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Article

Effect of Red Light and Some Applications on the Flower Induction and Yield of Acid Lime Trees

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Abstract: Limes are considered an important citrus fruit, and their importance increases due to their medicinal properties, which have been passed down through different civilizations and cultures. Lime farms in Egypt are currently suffering from a serious problem that has led to the removal of many trees and orchards, especially in the Beheira region. It has been observed that with this problem, the trees that undergo stimulating drought withholding water for a period of time to produce an off-season crop, which is the basis for most lime farmers to obtain economic returns, collapse completely and die within a period of 3-6 months. Therefore, the aim of this research, during the two successive seasons 2021 and 2022, was to induce lime orchards to flower out- of-season without holding irrigation water. Five different treatments were used without holding water as follow: T1: Control, T2: Red light (light intensity 20µm/ m^2/ second for 4 continuous hours), T3: Paclobutrazol 3.5 g/ tree as soil addition + (potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%), T4: Cycocel 1000ppm+ salicylic acid 200 ppm and T5: Flowering agent (50mg / 100 liter+ (potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%)). The results showed that red light treatment was superior in terms of early flowering, as flowering began one week after treatment, and the yield values were 19.33, 20.58 kg/tree in the first and second seasons, respectively. Moreover, the highest fruit weight and fruit juice percent were recorded with the red light treatment when compared with control or other treatments. This method was more distinctive in terms of sustainability, environmental aspects, and long-term economic benefits. On the other hand, total carbohydrates, N and C concentrations and then C/ N ratio were determined and reflected varied response with varied treatments.

Key words: Acid lime, Flowering, Red light, Cycocel, Paclobutrazol.

1. Introduction

Nearly as important as sweet oranges and mandarins are citrus fruit crops, including acid lime. It has high antioxidant qualities and is a good source of vitamin C. According to the Ministry of Agricultural 2024 report, the total acid lime cultivated area is 49515 feddan and the total production is 410525 tons. It is noticeable that, the prices of acid lime are high out- of- the season and this is a natural behavior for trees, as it is off- season crop, so farmers resort to trying to increase this crop outside the season to increase the economic return.

Moreover, numerous crops, like acid lime, that bloom multiple times a year without a rest period do not consistently deliver high- quality fruit **(Lal *et al*., 2017)**. Several horticulture techniques, such as girdling, ringing, pruning, the application of plant growth regulators, and crop regulation techniques, can be used to control citrus flowering and produce high-yield, superior-quality fruits during the appropriate season **(Mahesha and Singh, 2018 and Lal *et al*., 2017)**.

Flowering induction is a highly regulated developmental process in plants that involves the integration of external signals such as light and internal physiological conditions. While photoreceptors such as phytochrome detect the primary light signal, the subsequent cascade that converts this signal into a change in gene expression depends on a variety of physiological components **(Trivellini *et al*., 2023)**. Mineral acts as second messengers in plant cells, connecting light sensing to blooming. The link between red light and mineral elements in the stimulation of flowering is two-fold. Calcium serves as a short- lived second messenger in the phytochrome signaling pathway **(Tripathy and Roux, 2023)**. Phytohormones, Ca^{2+}, sucrose, proteins, and microRNA (miRNA) are the signal components that connect the light perception/ transduction pathway to the following optimization of nutrition absorption and utilization **(Xu *et al*., 2021)**.

Light quality influences genes expression involved in growth and development by activating photoreceptors signal cascades, including phytochromes, cryptochromes, and phototropins **(Giliberto *et al*., 2005)**. Light is an essential environmental component for plant growth and development because it provides an energy source for carbon fixation during photosynthesis and regulates other physiological processes through its signaling. Light also regulates blooming by affecting phytochromes and including or preventing photoperiodic plants **(Trivellini *et al*., 2023)**.

Although these reactions vary by plant species, red wavelengths typically have a strong effect on plant development and photosynthetic capability **(Kasajima *et al*., 2008)**. Red light has an impact on characteristics such as stem elongation, photosynthetic system, leaf extension, and chlorophyll content **(Szopa *et al*., 2018)**.

Signaling molecules known as plant growth regulators control the plant cell division, flowering and the development of fruits **(Talaat, 2023)**. Cycocel and paclobutrazol (PBZ), two growth retardants, have an antigibberllin action that inhibits vegetative growth and encourages early blooming **(Deshmukh *et al*., 2016)**. It has been discovered that cycocel works incredibly well in creating stress, including flowering **(Lal *et al*., 2017)**. Paclobutrazol (PBZ) treatment improves antioxidant potential, minimizes biennial bearing issues, limits plant development, reduces internodal length, inhibits shoot elongation, reduces leaf area, and boosts root to shoot ratio. It is said to be effective at inducing flowering in various tropical, subtropical, and temperate fruit crops **(Lal *et al*., 2023)**. Because of its low solubility and long-term residual activity, PBZ is usually administered to the soil as opposed to other retardants, which are commonly employed as foliar spray **(Gollagi *et al*., 2019)**.

Although both cycocel (CCC) and paclobutrazol (PBZ) have a clear effect on inducing flowering in plants, both face global restrictions and varying regulations. Some countries, such as Sweden, have banned PBZ due to environmental and health concerns, while others, such as the U.S., china, India, and Brazil, allow limited use with ornamentals, turf, and certain food crops, balancing agricultural benefits with safety. Regulations focus on Maximum Residue Limits (MRLs) in food and application methods, with certain locations allowing significantly lower or zero tolerance **(EFSA, 2010, 2016 and 2018)**.

The objective of this study was to induce flowering of acid lime trees without holding of irrigation water which leads to trees collapse in lime planted area in El-Beheira region suffering from a serious problem, as well as finding a method that has no harmful impact on trees and is safer for public health, humans, and the environment compared to the usual methods.

2. Materials and Methods

The current study was conducted at a private citrus orchard in Badr center area, El-Beheira Governorate, Egypt during two consecutive experimental seasons in 2021-2022. Acid lime trees (*Citrus* *aurantifolia* Swingle) five years old grown in sandy soil planted at 6× 7 m under drip irrigation system, were used to investigate the influence of red light, plant growth regulators as well as some nutrients under study on yield and fruit quality. Forty-five trees (three replicates with three trees at each replicate) were subjected to five investigated treatments without holding water irrigation as follows:

1. Control (Uniform fertilizer program).
2. Red light (light intensity 20 μm/ m^2/ second for 4 daily continuous hours).
3. Paclobutrazol 3.5 g/ tree + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1% **(Deshmukh *et al*., 2016)**.
4. Cycocel 1000 ppm+ salicylic acid 200 ppm **(Prabhu *et al*., 2017 and Thirugnanavel *et al*., 2007)**.
5. Flowering agent (1.5 % NAA+ 0.3% NAAM+ 0.3% Beta naphthyloxyacetic acid+ 97.9 % other additives) 50mg / 100 liter + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1% **(Arunadevi *et al*., 2019)**.

All treatments were applied as foliar sprays at the first week of October for each season except paclobutrazol treatment which was added as soil addition at the same date as well as red light treatment. The red light treatment was used for four consecutive hours after sunset until the first flowering of the treated trees appeared. Note that the wavelength of red light is 600-700 nm **(Chen *et al*., 2024)**. The spotlight used for supplemental lighting has a light intensity of 12000 lux, covering an area of 1400/ m^2 at a minimum intensity of 20 μm/ m^2/ second. Light intensity was measured with a portable lux meter-HI97500- Hanna instruments (μm/ m^2/ second (PPFD) = lux/ 5). Four spotlights can be used to cover an area of one feddan. There were 45 trees in all since each treatment was duplicated three times using a complete randomized block design, with three trees for each replicate. Forty-five trees (five treatments, three replicates, and three trees in each replication).

2.1. The following parameters were investigated:

2.1.1. Number of days: Number of days required for first flowering after treatments application.

2.1.2. Fruit Set: Twenty randomly chosen shoots from each treatment tree were used to calculate the initial fruit set at the pea size stage, which was then expressed numerical form. According to **Prabhu *et al*. (2017)**, the fruit set was computed and expressed in percentage at the pea stage as follows:

$$\text{Fruit set percentage} = \frac{\text{Number of fruits}}{\text{Total number of fruits formed at initial stage}} \text{ X } 100$$

2.1.3. Yield: Each tree's fruits were collected during the second week of April, and the yield was calculated as the quantity of fruits and their weight in kg.

2.1.4. Fruit quality: A representative sample of ten fruits from each replication was collected at harvest time, and the following traits were determined:

2.1.4.1. Fruit physical properties: Average fruit weight (g) and fruit juice percent % (w/ w) were measured.

2.1.4.2. Fruit chemical properties: According to **A.O.A.C. (1995)**, TSS %, acidity % (as mg citric acid/100 cm^3 juice), TSS/ acid ratio and vitamin C (ascorbic acid as mg/100 ml juice) were calculated.

2.1.5. Leaf chemical composition: According to **Miller (1959)**, 3,5-dinitrosalicylic acid was used to measure the total carbohydrates in the dry matter of the leaves. N and C concentrations were determined in dry matter of leaves at the end of experimental. Total N% was determined by semimicro Kjeldahl method described by **Plummer (1971)**. Organic carbon was determined in dried leaves according to **Jackson (1973)** and then C/N ratio was calculated.

2.1.6. Statistical analysis: In accordance with **Snedecor and Cochran (1980)**, the obtained data was statistically analyzed to determine the analysis of variance and significant variations between means.

Using the COSTAT computer program, the multiple comparisons of means were carried out in accordance with Duncan's multiple test range **(Duncan, 1955)**.

3. Results and Discussion

3.1. Number of days required for first flowering

Data presented in Table (1) demonstrated that, the minimum number of days for first flowering (first emergence of flower-bud) was obtained with red light treatment (T2) only after 7-8 days from the red light treatment in the two experimental seasons, respectively as compared with control or other treatments.

Table (1). Effect of red light, some plant growth regulators and some nutrients on number of days to first flowering, fruit set and fruit physical properties of acid lime

Treatments	2021				
	No. of days to first flowering (a days)	**Fruit set (%)**	**Fruit yield kg/ tree**	**Average fruit weight (gm)**	**Fruit juice percent (%)**
T1	40 a	32.03 e	12.20 c	37.24 e	41.81 e
T2	7 d	77.01 a	19.33 b	60.22 a	55.53 a
T3	36 b	39.71 d	13.25 c	42.74 b	52.82 b
T4	11 c	54.16 c	23.00 a	40.78 c	51.32 c
T5	40 a	73.47 b	6.6 d	39.88 d	48.28 d
2022					
T1	41 a	33.90 e	13.56 c	34.68 c	46.03 d
T2	8 d	85.61 a	20.58 b	66.48 a	57.01 a
T3	32 b	44.18 d	14.12 c	44.46 b	52.54 b
T4	16 c	55.72 c	24.82 a	39.43 d	49.68 c
T5	41 a	68.80 b	7.33 d	45.69 b	50.18 c

According to Duncan's multiple range tests, there was no difference at $p<0.05$ between the means in every column that fallowed by the same letter's.

Treatments key:

T1: Control (Uniform fertilizer program).

T2: Red light (light intensity 20 μm/ m^2/ second for 4 continuous hours).

T3: Paclobutrazol 3.5 g/ tree + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.

T4: Cycocel 1000ppm+ salicylic acid 200 ppm.

T5: Flowering agent (1.5 % NAA+ 0.3% NAAM+ 0.3% Beta naphthyloxyacetic acid+ 97.9 % other additives) 50mg / 100 liter + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.

The number of days until the first flowering is a key parameter that determines whether a crop is late or early. It is impacted by various elements such as genetic, environmental, physiological, dietary, hormonal, and cultural **(Thirugnanavel *et al*., 2007)**. Also, in citrus, yield and fruit quality are strongly dependent on flowering intensity, hence in many circumstances, its regulation is very important to improve the crop **(Agustí *et al*., 2022)**.

Data in hand are in harmony with those mentioned by **Baguma *et al*. (2023)** who found that, red light photoperiod extension caused early blooming and increased flower formation and fruit set in Ugandan cassava genotypes grown in field circumstances, where cassava breeding is dependable, synchronous, and prolific.

In this respect, modulating the light spectrum, in particular, allows for the regulation of light transduction mechanisms and manipulation of certain plant traits like as flowering induction, elongation, branching, secondary metabolites, nutritional status, seedling development, and cell proliferation **(Xu, 2020)**. Moreover, lights, particularly red light, acts as crucial environmental cues, regulating plant development and physiology *via* photoreceptors **(Casson and Hetherington, 2014)**. Phytochromes, a type of light receptor in plants, come in two main forms: inactive red light- absorbing (pr) and active far red light-absorbing (pfr) Smith, 2000. Photoreceptors sense the light environment and hence aid plants in determining the time of critical developmental events like as flowering and seed germination **(Kami *et al*., 2010)**. The phytochrome photoreceptor lies at the heart of the precisely calibrated biochemical process that links red light to flowering induction. Red light activates phytochrome B (phyB), which is then transported to the nucleus. Inside the nucleus, the active phyB-pfr from controls a complex signaling network that includes the degradation of repressors (such as PIFs) and the stability of the master blooming transcription factor, CONSTANS (CO). The ensuing accumulation of CO protein causes the production of mobile signal flowering locus T (FT), which eventually initiates the developmental switch to flowering at the shoot apex. This route guarantees that plants flower only when the ambient light circumstances are ideal for reproductive success **(Izawa *et al*., 2002)**. It is probable that Phy B, red light photoreceptor, can behave antagonistically to control blooming in response to light in distinct tissues **(Blazquez *et al*., 2003)**.

3.2. Fruit set

The highest values of fruit set were obtained by T2 (red light) followed by T5 (flowering agent compound treatment) as compared with control or other treatments during the two experimental seasons (Table 1).

In this respect, genotypes that rarely flower were more responsive in forking and flowering time, as evidenced by fewer days to first branching, lower height and number of nodes at first branching. Red light exposure also increased the number of branching levels, proportion of pistillate flowers, and their relationship with fruit set **(Baguma *et al*., 2023)**. Fruit set is the process by which a bloom develops into a fruit. It determines the amount of fruits on the plant, and hence has a significant impact on agricultural yield. Low fruit set, caused by excessive flower and fruit abortion, and reduces production in many crops **(Chen *et al*., 2024)**.

Also, the increasing of fruit set percentage using red light treatment (Table 1) may be due to an increase in carbohydrates concentration as will be discussed later.

In this respect, the light spectrum has a significant influence on carbohydrate status **(Heo *et al*., 2006)**. A part from hormones, carbohydrates play an essential function in fruit set **(Chen *et al*., 2024)**. Moreover, experiments in controlled environments are commonly used to study fruit set and its underlying mechanisms, including genetic analysis, carbohydrate and hormone profiling **(Ezura *et al*., 2023)**.

For the role of flowering agent (T5), NAA administration resulted in increased fruit set due to the improved nutritional quality of shoots, which provided better opportunity to set a larger number of fruits **(Arunadevi *et al*., 2019)**. Auxin is hormone found naturally in plants. It regulates a range of physiological processes as well as plant expression and growth. NAA's impact on cell elongation causes enhanced cell enlargement, division, and differentiation, which affects the quantity of flowers, fruit set, fruit size and weight **(Roopa *et al*., 2023)**.

3.3. Yield

As regard to fruit yield, the data in Table (1) revealed that, in the two experimental seasons the highest values were obtained by T4 (cycocel 1000ppm+ salicylic acid 200 ppm) followed by T2 (red light treatment) as compared with control.

Similar results were obtained by **Mahalle *et al*. (2010)** who reported that, in Hasta Bahar acid lime flowering (September and October), two sprays of cycocel 1000 ppm at a one month intervals before the initiation of flowering, that is in August and September, produced the maximum yield in terms of number of fruits/ tree, weight of fruits/ tree and this treatment also improved the fruit quality in terms of fruit juice percent, TSS, acidity, ascorbic acid content, peel and pomace%.

In this respect, also the effect of T4 (cycocel 1000ppm+ salicylic acid 200 ppm) on yield may be due to the role of salicylic acid (SA) which is essential for the growth and development of plants **(Sharma *et al*., 2023)**. By increasing cell size and division and changing differentiation patterns, two intriguing stimulators that may enhance date growth are GA_3 and salicylic acid **(Prakash *et al*., 2022)**. As regard to the effect of T2 (red light), the ability to control the light-growing environment by selecting specific wavelengths allows for the manipulation of specific plant morphological traits that have significant productive benefits for the horticultural industry, such as early flowering, continuous production, predictable yield, and plant habitus (rooting and branching) **Paradiso *et al*. (2021)**.

On the other hand, despite the increase in fruit set in trees treated with flowering agent treatment (T5), a decrease in the yield of these treated trees was observed, and this may be due to a deficiency in both total carbohydrates and carbon concentrations as will be explained later, since each of them has an effect on flowering and fruit set, and therefore the fruit yield.

In this respect, carbohydrates are used to build and develop citrus trees' blossoms and fruit **(Monerri *et al*., 2011)**. Moreover, carbohydrate consumption has been frequently highlighted as a component that promotes blooming. In alternate bearing varieties, carbohydrates deplete in all tree organs after a year of heavy cropping, and no blooms are produced the following season **(Martínez - Alcántara *et al*., 2015)**. There is no evidence that the carbohydrate content of leaves, branches, and roots influences flowering, but there could be an indirect effect **(Agusti *et al*., 2022)**. Also, the carbon deficit, an early fruit drop factor, raised ABA and ethylene levels, causing abscission **(Gómez-Cadenas *et al*., 2000)**.

Also, the loss in fruit yield, despite the higher fruit set percentage owing to flowering agent treatment (T5), could be related to auxin's role in vegetative growth. Whereas, spraying auxins before flowering promotes vegetative growth in the plant, as the best time to spray NAA is before flowering and the stage of small fruitlets, as is known and previously proven from previous research.

In this respect, auxin is fascinating since it appears to control the majority of plant growth and developmental responses **(Weijers and Wanger, 2016)**. Auxin regulates cell division and expansion at the molecular level, influencing plant growth and development. Unlike auxin, which is typically regarded as a growth hormone. The many constraints that auxin imposes on cell division and development are critical to many aspects of these processes **(Roopa *et al*., 2023)**.

Yield is the result of the interaction of various elements, including biochemical, physiological characteristics, and yield parameters. The goal of all cultural activities is to modify them and increase the yield **(Thirugnanavel *et al*., 2007)**. Yield –attributing factors such as the number of fruits per tree and average fruit weight contribute to average yield **(Deshlehra *et al*., 2022)**.

3.4. Fruit quality

3.4.1. Fruit physical properties

Concerning average fruit weight and fruit juice percent data presented in Table (1) illustrated that, during both of the experimental seasons the highest values of average fruit weight and fruit juice percent tended to be recorded with red light treatment when compared to control.

In this respect, the photosynthetic process is greatly impacted by red light, which both increases the amount of chlorophyll and inhibits the mobilization of carbohydrates from source organs **(Dou *et al*., 2017)**. Fruit volume and fruit weight are directly influenced by fruit juice percent **(Deshlehra *et al*., 2022)**.

3.4.2. Fruit chemical properties

Data represented in Table (2) revealed that, the highest values of vitamin C were recorded by T4 (Cycocel 1000ppm+ salicylic acid 200 ppm) and T5 ((Flowering agent ;1.5 % NAA+ 0.3% NAAM+ 0.3% Beta naphthyloxyacetic acid+ 97.9 % other additives) 50mg / 100 liter + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%)) when compared with control or other treatments.

Table (2). Effect of red light, some plant growth regulators and some nutrients on acid lime fruit chemical properties

Treatments	Vitamin C (mg/ 100ml)	TSS (%)	Acidity (%)	TSS/ acid ratio
	2021			
T1	32.67 cd	7.00 a	6.95 b	1.010 a
T2	30.83 d	7.05 a	6.88 b	1.030 a
T3	34.34 bc	6.80 a	7.11 b	0.960 b
T4	39.70 a	6.50 b	7.83 a	0.830 c
T5	36.02 b	7.00 a	7.03 b	0.996 ab
	2022			
T1	37.53 c	7.15 a	7.61 b	0.940 b
T2	32.67 d	7.00 a	6.68 c	1.050 a
T3	41.38 ab	6.00 c	6.81 c	0.881 c
T4	40.20 b	6.75 b	7.93 a	0.851 c
T5	42.55 a	7.00 a	6.76 c	1.036 a

According to Duncan's multiple range tests, there was no difference at $p<0.05$ between the means in every column that fallowed by the same letter's.

Treatments key:

T1: Control (Uniform fertilizer program).

T2: Red light (light intensity 20 µm/ m^2/ second for 4 continuous hours).

T3: Paclobutrazol 3.5 g/ tree + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.

T4: Cycocel 1000ppm+ salicylic acid 200 ppm.

T5: Flowering agent (1.5 % NAA+ 0.3% NAAM+ 0.3% Beta naphthyloxyacetic acid+ 97.9 % other additives) 50mg / 100 liter + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.

In this respect, the rise in ascorbic acid content could be attributed to plant growth regulators breaking down organic acids into sugars during fruit ripening **(Arunadevi, 2019)**. The rise in ascorbic acid content following NAA application could be attributed to the continues production of glucose- 6-phosphate throughout the growth and development of fruits, which was previously regarded to be a precursor to vitamin C **(Pandey, 1999)**. Moreover, the increased ascorbic acid content of fruit was attributed to an increase in the synthesis of catalytic activity by enzymes and coenzymes, which are involved in ascorbic acid production. Also, zinc is required for chlorophyll formation, pollination, and fertilization **(Kaya *et al*., 2005)**.

Concerning to the TSS/ acid ratio, data in Table (2) demonstrated that, highest values were recorded by T2 (red light treatment) followed by T5 (flowering agent; 50mg / 100 liter + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%) as compared to control.

In this respect, the plants response to light signals plant productivity features allow for the deliberate selection and activation of certain light- sensing pathways, as well as the formation of unique light systems, to govern plant output, quality, and production timing **(Folta, and Carvalho, 2015)**.

Regarding to T5 effect on TSS/ acid ratio, due to an increase in the mobilization of carbohydrates from source to sink, potassium nitrate sprays raised the TSS **(Meena and Kanpure, 2022)**. Also, the improvement in fruit quality caused by zinc supplementation could be related to its effect on carbohydrate synthesis and translocation, as well as carbohydrate enzyme activity **(Ram and Bose, 2000)**.

The maximum total soluble solids, acidity, and ascorbic acid content are critical characteristics that determine the quality of acid lime. The acidity of acid lime is mostly owing to the presence of citric acid lime, one of the most abundant plant acids. The ascorbic acid level is crucial since acid lime fruits are high in vitamin C **(Prabhu *et al*., 2017)**.

3.5. Leaf chemical composition

The highest values of total carbohydrates, organic carbon and C/ N ratio were obtained by red light treatment (T2) followed by cycocel (T4) as compared with control with some exceptions at the two experimental seasons. On the other hand, the data revealed that no detected trend was obtained in nitrogen concentration by all treatment (Table 3).

In this respect, light plays a vital function in both plant development and photosynthetic processes **(Yamori *et al*., 2016)**. Additionally, light serves as the energy source for the photosynthetic process, which transforms carbon dioxide into carbohydrates. Conversely, light functions as a signal, and plants may synchronise and adjust their growth to the constantly shifting light environment thanks to its dynamic perceptions and processing **(Trivellini *et al*., 2023)**. Phytochromes absorb red light, which is essential for the development of photosynthetic organs **(Urbonaviciute *et al*., 2007)**.

Table (3). Effect of red light, some plant growth regulators and some nutrients on carbohydrates, carbon, nitrogen concentrations and C/ N ratio

Treatments	2021			
	Carbohydrates %	**C %**	**N %**	**C/N ratio**
T1	1.306 e	28.55 d	1.76 b	16.22 d
T2	2.595 a	81.73 a	1.69 c	48.36 a
T3	2.192 c	69.37 b	1.76 b	39.42 b
T4	2.277 b	70.77 b	1.91 a	37.05 b
T5	1.522 d	50.21 c	1.80 b	27.89 c
2022				
T1	1.391 e	29.87 d	1.72 a	17.37 e
T2	2.797 a	76.97 a	1.69 a	45.54 a
T3	2.243 c	64.60 b	1.76 a	36.71 c
T4	2.385 b	76.76 a	1.81 a	42.41 b
T5	1.611 d	50.78 c	1.76 a	28.85 d

According to Duncan's multiple range tests, there was no difference at $p<0.05$ between the means in every column that fallowed by the same letter's.

Treatments key:

T1: Control (Uniform fertilizer program).

T2: Red light (light intensity 20 µm/ m^2/ second for 4 continuous hours).

T3: Paclobutrazol 3.5 g/ tree + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.

T4: Cycocel 1000ppm+ salicylic acid 200 ppm.

T5: Flowering agent (1.5 % NAA+ 0.3% NAAM+ 0.3% Beta naphthyloxyacetic acid+ 97.9 % other additives) 50mg / 100 liter + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.

3.6. Feasibility Study

In order to select the treatment with the highest profit, a feasibility study was carried out to ascertain the economic return for the treatments under consideration. Data illustrated in Table (4) showed that, T4 (cycocel+ salicylic acid) followed by T2 (red light) treatments achieved the highest profit. Also, red light treatment is more sustainable compared with other treatments whereas, the spotlight used for supplemental lighting has a light intensity of 12000 lux, covering an area of 1400/ m^2 at a minimum intensity of 20 µm/ m^2/ second. Four spotlights can be used to cover an area of one feddan, and these spotlights can be used for several years. Moreover, these treatment was superior in terms of early flowering, as flowering began one week after treatment as well as the highest values of fruit weight and fruit juice percent were obtained by red light treatment.

Table (4). Feasibility study for the applied treatments on yield of acid lime

Treat.	Yield/ fed. (Ton)			Yield return/fed. (Egyptian pound)			Treatment return/fed. (Egyptian pound)			Treatment Cost (Egypt pound)	Treatment profit (Egyptian pound)		
	2021	2022	Ave.	2021	2022	Ave.	2021	2022	Ave.		2021	2022	Ave.
T1	1.22	1.36	1.29	73200	81600	77400	0	0	0	0	0	0	0
T2	1.93	2.06	2.00	115800	123600	119700	42600	42000	42300	8	42592	41992	42292
T3	1.33	1.41	1.37	79800	84600	82200	6600	3000	4800	2250	4350	750	2550
T4	2.30	2.48	2.39	138000	148800	143400	64800	66000	65400	1428	63372	64570	63972
T5	0.66	0.73	0.70	39600	42000	40800	-33600	-40800	-	800	-	-	-

Treatments key:
T1: Control (Uniform fertilizer program).
T2: Red light (light intensity 20 µm/ m^2/ second for 4 continuous hours).
T3: Paclobutrazol 3.5 g/ tree + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.
T4: Cycocel 1000ppm+ salicylic acid 200 ppm.
T5: Flowering agent (1.5 % NAA+ 0.3% NAAM+ 0.3% Beta naphthyloxyacetic acid + 97.9 % other additives) 50mg / 100 liter + potassium nitrate 0.2%+ Zn 0.3 %+ B 0.1%.

*Lime acid fruit ton: 60000 Egyptian pound
** Costs associated with treatment included labour, material and spraying
Paclobturazol: 1750 Egyptian pounds+ (KNO_3+micronutrients: 200 Egyptian pounds).
Cycocel: 1080 Egyptian pounds + salicylic acid: 48 Egyptian pounds.
Flowering agent: 300 Egyptian pounds + (KNO_3 +micronutrients: 200 Egyptian pounds).

4. Recommendation

It could be concluded that, red light treatment was superior in terms of bringing the plants to flower a week after the treatment. Although, this treatment ranked second in terms of fruit yield and highest profit after the cycocel treatment as the yield values were 19.33, 20.58 kg/ tree in the first and second season, respectively, it is more sustainable as well as safer as compared with other treatments especially cycocel and paclobutrazol which are subject to restrictions in many countries due to their toxic effects. Thus we can recommend using red light treatment, which is less expensive, more sustainable, and safer for public, human health as well as has long-term economic benefits compared with other treatments. We also recommend adopting this treatment because of its other advantages, as it allows the farmer stakeholders to determine the most suitable time to offer the crop to the market, in order to determine the start date of flowering. It is also possible to extend the crop existing period by dividing the land into sections and applying this treatment gradually to the different sections. This treatment can also be carried out on young trees, since the preventing water irrigation process is not carried out with this treatment (without holding water irrigation), which ultimately leads to an increase in the farmer's economic return.

References

A.O.A.C. (1995). Association of Official Analytical Chemists. 15 ED. Washington DC, USA pp: 490-510.،

Agustí, M., Reig, C., Martínez-Fuentes, A. and Mesejo, C. (2022). Advances in citrus flowering: A Review. Crop and product Physiology. Front. Plant Sci., 13:868831.do10.3389/fpls.2022.868831.

Arunadevi, A., Ranjith, S.K.C., Rajangam, J. and Venkatesan, K. (2019). Effect of plant growth regulators on growth, yield and quality of acid lime (*Citrus aurantifolia* Swingle.) var. PKM1. Journal of Pharmacognosy and phytochemistry, 8(3): 3438-3441.

Baguma, J. K., Mukasa, S. B., Nuwamanya, E., Alicai, T., Omongo, C., Hyde, P.T., Setter, T. L., Ochwo-Ssemakula, M., Esuma, W., Kanaabi, M., Iragaba, P., Baguma, Y. and Kawuki, R. S. (2023). Flowering and fruit-set in cassava under extended red-light photoperiod supplemented with plant-growth regulators and pruning. BMC Plant Biology, 23:335, https:// doi. org/ 10. 1186/s 12870-023-04349-x.

Blazquez, M.A., Hoon, J.A. and Weigel, D. (2003). A thermosensory pathway controlling flowering time in Arabidopsis thaliana. Nature genetics33, 168-171.

Casson, S.A. and Hetherington, A.M. (2014). Phytochrome B is required for light-mediated systemic control of stomatal development. Current Biology, 24(11):1216-1221. https://doi.org/10.1016/j.cub.2014.03.074.

Chen, S., Dalla, V.V., Kohlen, W., Kusuma, P., Offringa, R., Leo F., Marcelis, M. and Heuvelink, E.P. (2024). High ratio of blue: red light reduces fruit set in sweet pepper, which is associated with low starch content and hormonal changes. Environmental and Experimental Botany, 225,105850, 1-11.

Deshlehra, R., Pyasi, R. and Singh, K.V. (2022). Impact of growth regulators and micronutrients on growth, yield and quality of acid lime (*Citrus aurantifolia* Swingle) under HDP system. The Pharma Innovation Journal, 11(2): 362-366.

Deshmukh, H.K., Paithankar D.H., Nimbolkar P.K., Dewangan R.K and Awachare C. (2016). Effect of plant growth regulators and micronutrients on reproductive attributes of acid lime (*Citrus aurantifolia* Swingle) in hasta bahar cropping season. J. Hort. Sci.,11(1):63-66.

Dou, H., Niu, G., Gu, M. and Masabni, J. (2017). Effects of light quality on growth and phytonutrient accumulation of herbs under controlled environments. Horticulturae, 3, 36.

Duncan, D.B. (1955). Multiple range and multiple F Tests Biometrics, 11: 1-24.

European Food Safety Authority (EFSA) (2010). Conclusion on the peer review of the pesticide risk assessment of the active substance paclobutrazol. EFSA Journal, 8(11)1876.

European Food Safety Authority (EFSA) (2016). Review of the existing maximum residue levels for chlormequat according to Article 12 of Regulation (EC). EFSA Journal, No 396/2005.

European Food Safety Authority (EFSA) (2018). Peer review of the pesticide risk assessment of the active substance 1-methylcyclopropene. EFSA Journal.

Ezura, K., Nomura, Y. and Ariizumi, T. (2023). Molecular, hormonal, and metabolic mechanisms of fruit set, the ovary-to- fruit transition, in horticultural crops. J. Exp. Bot., 74(20), 6254-6268.

Folta, K.M. and Carvalho, S.D. (2015). Photoreceptors and control of horticultural plant traits. Hort. Science, 50, 1274–1280.

Giliberto, L., Perrotta, G., Pallara, P., Weller, J.L., Fraser, P.D., Bramley, P.M., Fiore, A., Tavazza, M. and Giuliano, G. (2005). Manipulation of the Blue Light Photoreceptor Cryptochrome 2 in Tomato Affects Vegetative Development, Flowering Time, and Fruit Antioxidant Content. Plant Physiol., 137, 199–208.

Gollagi S.G, Jasmitha, B.G. and Sreekanth, H.S. (2019). A review on: Paclobutrazol a boon for fruit crop production. J. Pharmacog Phytochem., 8(3): 2686-2691.

Gómez-Cadenas, A., Mahouachi, J., Tadeo, F. R. and Primo-Millo, E. (2000). Hormonal regulation of fruitlet abscission induced by carbohydrate shortage in citrus. Planta, 210:636-643.

Heo, J.W., Lee, C.W. and Paek, K.Y. (2006). Influence of mixed led radiation on the growth of annual plants. J. Plant Bio., 49, 286-290.

Izawa, T., Oikawa, T., Sugiyama, N., Tanisaka, T., Yano, M. and Shimamoto, K. (2002). Phytochrome mediates the external light signal to repress FT orthologs in photoperiodic flowering of rice. Genes and Development 16:2006–2020 © 2002.

Jackson, M.L. (1973). Soil chemical Analysis. Prentic Hall of India pvt. Ltd., New Delhi. 498 p.

Kami, C., Lorrain, S., Hornitschek, P. and Fankhauser, C. (2010). Light-regulated plant growth and development. Current Topics in Developmental Biology 91:29-66. https://doi.org/10.1016/S0070-2153 (10)91002-8.

Kasajima, S., Inoue, N., Mahmud, R. and Kato, M. (2008). Developmental response of wheat cv. Norin 61to Fluence rate of green light. Plant Prod. Sci., 11(1):76-81.

Kaya, M., Atak, K., Mahmood, C., Ciftc, Y. and Ozcan, S. (2005). Effects of pre-sowing seed treatment with Zn and foliar spray of humic acids on yield of common bean (*Phaseolus vulgaris* L.). Int. J Agric. Bio., 10: 56-65.

Lal, M., Sood, Y., Kaur, A. and Kumar, A. (2023). Effectiveness of Paclobutrazol to Augment Fruits Production – A Review Environment and Ecology, 41 (1): 13-22, January–March 2023 ISSN 0970-0420.

Lal, N., Sahu, N., Marboh, E.S. Gupta, A.K. and Patel, R.K. (2017). A Review on Crop Regulation in Fruit Crops. Int. J. Curr. Microbiol. App. Sci., 6(7): 4032-4043.

Li, L., Yan, W., Yao, H., Li, H., Guo, X., Cheng, D., Sun, J. and Chen, J. (2023). Influences of two plant growth regulators on the fruit quality of the 'Crimson Seedless' grapes. J. Plant Growth Regul., 42:771–779. https://doi.org/10.1007/s00344-022-10585-6.

Mahalle, S.S., Ingle, H.V. and Sable, P.B. (2010). Influence of plant growth regulators and chemicals on yield and quality of Hasta bahar in Acid lime. Green Farm, 1: 285-87.

Mahesha, N. and Singh, S.R. (2018). Effects of GA_3 and shoot pruning on flowering and yield in Assam lemon (*Citrus Limon* Burm. F. Bangladesh J. Bot., 47(3): 509-514.

Martínez-Alcántara, B., Iglesias, D. J., Reig, C., Mesejo, C., Agustí, M., and Primo-Millo, E. (2015). Carbon utilization by fruit limits shoot growth in alternate-bearing citrus trees. J. Plant Phys., 176, 108–117. doi: 10.1016/j. jplph.2014.12.001.

Meena, N. and R.N. Kanpure, (2022). Effect of Foliar Spray of Nutrients and Plant Growth Regulator on Quality and Yield of Acid lime (*Citrus aurantifolia* Swingle) Environment and Ecology, 40 (3): 1087—1091, July—September 2022 ISSN 0970-0420.

Miller, G.L. (1959). Analytical Chemistry, 31: 426-428. 19.

Monerri, C., Fortunato-Almeida, A., Molina, R.V., Nebauer, S.G., Garcia-Luis, A. and Guardiola, J.L. (2011). Relation of carbohydrate reserves with the forthcoming crop, flower formation and photosynthetic rate, in the alternate bearing 'Salustiana' sweet orange (*Citrus sinensis* L.). Scientia Horticulture, 129(1): 71-78.

Pandey, V. (1999). Effect of 'NAA' and 'GA_3', spray on fruit retention, growth, yield and quality of Ber (*Zizyphus mauritiana* Lamk.) cv. 'Banarasi karaka'. Orissa Journal of Horticulture, 27(1):69-73.

Paradiso, R. and Proietti, S. (2021). Light-quality manipulation to control plant growth and photomorphogenesis in greenhouse horticulture: The state of the art and the opportunities of modern LED systems. J. Plant Growth Regul., 41, 742–780.

Plummer, D.T. (1971). An introduction to practical biochem. Published by Mc Graw Hill Book Company (U.K.) Limited.

Prabhu, M., Parthiban, S., Ramesh Kumar, A., Usha Rani, B. and Vijayasamundeeswari, A. (2017). Regulation of flowering in acid lime (*Citrus aurantifolia* Swingle). Indian J. Agric. Res., 51 (4): 384-387.

Prakash, R., Jokhan A.D and Singh, R. (2022). Effects of foliar application of gibberellic acid, boric acid and sucrose on noni (*M. citrifolia* L.) fruit growth and quality. Sci. Hortic., 301:111098. https://doi.org/10.1016/j.scienta.2022.111098.

Ram, S.A. and Bose, T.K. (2000). Effect of foliar application of magnesium and micronutrients on growth, yield and fruit quality of mandarin orange (*Citrus reticulata* Blanco). Ind. J. Horti., 57(3): 215-220.

Roopa, S., Mishra, T., Bhattacharya, S., Bhadra, A., Raj, S.S., Shrivastava, R. and Patil, S.J. (2023). Role of IAA in plant growth, development, and interaction with other phytohormones. Eur. Chem. Bull., 12(SpecialIsuue5), 5293-5297.

Sharma A, Kohli SK, Khanna K, Ramakrishnan M, Kumar V, Bhardwaj R, Brestic M, Skalicky M, Landi M, Zheng B. (2023). Salicylic acid: a phenolic molecule with multiple roles in salt– stressed plants. J Plant Growth Regul. https://doi.org/10.1007/ s00344-022-10902-z.

Smith, H. (2000). Phytochromes and light signal perception by plants - an emerging synthesis. Nature, 407, 585-591.

Snedecor, G.W. and Cochran, W.G. (1980). Statistical Methods, 6 Ed. Iowa State Univ., Amess. Iowa.

Szopa, A., Starzec, A. and Ekiert, H. (2018). The impact of monochromatic lights in the production of phenolic acids and flavonoids in shoot cultures of *Aronia melanocarpa*, *Aronia arbutifolia* and *Aronia × prunifolia*. Journal of Photochemistry and Photobiology Biology, 179.

Talaat, N.B. (2023). Role of phytohormones in regulating abiotic stresses in wheat. In: Khan MK, Pandey A, Hamurcu M, Gupta OP, Gezgin S (eds) Abiotic stresses in wheat. Academic Press, pp 111–130. https://doi.org/10.1016/B978-0-323-95368-9.00019-9.

Thirugnanavel, A., Amutha, R., Baby Rani, W., Indira, K, Mareeswari, P., Muthulaksmi, S. and Parthiban, S. (2007). Studies on regulation of flowering in acid lime (*Citrus aurantifolia* Swingle). Research Journal of Agriculture and Biological Sciences, 3(4): 239-241.

Tripathy, M.K. and Roux, S. J. (2023). Role of calcium in regulating key steps in phytochrome-induced signaling pathways. Physiol. Mol. Biol. Plants, 27 (12): 1875-1879. doi: 10.1007/s12298-023-01403-8.

Trivellini, A., Toscano, S., Romano, D. and Ferrante, A. (2023). The role of blue and red light in the orchestration of secondary metabolites, nutrient transport and plant quality. Plants, 12(10).

Urbonaviciute, A., Pinho, P., Samuolien˙e, G., Duchovskis, P., Vitta, P., Stonkus, A., Tamulaitis, G., Žukauskas, A. and Halonen, L. (2007). Effect of short-wavelength light on lettuce growth and nutritional quality. Sodinink Daržinink, 26, 157–165.

Weijers, D. and Wanger, D. (2016). Transcriptional responses to the auxin hormone. Annual Review of Plant Biology, 67, 539-574.

Xu, D. (2020). COP1 and BBXs-HY5-mediated light signal transduction in plants. New Phytol., 228, 1748–1753.

Xu, J., Guo, Z., Jiang, X., Ahammed, G.J. and Zhou, Y. (2021). Light regulation of horticultural crop nutrient uptake and utilization. Hortic. Plant J., 7, 367–379.

Yamori, W., Makino, A. and Shikanai, T. (2016). A physiological functions of cyclic electron transport around photosystem I in sustaining photosynthesis and plant growth. Annu. Rev. Plant Biol., 67, 81-106. https:// doi.org/10.1038/srep20147.