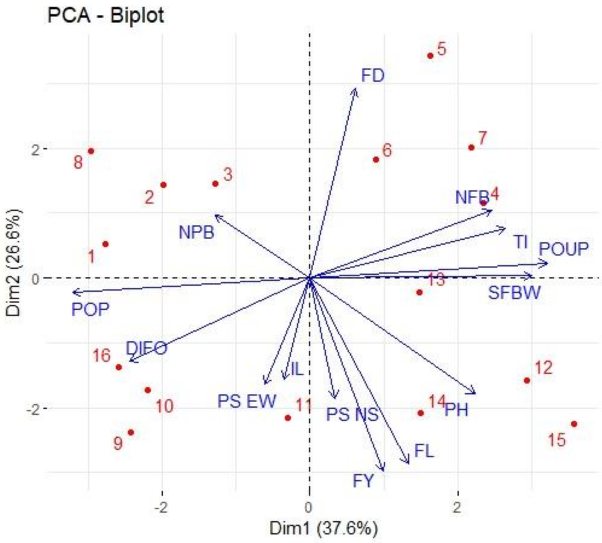

Figure 4. *PCA biplot depicting quantitative characters in two-dimensional ordination*

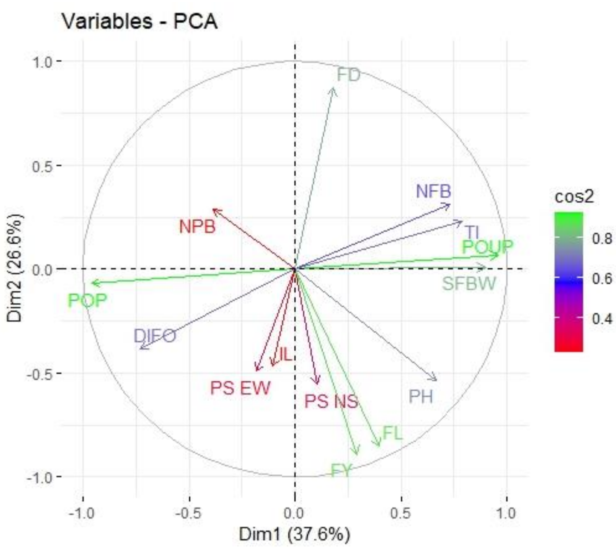

Figure 5. *PCA variables displaying in two dimension*

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The PCA variable in two dimension indicate that in Dim1 had positive association with Percentage of unopened flower buds (POUP), Single flower bud weight (SFBW), Number of flower buds per inflorescence (NFB) and Total number of inflorescence plant^{-1} (TI).

Conclusion

To conclude the present investigation, the illumination with different colored LED lights did not influenced the time of bud opening of nerium. However, inflorescence with highest number of flower buds (9.25), single flower bud weight (223.30 mg), flower length (3.70 cm), flower diameter (3.83 cm), highest percent (93.05) of unopened flower buds and flower yield (230.80 g plant^{-1}) was achieved in the treatment with water spray (Fog) 15 min for every 1 h. The same treatment exerted the highest gross income (USD 4753.90) and net returns (USD 3096.70) with benefit cost ratio (2.87) and demarcates the varying time of harvesting i.e. during the winter season (November to December month) flower buds can be harvested up to 8.10 AM, while in summer season (May-June) harvesting can be done up to 6.10 AM. The first four Principal Component explained 89.09% of overall variation of the components. The maximum percentage of unopened flower buds and minimum percentage of opened flowers exhibited in the fogging (water spray) @ 15 min h^{-1} treatment which facilitated the growers for harvesting and packing of flower buds either in the previous day evening and also in the next day morning. The extended duration of harvest of nerium flower buds can be achieved by water spray in the form of fog for every 15 min for every 1 h without any illumination of LED lights. This treatment was also found to be outperformed when compared to other treatment combinations and thereby avoiding the drudgery of harvesting in the mid night or the early morning hours as preferred by the progressive nerium growers.

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