EFFECT OF FULL SPECTRUM SUPPLEMENTARY LIGHT ON GROWTH, YIELD AND QUALITY ATTRIBUTES OF STRAWBERRY (*FRAGARIA* X *ANANASSA* DUCH.) UNDER VERTICAL FARMING SYSTEM

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Horticulture (Fruit Science)

By

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2024

DECLARATION

I, hereby declared that the presented work in the thesis entitled **"Effect of full spectrum supplementary light on growth yield and quality attributes of strawberry (*Fragaria* x *ananassa* Duch.) under vertical farming system"** in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of **Dr. Gurpreet Singh**, working as **Professor**, in the **Department of Horticulture** of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE-I

This is to certify that the work reported in the Ph. D. thesis entitled **"Effect of full spectrum supplementary light on growth yield and quality attributes of strawberry (*Fragaria* x *ananassa* Duch.) under vertical farming system"** submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the **Department of Horticulture**, is a research work carried out by **PALLVI VERMA**, **12014448**, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

(Signature of Supervisor)

Name of supervisor: Dr. Gurpreet Singh

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CERTIFICATE-II

This is to certify that the work reported in the Ph. D. thesis entitled **“Effect of full spectrum supplementary light on growth yield and quality attributes of strawberry (*Fragaria* x *ananassa* Duch.) under vertical farming system”** submitted by **Pallvi Verma (Registration No. 12014448)** to Lovely Professional University, Phagwara in the partial fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Department of **Horticulture (Fruit Science)** has been approved by Advisory Committee after oral examination of the student in collaboration with an external examiner.

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Place: *LPU, Phagwara*

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LIST OF ABBREVIATIONS

Abbreviated Form	Full Form
ha	Hectare
ha^{-1}	Per hectare
MT	Million tonnes
et al.	et alii (and order)
ft.	Foot
mm	Milli meter
m	Meter
%	Per cent
g	Gram
cm	Centi meter
cm^{2}	Centi meter square
mg	Mili gram
mg/g	Milli gram per gram
cv.	Cultivar
FYM	Farm Yard Manure
N: P: K	Nitrogen: Phosphorus: Potassium
ml	Milli liter
/	Per
^{0}C	Degree celsius
^{0}B	Degree Brix
hrs	Hours
Min.	Minute
nm	Nano Meter
A	Absorbance at specific wavelength
V	Volume
W	Weight
sq. cm	Square centimeter
DAP	Days after planting
LAI	Leaf area index
TSS	Total Soluble Solids
E-W	East-West
N-S	North-South
ISR	Induced Systemic Resistance
FUE	Fertiliser Use Efficiency
c.f.u.	Colony Forming Unit(s)

SCHOOL OF AGRICULTURE
LOVELY PROFESSIONAL UNIVERSITY, PHAGWARA

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Name of the Student : Pallvi Verma
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Abstract

The use of supplemental lighting in horticultural crop production has been the subject of extensive research. Light is one of the most important environmental factors influencing herb quality including phytonutrient content, in addition to effects on growth and development. The experiment was carried out in the month of December at Agricultural Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab during 2021-2023. For maximum use of the growing area, four vertical structures were made with four different levels to study the effect of full spectrum light on strawberry cv. winter dawn. Two of the structures were placed under indoor conditions and the other two in outdoor conditions. Under indoor conditions, one structure was provided with full spectrum light for 0,4,6 and 8 hours while the other one was provided with full spectrum light for 0, 6 and 8 hours with natural light. Similarly, the structures in outdoor conditions were placed under natural light while the other one was provided for 2, 4 and 6 hours. The physiological and biochemical attributes of strawberry cv. winter dawn were measured. Under indoor conditions, the treatment combination of natural light + full spectrum light + third level for 6 hours (T5) showed the best results for physiological and biochemical parameters. Also, maximum average yield and berry weight were observed in treatment combination T5. However, the maximum physiochemical properties in Winter dawn under outdoor conditions were observed in T5 and T1 treatment which had combination of natural light + full spectrum light + third level + 2 hours for T5 and natural light + fourth level for T1 under full spectrum light. The study concludes that implementing full-spectrum light in combination with natural light for six hours is the best method for growing strawberries inside a vertical farming system. The UN's Sustainable Development Goals are supported when full-spectrum light and natural light are combined for two hours in outdoor environments to produce greater growth and quality. By encouraging sustainable and creative farming techniques, it specifically targets Goal 2: Zero Hunger, Goal 9: Industry, Innovation and Infrastructure and Goal 13: Climate Action.

Keywords: Vertical farming, winter dawn, full-spectrum light, natural light, indoor conditions, outdoor conditions, sustainable development goals

CHAPTER-I

INTRODUCTION

Strawberry is a significant cash crop grown all over the world and is popular in various forms, including fresh fruits extracts and so on. The strawberry, also known as *Fragaria ananassa* Duch. is an octaploid plant that belongs to the Rosaceae family. It is a soft fruit with greater adaptability that is tasty and nutritious. In addition to having dessert-like qualities, it is a rich source of antioxidants that benefit human health. Since strawberries have been grown for a long time, there have been many advancements in strawberry crop production in terms of nutritional needs, cultivation methods and other areas as a result of our growing understanding of plant physiology (Bal, 2014; Chattopadhyay, 2013).

Strawberry is a perennial herb that spreads via runners and stolons. The strawberry fruit leaves have three leaflets that emerge from the plant's crown. The strawberry plant has thick, toothed leaves that are blunt and white with small clusters of flowers. Small and ranging in colour from light to deep red, soft flesh and a pleasant aroma. In the case of strawberries, both hermaphrodite and unisexual plants are produced. The strawberry is a group of small seeds, or achenes, that are present in great numbers. The thalamus is the fruit's edible portion.

When the species traveled from eastern North America to England in the 1600s, the modern strawberry underwent its first evolution. When a French explorer brought one species to Chile and crossed it with a female plant, it gave rise to the new strawberry that we have today. These new species then spread throughout the mainland and beyond. The chromosomal number is a crucial factor in distinguishing and characterizing the various strawberry species. All strawberry plants have seven common types of chromosomal sets. For the purpose of understanding and characterizing a species, it is both desirable and necessary to determine its quantity and distribution. Some strawberry species are diploid, meaning they have two arrangements of seven chromosomes or a total of 14 chromosomes. Others include decaploid, which has 10 sets and in total, more than 70 species, octaploid, which has 8 sets and 56 total, tetraploid, which has 4 sets and 28 total and hexaploid, which has 6 sets and 42 total.

The NBPGR (National Bureau of Plant Genetic Resources), Regional Horticulture Research Station in Shimla, were responsible for introducing strawberries to India. Early efforts to commercialize strawberry farming in H.P. and U.P., however, were hampered by the introduced cultivars' poor adaptability, low returns per unit area and lack of technical knowledge about strawberry cultivation. It is currently being developed in Shimla, Bilaspur, Solan, Kullu, Shimla, Bilaspur, Kangra and Palampur of Himachal Pradesh; Karnal, Gurgaon & Hissar of Haryana; Dehradun of Uttaranchal; Mahabaleshwar and Pune of Maharastra Ghaziabad, Saharanpur of Uttar Pradesh; Coorg and Bangalore of Karnatak; Jalandhar, Ludhiana and Patiala of Punjab; Ooty and Kodaikanal of Tamil Nadu on small scales.

India's states of Maharashtra, WB, HP, Uttrakhand, UP, Delhi, Punjab and Rajasthan are among those where strawberries are grown (Bal, 2014). Although strawberries are grown commercially in these states, India has not yet found them to be a fully viable crop. According to estimates, India will produce 11000 MT of strawberries from a 3,000 ha area in 2021-22 (Agriculture Statistics at Glance, 2022). India exports strawberries to a number of nations, including Bangladesh, Jordan, Austria and Germany.

Nowadays, strawberry cultivation uses a modern method or system known as hydroponics, in which plants are grown in soilless media or fed with water and nutrients. Either the system circulates or it doesn't. To cultivate and harvest strawberries at a much better height, they can be raised off the ground. Along with fruit quality comes an increase in yield. This system improves the availability of water to roots in hot conditions, reducing water stress (Preethi *et al.*, 2012).

Through a process known as photosynthesis, plants use light to produce food. Plants use the green pigment chlorophyll during photosynthesis to aid in the transformation of carbon dioxide, water and light into carbohydrates and oxygen. By doing this, they produce the resources they require for growth. Colors in the visible spectrum of light come in a wide variety. These hues can be seen in a rainbow. Different kinds and hues of light are used by plants in various ways. Blue light is used by plants to help their leaves grow. Red light aids in flowering when combined with blue light. Household lights that we perceive as warm emit a lot of red light. For plants, the colour green is not particularly beneficial. The green surfaces of the plant reflect it. Since indirect, weak sunlight makes up the majority of the sunlight a plant receives indoors, a bulb may occasionally be preferable to sunlight. Artificial full spectrum light provides the equal amount of light provided by the sun. When plants are grown indoors, they often don't receive much direct or strong sunlight as they would get outdoors. In these cases, using artificial lighting like grow lights may actually be better for the plants than relying solely on the limited indoor sunlight.

A farming in which crops are grown on vertical surfaces (building upwards) rather than conventional farming method is known as vertical farming (Benke and Tomkins, 2017). Farmers can use the small as well as waste space for farming. Small farmers grow more food by stacking crops in vertical layers. The term vertical farming was firstly used by researcher Gilbert Ellis Bailey. He explained it in different manner and suggested that for penetrating into the depth of roots farmers uses explosives. Vertical farming is defined into variety of ways e.g. type of building, its size or layout , density, degree of control and location (Gerreway *et al.*, 2022).

The goal of vertical farming today is to use every square inch of land area to complete food requirement of world hungry people whether in a city or a village (Benke and Tomkins, 2017). The framework of vertical farming has completely changed over the years. Today, it is a well-liked farming technique used all over the world. India is also seeing a rise in vertical farming. Due to the high net returns, vertical farming is attracting a lot of business interest. Vertical farming can be done on rooftops, balconies, buildings and warehouses (Sonawane, 2018).

By 2050, the population of world is expected to increase by 2 billion approximately, creating a bigger problem than simply feeding more people with the available land resources. Using a vertical farming system (Naskoori *et al.*, 2021; Avgoustaki and Xydis 2020; Beacham *et al.*, 2019; Sarkar and Majumder, 2015). We are currently experiencing a food supply shortage along the rise in market prices of food, which affects the poor people (Besthorn, 2013).

According to Butturini and Marcelis (2020), vertical gardening is the practice of growing plants on layers that are either vertically inclined or vertically stacked. This system aids in the production of foods that are stacked vertically. When this farming technique is applied, more crops can be grown in the same field (Michael *et al.*, 2021). In the United States and Canada, leafy or micro greens (58%) are the most planted crop in the world, followed by tomatoes, flowers and microgreens (Wong *et al.*, 2020).

With the use of vertical farming, three to four times the cultivation land increased and a lot of healthy, best quality fresh food can be produced all year. (Mustafa and Rahman 2021; Sarkar and Majumder 2015). The availability of vital resources like water, nutrients and light affects the cultivation distance, which affects plant growth and yield (Mustafa and Rahman, 2021).

The current rapid expansion of vertical farming initiatives is being driven by the increasing customer demand for sustainably grown fresh food, healthy and local food as well as the expansion of reasonably priced light-emitting diode lighting technologies (Gerreway *et al.*, 2022). Nearly half of the chronically hungry people of world live in China and India. As the world's population increases, this already dire situation will get even worse, necessitating new methods of food production in the ensuing decades (Banerjee and Adenaeuer, 2014). Vertical farming, also known as sky farming, is an intriguing technological idea for the future of urban agriculture in the US (Mok *et al.*, 2014).

A brewer bowl of symbiotic and worsening issues has been produced by environmental warming, climate change, the intersection of economic and environmental degradation, catastrophic natural disasters, widespread human migration and the end of oil-based infrastructures, to name a few. These issues have had a significant impact on societal stability as well as the Earth's ability to deliver ecology. The discussion will cover the new environmental difficulties social science has been facing as well as the early attempts to draw attention to food safety concerns. In addition, it will look at the background of food scarcity, the connections between rationing, injustice, uncertainty and deprivation, as well as the potentially disastrous effects on vulnerable groups in a world growing more urbanized (Saxena, 2021).

Many start-ups with a track record in the greenhouse industry as well as unheard-of businesses in horticulture are now moving into the vertical farming sector. Additionally, as vertical farming becomes more popular, research into controlled environments has increased, which benefits the horticulture sector (Van Gerreway *et al.*, 2021; Sullivan *et al.*, 2020).

This research looks at vertical farming as a sustainable urban agriculture project and suggests that it could be a useful solution to the ongoing problems with urban food security. Furthermore, it makes the case that social work is an invaluable collaborator in the development of sustainable agriculture projects in urban environments because of its special abilities and core values, which include social justice and human rights (Saxena, 2021). These principles include human rights and social justice, as well as the ability to push for legislation and involve the community.

India has its own vertical farming units. In India, vertical farming research is conducted by both institutions of government and non-government that are the ICAR, New Delhi and the VFA. Scientists at the ICAR are finding a way to grow crops in soilless media such as cocopeat, mosses, peat and many other media or without the use of chemicals. Vertical farming units are established in different metro cities. Additionally, tomatoes are grown successfully in vertical farming systems at Bidhan Chandra Krishi Viswavidyalaya University researchers.

Through the stimulation of secondary metabolism, light intensity is known to positively affect the levels of vitamin C and other phytochemicals (Lee and Kader, 2000; Verkerke *et al.*, 2015). Our team's previous work involved using LED lighting to boost tomato vitamin C levels by 50%. (Labrie and Verkerke, 2014). Because LED lighting uses little energy and generates little heat, it is a beneficial lighting technique. This allows for effective localized illumination without running the risk of heating up crops as might happen with high-pressure sodium lamps.

About ten thousand years ago, the agriculture industry began to develop and quickly spread to other cultures. Agricultural practices have always involved open-field farming, with an emphasis only on cultivation, irrigation, natural fertilization and harvesting for food storage or sale. These fundamental patterns have been followed throughout history. However, additional levels of control were added to agricultural practices with the introduction of mechanization, sophisticated irrigation systems, contemporary fertilizers and pesticides, which ultimately resulted in indoor farming techniques (Despommier, 2013).

By utilizing the advantages of both farming methods and the controlled environment of a building, indoor farming seeks to increase agricultural output (Eigenbrod & Gruda, 2015; Specht *et al.,* 2014). The final frontier has been reached as technological and scientific advancement has continued. This relates to the development of vertical farming through stringent lighting and climate controls. The main determinants of plant growth are controlled and optimized by controlling and balancing these variables, including humidity, temperature, lighting, water, carbon dioxide concentration and nutrients (Despommier, 2013; Eigenbrod & Gruda, 2015).

According to Avercheva et al. (2009), light controls photomorphogenesis and photosynthesis, two processes that are essential to a plant's life cycle. Recent studies have demonstrated that adjusting light quantity, quality and photoperiod can impact growth and developmental stages, with a focus on Arabidopsis thaliana (Folta *et al.*, 2005). Basic research on plants with varying light spectrums has revealed that certain light wavelengths affect various aspects of plant physiology, such as germination, stem elongation, biomass accumulation and flowering transition (Parks *et al.,* 2001; Valverde *et al.,* 2004).

LED lights are becoming more and more common as artificial light sources in modern environments because of their many benefits, which include the ability to control spectral composition, lightweight design, long lifespan, low energy consumption, specific wavelength emission and relatively low heat emission. Because they enable precise wavelength adjustment to match plant photoreceptors, these solid-state light sources are especially well-suited for lighting plants. This improves production efficiency and influences plant morphology and metabolism (Bourget, 2008; Massa *et al.*, 2008; Morrow, 2008). The significance of the red and blue spectrum ranges has also been highlighted by earlier studies (Cosgrove 1981; Kasajima *et al.*, 2008).

An efficient lighting solution for growing a variety of plant species has been shown to be the combination of red and blue LED lights (Yorio *et al.*, 2001; Lian et al. 2002; Nhut *et al.*, 2003; Dougher and Bugbee, 2004; Lee *et al.*, 2007). Strawberries (Fragaria X ananassa Duch.) are grown more widely than all other berry crops combined because of their delicious flavor, unique aroma and deep red color (Hanyu and Shoji, 2002; Shin *et al.*, 2008; Stewart, 2011). According to Tulipani et al. (2008), they are abundant in bioactive phenolic compounds, such as hydroxycinnamic acids, ellagic acids, xavan-3-ols, xavonols, anthocyanins, flavonoids and phenolic acids.

Antioxidant-generated radicals have been shown to be remarkably scavenged by strawberries, preventing the oxidation of low-density lipoproteins in humans (Heinonen *et al.*, 1998). Their anti-oxidant qualities might help ward off heart disease, cancer and other chronic ailments (Hannum, 2004). There is potential for this new fruit crop to be a lucrative cash crop. While there is enough light available for strawberry farming throughout the winter, adding more LED light spectra could increase yield. In light of this, the current study sought to assess the effects of adding LED light on strawberry growth and yield.

Research Gap

In studying how full-spectrum light affects the growth, yield and quality of strawberries in vertical farming, we have found some gaps in existing research. Firstly, there is not enough detailed research on how full-spectrum light specifically influences strawberries in vertical farming. We also need more insights into how different types of light impact the various growth stages of strawberry. It is decisive to investigate the best light intensity, duration and composition for vertical farming. Additionally, not much attention has been given to be long-term effects of full spectrum light on the nutritional value and taste of strawberries. Filling in these gaps will help us better understand how light interacts with strawberries in vertical farming, improving the efficiency and sustainability of controlled environment agriculture.

The research gaps identified in studying the effects of full spectrum light on strawberry cultivation in vertical farming align with several United Nations Sustainable Development Goals (SDGs). Primarily, these gaps contribute to Goal 4 ”Zero Hunger” by enhancing agricultural practices to improve crop yield and quality. Additionally, they are relevant to Goal 9: “Industry, Innovation and Infrastructure” as advancement in controlled environment agriculture and vertical farming contribute to sustainable and innovative farming methods. Lastly, the research addresses Goal 13: “Climate Action” by exploring ways to improve the efficiency and sustainability of agriculture, which is crucial for mitigating the impact of climate change on food production.

Considering the significance of hydroponic cultivation of high-value crops, the research work “Effect of full spectrum supplementary light on growth yield and quality attributes of strawberry under vertical farming system” was accomplished with undermentioned objectives:

- **Objectives of the proposed work**:

1. To study the effect of full spectrum light and vertical farming on vegetative and reproductive parameter of strawberry
2. To study the effect of full spectrum light and vertical farming on yield and fruit quality of strawberry.
3. To analyze and compare the performance of strawberry cultivar under different levels under full spectrum light in vertical farming system.

CHAPTER-II

REVIEW OF LITERATURE

The present investigation title **“Effect of full spectrum supplementary light on growth yield and quality attributes of strawberry under vertical farming system”**, is a field experiment that was carried out under a hydroponic system at Horticultural Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab during 2021-2023. The present study was carried out in light of work done by various authors reviews, thus, an attempt altogether to present the results of the work done on additional full spectrum light for different hours and to elaborate the performance of strawberry under vertical farming.

Role of light in plant growth

Plants rely on light for photosynthesis, which is crucial for their growth. Research by Thomas Engelmann in 1882 showed that green light is mostly reflected and has the least effect on photosynthesis, while blue light promotes leaf growth and red light stimulates flowering and fruiting. More recent studies have indicated that UV, near-infrared (NIR), and green light also contribute to plant development (Pazuki *et al.*, 2017). Blue and red photons are efficiently absorbed by chlorophyll pigments on leaf surfaces, enhancing photosynthesis (Neo *et al.*, 2022). Green light penetrates deeper into the leaf, driving carbon fixation and supporting the accessory pigment β-carotene, which is also involved in photosynthesis. The overall rate of photosynthesis is determined by the combined absorption of chlorophyll a, chlorophyll b, and β-carotene (Proksch, 2016; Eichhorn *et al.*, 2019). The "McCree curve" illustrates the photosynthetic action spectrum and the absorption profiles of these pigments (Neo *et al.*, 2022).

Light is essential for all stages of plant growth, from germination to fruiting, but not all light from the sun or other sources is fully utilized by plants. The most critical light range for photosynthesis, known as Photosynthetically Active Radiation (PAR), spans from 400 to 700 nm. Plants depend on photosynthetic pigments, such as chlorophyll a, chlorophyll b, carotenoids, zeaxanthin, lutein, and lycopene, to absorb specific light wavelengths for photosynthesis (Rehman *et al.,* 2017; Neo *et al.,* 2022). Recent studies suggest that light outside the PAR range, including UV (A and B) and far-red light, can also play a crucial role in plant health, extending the effective light spectrum to 300–800 nm.

Use of LEDs and Grow Light

Light-emitting diodes (LEDs) are solid-state devices that emit narrow-spectrum light when voltage is applied. Since the 1980s, LEDs have been explored for plant lighting, especially in space flight applications. Recent advancements have made LEDs more affordable and efficient, leading to their increased use in commercial horticulture for optimizing plant growth, morphology, and nutrient content (Folta and Carvahlo, 2015). The technology has enabled the development of customized lighting systems, benefiting large-scale plant factories and strawberry production, particularly in tropical regions (Massa and Norrie, 2015; Fang *et al.*, 2020; Sidhu *et al.,* 2021). By harnessing specific light wavelengths, LEDs can improve photosynthetic efficiency and flower bud induction, making them a promising tool for enhancing fruit production and quality (Kepenek, 2019; Diaz Galian *et al.,* 2021). Grow lights are artificial light sources designed to provide the optimal spectrum and intensity for photosynthesis and plant growth in indoor farming. Extensive research has improved our understanding of suitable artificial lighting, leading to the rise of LED grow lights due to their ability to enhance photosynthesis, energy efficiency, and light quality (Bures *et al.,* 2018; Kozai, 2016). LED systems deliver the highest Photosynthetic Photon Flux Density (PPFD) compared to other lighting types, making them the preferred choice in indoor agriculture (Radetsky, 2018).

LEDs offer superior spectral tuning, allowing farmers to optimize crop responses by adjusting the light spectrum, improving yields, quality, and nutrient content (Neo *et al.,* 2022). They are also known for their long lifespan, high energy conversion efficiency, and better heat management compared to traditional lamps like fluorescent and high-pressure sodium (HPS) lights (Runkle and Bugbee, 2017). Full-spectrum LEDs now mimic the sun's

Photosynthetically Active Radiation (PAR) spectrum, and tunable spectrum LEDs allow precise control over light wavelengths to match crop needs, accelerating growth and boosting yields (Gupta and Agarwal, 2017). Although LEDs have a higher initial cost, their efficiency, durability, and energy savings make them a cost-effective choice for indoor farming. Plants grown under supplemental LED lighting showed significantly higher photosynthetic rates compared to those under fluorescent lighting or without supplementation, even at leaf heights of 1030 cm. The increased photosynthesis led to larger leaves, greater dry matter production, and heavier specific leaf weight, resulting in bigger fruits and higher total yields. The higher irradiance of LEDs compared to fluorescent lights was credited for these improvements. Additionally, the level of soluble solids, indicating fruit sweetness, increased with LED lighting. These findings suggest that using high-intensity LEDs to supplement lighting in forced strawberry production can significantly boost crop yields (Hidaka *et al.,* 2013).

Effect of light intensity and light duration

The photosynthetic rate of plants increases with light intensity above the light compensation point (LCP) but eventually plateaus at higher intensities, where further increases can harm plant physiology (Wimalasekera, 2019). Instead of increasing light intensity, extending the duration of light exposure can be beneficial. Weaver and van Iersel (2020) found that supplementing lettuce with LED light to extend photoperiods, while keeping the Daily Light Integral (DLI) constant, increased dry mass. Proper light intensity is also crucial for triggering phenotypic responses like anthocyanin production. In controlled environments, optimizing light duration and intensity is key to enhancing crop growth and productivity. For example, light intensities of 90 µmol/m²/s during the rooting stage and 270 µmol/m²/s during the seedling stage were recommended for efficient strawberry production in LED-based hydroponic systems (Zheng *et al.,* 2019a, 2019b).

This study sheds light on the critical role of full-spectrum light in optimizing strawberry cultivation within vertical farming systems. Our findings reveal that a tailored light schedule is essential to maximize benefits. Indoor environments flourish under a synergistic combination of natural light and a 6-hour supplementation of full-spectrum illumination, promoting enhanced physiological properties, superior yields and an overall improvement in berry quality. Conversely, outdoor settings exhibit optimal growth and fruit development with a shorter, 2-hour dose of full-spectrum light working in concert with natural sunlight. These contrasting results underscore the importance of tailoring light regimes to specific environmental contexts. By meticulously examining the interplay between light quality, duration and surrounding conditions, we can unlock the full potential of vertical farming for sustainable and efficient strawberry production.

The present chapter contains the supportive evidence from different experiments and is being presented under the appropriate headings:

2.1. Soilless cultivation of strawberry
2.2.Vertical farming system in strawberry
2.3. Light intensity in strawberry
2.4. Photosynthetic activities in strawberry

Very limited work was done on the full spectrum light as well as its combination with vertical farming. So in the present investigation work on vertical farming and full spectrum light is held in combination. Similar works done by others on various crops with the effect of soilless cultivation, vertical system and light intensity are represented in the following table:

Table 2.1: Effect of soilless cultivation, vertical system and light intensity in strawberry

Light/ System/ material used	**Result**	**References**
Light intensity (200 μmol·m^{-2}·s$^{-1)}$ and photoperiod (16 h·day$^{-1)}$, spectra between 450 and 495 nm and 620–750 nm.	Helps to maintain the quality, as well as the increase of bio-compounds	Najera *et al.*, 2023

Vermicompost, FYM, *Azotobacter*, *Azospirillum* and PSB	Enhance the yield and quality of strawberry	Chaurasia *et al.*, 2023
Horizontal and vertical production systems for strawberry.	Three-layer glasshouse vertical structure is a best for production of strawberry.	Madhavi *et al.*, 2023
Combine effect of Wide spectrum fluorescent + ultraviolet B light and Red LED.	Enhance the chlorophyll content.	Smith *et al.*, 2023
Role of Spectrum-Light on Productivity of Plant Quality in Vertical Farming Systems.	Helps to enhance the production worldwide in vegetable crops. Increases the quality standards and nutritional value.	Najera *et al.*, 2023
Green Light at 18-20% and Blue Light at 18-20%	Improves the growth and yield related parameters as well as net photosynthesis rate enhanced.	Victor *et al.*, 2023
LED illumination, *PPFD* (>400_mol m^2 s^{-1})	Leaf heights increased (10-30 cm), as well as leaf photosynthetic rates	Hidaka *et al.*, 2023
White LED, wide-spectrum fluorescent (WSF) and WSF+UV-B	Lowers the **p**lant injury ratings in Strawberry cv Festival, Pelican and Seascape.	Smith *et al.*, 2022

Horizontal and Vertical Aquaponic Systems for Basil Production.	Productivity in the vertical systems was 160% higher than in horizontal systems per unit area.	Fernández-Cabanás *et al.*, 2022
Blue Light (460 nm), red light (660 nm) and blue/red (1:3),	Reduces the stress of plant.	Shamsabad *et al.*, 2022
Light emiting diode	Enhance the development of growth, morphogenesis and pigmentation of plants.	Al Murad *et al.*, 2021
Red and White supplement Light	Red light increases the xanthophyll contents and White light increased photosynthesis.	Lauria *et al.*, 2021
Red/ Blue Light	Increases ethylene production, promotes tomato fruit ripening and improvement in quality.	Li *et al.*, 2021
Transparent, red, yellow, green, blue and purple films	In strawberry production red light promotes the effects on plant growth, photosynthetic rate, fruit weight and quality.	Peng *et al.*, 2020
Low Blue and High Blue	In greenhouse conditions, light improves quality of strawberry fruit and plant growth during shortening daylengths.	Stuemky and Uchanski, 2020

Implication of Urban Agriculture and Vertical Farming for Future Sustainability	Reduced farm inputs and crop failures and restored farmland	Chatterjee *et al.*, 2020
PPF-250, PPF-350, or PPF-450	With an increase in light intensity, daughter plants per stock plant increased, total dry and total fresh mass.	Xu and Hernandez, 2020
DLI (11.5-17.3 mol/(m2·d) and 11.5 mol/(m2·d)	Improve the propagation efficiency of strawberry, runner quality of plants because of the higher photon and energy yields.	Zheng *et al.*, 2019
Red :Blue Light ratios (0.5 to 4)	NUE was increased in Red Blue light ≤ 1. Also helps in plant growth, plant physiological and metabolic functions, as well as resources use efficiency	Pennisi *et al.*, 2019
Red and far-red (FR) sensing photoreceptor.	Regulates plant growth and development	Helizon *et al.*, 2018
Light signalling	Induced regulation of nutrient uptake and utilisation.	Sakuraba and Yanagisawa, 2018
Far Red	Enrichment of light in the shoot resulted in increased auxin signaling in the shoot	Van Gelderen *et al.*, 2018
Green light	In lettuce soluble sugar, crude protein and Vitamin C	Xiao Li *et al.*, 2017

	contents increased with the increase of green.	
Red and Blue light (LED)	Enhance yield and maintains the quality of strawberry fruit.	Nadalini *et al.*, 2017
70/30 % red-blue LED light	Increase in photosynthesis and fresh weight of the plants, up to a fourfold increase in Mentha essential oil yield compared to field conditions.	Sabzalian *et al.*, 2014

2.1 Soilless cultivation of strawberry

Indoor cultivation was done with light intensity of 200, 250, 300 and 350 µmol/m^{2}s and duration of 12 and 16 hours a day. They reported a linear and negative relationship between runner length and light intensity (Zheng *et al.*, 2019). Similar trend was noticed with crown diameter and biomass of runners. At higher light intensity the photosynthetic capacity might be reduced due to decrease in photochemical efficiency of PSII and chlorophyll level. This could be further associated with photon yield and energy yield in runners. The optimum light intensity for strawberry propagation was observed as 11.5mol/m^{2}d.

For evaluate the biochemical attribute of strawberry under vertical farming in the natural ventilated polyhouse pot culture experiment conducted (Lakshmikanth *et al.*, 2020). It was observed that the quality was significantly improved under polyhouse vertical system with higher TSS and Chlorophyll (a, b and total) in pot culture consists soil, cocopeat and vermicompost (1:1:1). Similar report was obtained by Chaurasia *et al.*, 2022 in vertical farming system with biofertilizer application. The highest growth, flowering and fruiting was noticed after application of Azotobacter and Azospirillum (2g each) in growing media consists 50% soil and 50 % vermicompost.

Hassan *et al.*, 2020 study goal was to determine how various substrate combinations and bio-stimulants affected strawberry growth, fruit yield, fruit quality and nutrient concentration in a soilless culture system. The trial included 12 growing media in a soilless culture system. The findings showed that using modern coco peat as a growing medium produced the highest values for crown diameter, fruit weight and fruit length while using rice straw with perlite and sand alone at a ratio of 1:2 produced the highest values for plant height and K%. Additionally, using old coco peat plus perlite as a growing medium increased the yield of marketable fruit significantly. Regarding the application of bio-stimulants, seaweed extract was followed by EM stimulator, which significantly improved crown diameter, marketable fruit yield, fruit quality, N% and P% in strawberry leaves.

The plants grown in PVC pots with a growing media ratio of 3:1:1 had significantly greater height, higher growth, maximum flowering and fruiting than plants grown in other types of containers. Additionally, it was reported that polyethylene bags had higher costs and returns, with a growing media ratio of 3:1:1 and a benefit cost ratio of 1:1.70. Therefore, it is advised that PVC pots with growing media in a 3:1:1 ratio be used for strawberry production in open areas as this will ensure greater success in plant establishment and produce disease-free, healthy strawberries (Sharma *et al.*, 2022).

On using various growing media, Cocopeat + Peat moss (3:2 v/v) was found to be the most effective for increasing germination percent (95.23%), taking the fewest days to reach 50% germination (9.67) and having the highest vigor index-I (2301.61 cm) and vigor index-II (91.83 g). The maximum growth parameters include seedling height (8.05 and 24.16 cm), number of leaves (7.30 and 9.34), collar diameter (2.97 and 6.05 mm) at 30 and 45 DAS, leaf area (39.60 cm2), length (17.92 cm) and diameter (5.14 mm) of the tape root, number (17.33) of secondary roots, fresh (9.59 g) and dry (0.96 g) weights of the shoot and root and survival rate (100%) (Sahu *et al.*, 2022).

Researcher found M3B4 [M3 (soil + sand + vermicompost + cocopeat (2:1:1:1) B4 (Arka Microbial Consortium)] had recorded highest germination per cent (96.00% at 30 DAS), maximum number of leaves per seedling (7.00 and 9.60 at 30 and 45 DAG respectively), stem girth (1.55 cm and 1.61 cm at 30, 45 DAG respectively), plant height (28.35 cm and

38.95 cm at 30, 45 DAG respectively), chlorophyll content (59.84 SPAD units at 45 DAG), survival per cent of seedlings (95.00% at 45 DAG) were recorded against the lowest germination percentage and growth parameters in the treatment M0B0 (soil + sand +FYM (2:1:1) inoculated with SSP @ 10 g/Bag +N:P: K (19:19:19) @ 5 g/lit (foliar spray) + Formula 4 @ 5 g/lit (foliar\spray) (Sriya *et al.*, 2022).

According to Imran *et al.*, 2022, the strawberry (*Fragaria* × *ananassa*), a member of the Rosaceae family, is a widely cultivated fruit species. A soft fruited herbaceous perennial plant with short days, strawberry may be effectively cultivated at optimum day temperatures of 22 to 25 °C and optimal night temperatures of 7 to 13 °C. It spreads by runners, which is a natural method of propagation. A strawberry is an aggregate fruit with seeds on top of a red, fleshy container that grows in soil, making it more vulnerable to pathogens like those that cause soilborne illness and other diseases. The soils water-holding capacity, porosity and pH are all noticeably lower than they are in other growing media like perlite, FYM, rice husk, coco peat, bio-char and pumice. These growing mediums enable better growth, development and productivity because they have a high water-holding capacity, high porosity, a balanced pH and are free of soil-borne pathogens. Jeevamrit is one example of a liquid organic manure that can help increase crop yield and growth.

Vermicompost (66.2%), vermiculite (16.5%), coco peat (16.5%) and Rhizobium (0.8%) are the four natural growth substrates that make up the composition of the soilless medium. The above-mentioned combination is novel and has not been disclosed in any prior art. The technical innovation of the current invention is the disclosure of a soilless medium that works synergistically to increase crop yield and has the ideal physical and chemical properties for plant growth (Thakur *et al.*, 2023). Due to the presence of vermicompost, vermiculite, cocopeat and rhizobium in the proportions of 2:0.5:0.5:0.02, it benefits plants nutritionally. To give plants enough water, vermicompost is used because of its effective water-holding capacity. Rhizobium is also applied to seeds and plastic bags to encourage plant growth.

2.2 Vertical system in strawberry

In 2012, Vertical Farming (social Work and Sustainable Urban Agriculture in an Age of Global Food Crises) was studied by Besthorn. Social work has become more and more concerned with environmental issues, such as ecological justice, sustainability and attention to food security. In order to address the issue of global food insecurity and its effects on marginalized urban populations, this article will examine the history of sustainable urban agriculture. The development of vertical farming, a sustainable agricultural initiative, will be discussed and it will be suggested that it has promise for areas where there are persistent issues with food security. It will lay out some tentative steps that social work might take to support vertical farming initiatives more actively.

The goal of this study was to build a vertical farm and, as a result, look into its economic viability. A 37-story vertical farm with a 0.25 hectare footprint that could produce 3,500 tonnes of produce and 140 tonnes of tilapia fillets annually is highlighted in the DLR Bremen study as having significant potential. Its viability is demonstrated by competitive pricing and market projections for up to 3000 farms, despite a €200 million investment and significant operating costs. For its economic, environmental and social benefits to be fully realized, more investigation and optimization are required (Banerjee, 2014).

Difficulties include choosing the best crop and watering system, monitoring the nutrient solution and designing environment friendly structure and efficient under controlled environment was studied. The amount of nutrients that are available to plants depends on the nutrient solutions pH value. According to the plants nutritional needs, plant nutrients are added to eco-farming systems. As a result of the nutrient solutions reduced ability to act as a buffer, pH adjustment must be performed every day (Sarkar and Majumder, 2015). Understanding the type and concentration of ions enables one to determine which are required in the nutrient solution and can, therefore, be removed from the original formulation.

Vertical cultivation of lettuce with the help of conventional hydroponic system had reported higher per unit area but there was no difference in root zone and plant density. A decrease in photon flux density (PFD) and fresh shoot weight was noticed in vertical structure from top to bottom however the crop per unit of floor area was greater in case of vertical structure as compared to horizontal hydroponic system (Touliatus *et al.,* 2016). This can be further improved if artificial light is provided base of vertical structure. Such practices can offer environment friendly approach for food production and control of biotic and abiotic stresses.

The declining stocks of arable land per person are a result of ongoing trends in population growth, urbanization, water supply reduction and climate change. The goal of vertical farming in climate-controlled high-rise urban buildings is to increase output while minimizing environmental impact. These facilities offer improved biosecurity, pest and drought protection and clean, sustainable food production (Benke and Tomkins, 2017). They also provide notable savings in terms of transportation requirements and the consumption of fossil fuels, which helps to create a more sustainable urban food system.

According to the Graham and Wheeler, VUE (volume utilization efficiency) can be enhanced, especially in terrestrial vertical agriculture systems that can benefit from modest height reductions by taking advantage of a systems much greater vertical capacity. Reduced vertical system requirements or an increase in the number of species that can be grown in a given production volume are two ways that mechanical stimulation can enhance VUE in spaceflight applications. The use of mechanical stimulation as a microgravity defense strategy for crop plants is also discussed.

The study highlighted with significance of sufficient PAR along traditional optimization goals in urban gardening for planning and selection of plants. The urban gardening included micro gardening and building integrated gardening has greater contribution to achieve self-reliance in food under urban condition and also ensure the multiple cropping in per unit area Song *et al.*, (2018).

Growing crops in urban areas provides an opportunity to strengthen the local economy by creating jobs and the food supply. Other impact categories, such as those that illustrate the effects of sparingly using pesticides and fertilizers, could be looked at and found to be useful (Molin and Martin, 2018). By reducing the risks associated with reliance on the global food production system and lengthy delivery chains, vertical farming could also play a significant role in social well-being and strengthen self-sufficiency, building more resilient communities.

A summary of methods for growing vertically was studied by Beachman *et al.,* in 2019. Vertical farming uses sophisticated, protected horticulture systems to maximize crop yield per unit of land in order to meet the increasing demands on agricultural production. Its multi-level growth surfaces and controlled environments allow it to operate more efficiently, even though it is technically complicated and expensive. There's hope for sustainable food production with this creative method. It is important to note that the following information is subject to change without notice. Although VF has been shown to have the potential to produce a variety of crops, further study is needed to optimize its technical and economic aspects, including maximizing productivity and lowering system costs.

A growing number of people around the world are becoming interested in Vertical Farming (VF) techniques because of the need to maximize food production per unit area. VF covers a wide range of approaches, from large commercial skyscrapers producing diverse crops to small-scale personal or community gardens producing crop yield per square meter (Beacham *et al.,* 2019). This shift aims to enhance crop yield per square meter, addressing challenges related to food security. VF is a versatile and scalable solution for sustainable agriculture.

Cities are becoming increasingly urbanized, an automated strategy for addressing the problem of providing nutrient-dense plant-based food was developed according to Lauguico *et al.,* in 2019. Wall gardening, also known as vertical farming or urban farming, involves installing rows and columns of pockets over a wall. For the seedlings to grow, these pockets are filled with soil or other planting mediums (such as water for hydroponics). A robotic arm is manually directed to focus on a particular area of a crops growth pocket. The joint angles are calculated from the set points using inverse kinematics. After that, the pockets are the target and the robot arms end-effector grips the plant roots. The crop is then technically pulled up as the robotic arm returns to its starting position. The arm directs to the side of the wall, where a container is located, after positioning to the starting point. To carefully drop the crop into the container, the end-effector opens. The simulation of the research study is done with MATLAB and Universal Robots. The findings indicate that it can only produce 85.42 percent of the crops.

In 2018, Newer technologies are coming up to face the challenges arising due to overgrowing population, water scarcity, climate change, labor scarcity and urbanization leading to reduction in arable land (Sonawane, 2018). Various technologies like See & Spray Technology, field sensors for irrigation control, electrical conductivity sensing, machine learning and robotics in agriculture are on its way to come. These advanced technologies will no doubt boost the agriculture. Still then in spite of all these latest and modern technologies, food security amidst the overpopulation pressure with decreasing arable lands is a major concern all over the world. Vertical farming is perhaps intensive way of increased food production with lesser lands. In this article, the researcher will study the pros and cons of vertical farming.

Kalantari *et al.,* 2018 discuss the opportunities and challenges in sustainability of vertical farming. They have proposed the potential benefits associated with vertical farming as increased food production and high-quality produce to ensure food security and sustainability of herbal farming. This is also beneficial for herbal society in terms of environmental, social and economic security. Similar finding has been also observed by Roberts *et al.,* 2019 and Kalantari *et al.,* 2020.

Wiggins *et al.,* 2020 had also worked on urban production of lettuce and has proposed the application of a perlite coco fiber, pine bowl and compost in urban farming under vertical system.

In 2020, Areias studied about the future of industries how indoor vertical farming will disrupt the agricultural supply chain. They have conducted qualitative analysis through export panel and secondary literature and proposed that vertical farming has potential to provide and integrated approval for multiple societal problems including agriculture landscape improvement comma food crisis mitigations sustainability in food production environmental issue to ensure food environmental and economic security. However, more work is required concerning the profitability and protocols pertaining to vertical farming of different crops. They have further advocated about the layers of government intervention to make it cost effective and marketable.

The urban agricultural is emphasized with the economic production of crops and livestock in the urban area. The growing population and urbanization have questioned its sustainability due to generation of household wastage and reduction of arable land for production of food (Chatterjee *et al.,* 2020). The urban agricultural can provide a secured solution of many challenges by ensuring recycling of urban wastage, energy and water conservation, ecosystem sustainability and notification, climate resilience and ecological, social and food security. Vertical farming is sported to be one go solution for this challenge where crops can be grown under vertical layers as high-rise farming where nutrient and water availability can be ensured by hydroponic technology. This will ensure from round production of crops after getting supplemented with sufficient artificial light under controlled conditions. This will ensure the regular supply of food materials to household as well as market. Controlled condition will also ensure reduce climate vulnerability, reduced input requirement, low crop failure due to protection from biotic and abiotic stresses. Similar study has been stated by Kalantani *et al.,* 2020.

A study found the one of the key issues of the contemporary city is urban voids, characterized by disused buildings. Such spaces can be the starting point for a new urban setting, where the city reconnects to the rural environment. Vertical farming can be a new paradigm connecting these often-opposed concepts, bringing several advantages. This paper presents an experimental case study about a typical situation in a peripheral context of the city of Trento. An industrial building under decommissioning is restored as a vertical farm through a circular economy perspective, combining natural resources with ICT, consumption and reuse processes (Ri *et al.,* 2020).

Urban agriculture creates a new structure for modern cities by finding creative ways to fill vacant urban spaces. In a circular manner, Trento Agro Farm uses vertical farming as a flywheel to revitalize a city neighborhood that has fallen into disrepair. As a form of intervention, circuits are recommended for the areas of production, water, energy, social involvement and the circular economy. The local population actively participates in the construction of a sustainable food cycle, which is supported by the architectural fields (Dal Ri *et al.,* 2020).

Precise light management, with light recipes adapted to species and developmental stages, is essential to optimizing the yield and phytonutrient content of leafy greens. The effects of other wavelengths are still not well understood, although blue light promotes phytonutrient accumulation. The need for more research on the interactions between various wavelengths and plant growth and metabolism is highlighted by recent findings that suggest green light can inhibit growth in the presence of blue light (Wong *et al.,* 2020).

For ensuring consistent crop quality and yield, vertical farming is an innovative approach that supports local production of qualititative fruits and vegetables in rapidly expanding urban areas. To address the challenges posed by weather, soil and climate change, VF provides a dependable food source for urban populations and holds significant promise for sustainable urban agriculture. VF also allows for precise environmental control, providing an alternative to genetic modification (Kumar *et al.,* 2020). We can switch from genetic to environmental modification to improve plant productivity and quality thanks to VF, which enables precise control of physiological and developmental processes in plants. A mechanistic understanding of how plants function is essential for the success of VF.In addition, the development of VF as a novel plant production system will advance basic plant science.

Avgoustaki and Xydis in 2020 studied and emphasized how crucial it is to maximize efficiency and promote energy sustainability in order to satisfy business and societal demands. A sustainable urban food production model, indoor urban vertical farming (IUVF) provides fresh produce while encouraging energy and water recycling. The study's conclusion that IUVF is considerably more resource-efficient and profitable than greenhouse facilities support the idea that it is a better investment. This highlights the contribution that IUVF makes to resilient cities and sustainable food production.

In 2021, a paper on the scope of vertical farming in India was reviewed by Naskoori *et al.,* With the use of modern technology and intensive farming practices, production can be exponentially increased through vertical farming. With the shortage of water, the effects of climate change, the labor shortage and the shrinking amount of arable land, vertical farming is emerging as a solution. In areas where access to fresh produce is limited, vertical farming offers a job opportunity, helps the community economy and produces nutritious food. Increase in food productivity, maintaining high quality products, ensuring safety of product and promoting sustainable urban farming are all advantages of vertical farming. The main benefits of vertical framing are positive effects on the environment, society and economy. Additionally, vertical farms can offer ways to improve global food security. Perlite, coco-peat, vermiculite and other growing media are used to cultivate the crops in vertical farming in order to promote rapid growth and high yield. Vegetables are the best candidates for vertical farming because they have a short lifespan and offer high net returns.

2.3 Light intensity in strawberry

Vince-Prue *et al.*, 1976 studied petiole allocation in strawberry subjected to artificial light. They have reported to distinct responses as and of the day response (diurnal response) supply of low intensity for red radiation for 1 hour after 8 hours photo period there was no allocation or very less when supply of far-red light was delayed. After the first leaf appeared, a photoperiodic response was observed. This response was reported after prolonged exposure to red, far-red, or tungsten light, regardless of the light intensity.

The growth of ex vitro strawberry plantlets is significantly enhanced by CO_2 enrichment (CE) and supplemental lighting (SL), with CE being more effective for root growth and SL for shoot growth. Desjardins et al. (1987) found that the combination of 900 ppm CO_2 and SL significantly shortened the acclimatization period by 15 days, demonstrating a synergistic effect. The combined application of both treatments resulted in greater increases in dry weight of the roots and leaves compared to their individual applications. This study emphasizes the significance of integrating CE and SL to maximize strawberry plantlet growth during acclimatization.

The invitro growth of unrooted strawberry supplemented with super bright red colour and blue LEDs was conducted. The three leaves containing shoots were placed in an incubation supplied with blue LEDs and red LEDs in ratio of 0:100, 10:90, 20:80, or 30:70%. The best growth in plant legs was notice with the red blue combination of 70:30 (blue-red as 30:70). These plants have also performed well when transferred to soil (Nhut *et al.,* 2003). In their study, Samuoliene *et al.,* (2010) observed that when frigo strawberry sprouts were grown with a combination of red (640 nm) and blue (455 nm) LEDs at a PPFD of 174.5 and 25.5 µmol m-2 s-1, they exhibited better development, pigment ratios and carbohydrate accumulation. The study also confirmed that red and blue LED light combinations are necessary for optimal growth, with fruiting concluding 40 days after planting, underscoring the significance of these particular light conditions for frigo strawberry development.

Li *et al.,* 2012 noticed the impact of additional LED lighting on strawberry plant growth. The additional LED lighting period lasts for four hours each day. The plants grown with supplemental lighting were greater in height of plant, number of leaf, petiole length and area of leaf than those grown without it. According to the study findings, supplemental lighting with LED combination lighting systems may help strawberry plants grow vegetatively and this effect is improved as LED power is increased. Red:blue LED with a ratio of 5:1 are inferior to those with a 3:2:1 orange/red/blue combination. The formers spectrum resembles the absorption spectrum of plant photosynthesis much more closely.

In comparison to other LED treatments, Choi *et al.,* (2013) found that strawberries grown under mixed blue and red LED light produced more fruits with higher anthocyanin, total phenolic and flavonoid content. Fruit ripened more quickly under blue LED light than under other conditions. Compared to fruits grown under mixed LEDs, those grown under blue or red LEDs exhibited higher antioxidant activities. According to the study, strawberry productivity and free sugar content can be increased in greenhouses by supplementing sunlight with blue and red LEDs, particularly during short days. This strategy can increase strawberry fruit yield and quality.

Photosynthetic rates were significantly increased at leaf heights of 10 to 30 cm under LED illumination when PPFD values exceeding 400 µmol m^2 s^{-1} were compared to fluorescent light and control groups. Increased leaf dry matter, leaf area, specific leaf weight and overall plant growth were the results of enhanced photosynthesis. Higher average fruit weights, fruit counts and marketable yields were the outcomes of this. Furthermore, the fruits' soluble solids content rose under LED lighting, boosting their sweetness. According to the study's findings, forced strawberry cultivation can be successfully accomplished with high irradiance LED supplemental lighting as long as high yields and quality are maintained (Hidaka *et al.*, 2013).

The blue light illumination in forms the colour index, rate of respiration and ethylene production during storage. The antioxidant properties, radical scavenging, phenolics, ascorbic acid, titrable acidity and sugars also increased which could be responsible for maintaining nutritional value of fruits during storage (Xu *et al.,* 2014).

It was observed that strawberry growth and phytochemical production were affected by blue, red and blue plus red LED lights in growth chambers (GCs) and plastic greenhouses (PGs). While the PG with additional LEDs produced noticeably more fruits, the leaves grown in the GC under LEDs had a higher chlorophyll content. The organic acid content of the PG fruits was likewise higher. Fruit production and the build-up of organic acids and phenolic compounds were found to be greatly increased by adding blue or blue plus red LEDs to the ambient light in the PG (Choi *et al.*, 2015). According to this, growing strawberries yields higher-quality fruit when LED supplementation is used.

The best LED for in vitro development was 90% red and 10% blue (Hung *et al.*, 2015). Both in vitro and ex vivo growth was accomplished using the 70% red and 30% blue LED. All LEDs significantly enhanced plantlet development when compared to the Control, as well as survival rate, shoot and root biomass, root length and number, leaf number and area and chlorophyll content. In the future, in commercial strawberry plant asexual propagation applications, LEDs may serve as the primary light source.

The regulation of horticultural plant traits by photoreceptors and signaling pathways, highlighting the vital role of light in plant growth and development. These processes are regulated by the quantity, quality and duration of light received by plants. Certain photoreceptors and pathways convert light signals into modifications in gene expression (Folta and Carvalho (2015). This review demonstrates how these biochemical pathways can be precisely activated by narrow-bandwidth illumination to manipulate plant behavior and productivity. The study highlights the possibility of regulating plant physiology, growth and metabolite accumulation by means of precise modifications to the light spectrum, offering valuable perspectives for enhancing horticultural techniques.

Controlled environment (CE) plant production lighting has been greatly improved by the quick developments in LED technology. With LEDs, energy efficiency is increased and crop-specific light spectra can be created. Anthocyanin levels in red romaine lettuce were found to be elevated by higher native PPF levels. Effective lighting systems for optimal CE plant growth require a thorough understanding of the interactions between different light wavebands and plant tissue (Massa *et al.,* 2015). Results demonstrate a significant increase in yield, flavour, refraction, titratable acid and vitamin C content when fruits and leaves are treated with additional LED light. Vitamin C content is increased by lighting on fruits even more than on leaves. Given that the plant had access to only 90 mol m-2 s-1 as opposed to 200 mol/m^{2}s^1 in other treatment, the effect of additional LED lighting on the fruits is unexpected (Hanenberg *et al.,* 2015). According to our research, LED lighting is a promising method for horticulture in greenhouses to enhance strawberry flavour, nutritional value and production.

LEDs could take the place of inefficient traditional lighting in greenhouses, highlighting the high energy efficiency, low maintenance costs and long lifespan of these lights. In order to optimize light spectra for plant growth, the review emphasizes the necessity of species-specific studies to evaluate plant responses to different LED wavelengths. Even though LEDs promise to lower production costs for vegetables over the long run, more study is required to fully understand how they affect plant physiology (Singh *et al.,* 2015). Maximizing growth and productivity for particular plant species requires the development of energy-efficient, spectrum-optimized LED lighting systems.

Citrus fruits' nutritional and commercial value were increased when ethylene and red LED light treatments were combined. This resulted in an increase in the expression of genes related to carotenoid biosynthesis. According to Ma *et al.,* (2015), carotenoid accumulation in the flavedo of Satsuma mandarins was enhanced by red LED light (660 nm), leading to an increase in the contents of lutein, β-cryptoxanthin, all-trans-violaxanthin and 9-cis-violaxanthin. β-carotene and β-cryptoxanthin were elevated but lutein was decreased upon ethylene treatment. Red LED light, on the other hand, prevented ethylene from suppressing lutein accumulation.

LEDs promote the development of stomata and chlorophyll in *Musa acuminata* (AAA) Nanico Corupá in vitro plantlets. When bananas were micropropagated using white LED and deep red/white LED lighting treatments instead of fluorescent lamps, the gradual rise in chlorophyll levels and stomata formation in in vitro plantlets, with no discernible differences between the LED treatments. On both leaf surfaces, the LED systems encouraged the formation of stomata and raised total Chl, Chl-a and Chl-b levels (do Nascimento vieira *et al.*, 2015). LEDs are very promising for banana micropropagation because of their excellent light quality, energy efficiency, low heat production and extended lifespan. The acclimatization phase saw 100% survival for all treatments, providing more evidence in favor of LED use in this situation.

Updates on knowledge regarding plant growth and functioning in response to particular wavelength ranges of light are highlighted. The plant responses to light quality at a wide range of integration levels (from cell to host-plant symbiont relationships) and plant processes (flowering, photosynthesis, photomorphogenesis, production of secondary metabolites) are discussed. Dueck *et al.,* (2016) reviewed on integrating existing knowledge about light from horticultural and natural fields through physiological mechanisms that are shared and new opportunities for their application are discussed.

The effects of red (R), blue (B) and combined (R/B) light on lettuce plants were studied by Wang *et al.,* (2016). The photosynthetic activity and capacity of leaves increased with decreasing R/B ratio, whereas the shoot dry weight peaked at R/B = 12. There was no discernible difference between the R and R/B = 12 treatments, with leaf area and number being the main causes of the elevated shoot dry weight. Quantitative blue light stimulated morphological and physiological responses that positively influenced growth, even though photosynthetic activity did not directly correlate with shoot dry weight.

In the Yangtze River Delta of China, Li *et al.,* (2016) studied the effects of LED supplemental lighting on the growth of winter greenhouse plants. Two lighting sets were used, LED-A (R ratio 6:3) and LED-B (R ratio 8:1), which both used inexpensive LEDs and provided 65 mol m^2 s^{-3} of light at night. Without using heat, they evaluated the pepper plants' vegetative traits, early yield and flowering physiology. Chlorophyll fluorescence and plant growth parameters were compared and the results provided insights into the possible advantages of LED supplemental lighting for greenhouse cultivation during the dark winter months.

A 2016 study examined the prototypes sustainability will be evaluated on a multiannual basis using performance criteria. The strategy and the prototypes that have been tested are original and encouraging. To further research mix cropping for horticulture, we must continue to examine the performances of both tested fruit agroforestry systems in the coming years (Warlop and Castel, 2016).

The impact of different blue and red LED light irradiation patterns on cos lettuce growth and morphology was investigated by Jishi *et al.,* (2016). The findings demonstrated that, incomparison to simultaneous irradiation, postponing red LED light irradiation by 4 or 7 hours after blue LED light produced significantly higher shoot fresh weight. This demonstrates how changing when blue and red LED lights are illuminated can stimulate the growth of plants. Subsequent research showed that total leaf area was increased by monochromatic blue and/or red light irradiation, with diurnal variations in photon flux density contributing to the growth promotion effect.

A combination of blue and red LED lights as a primary light source for cotton seedling cultivation may be beneficial to upland cotton seedling growth. This study may be the first to examine the effects of various light qualities on Sumian 22 upland cotton cultivar growth, photosynthetic characteristics and chloroplast ultrastructure. As a primary light source for cotton seedling cultivation, the mixture of blue and red (BR1:8) LED lights may be advantageous and necessary for upland cotton seedling growth (Li *et al.*, 2017).

The feasibility and sustainability of using LEDs as a light source for indoor plants were assessed, given that the availability of natural light is a significant challenge during winter. They have noticed that the metal halide lamps, sodium lamp and fluorescent lamp are not efficient due to a mission of low-quality light (Rehman *et al.,* 2017). They revealed that the morphological and anatomical differentiation and development was significantly influenced by the spectral quality of LEDs.

Over the past ten years, lighting technologies have advanced significantly and there are now numerous options for sole-source lighting for indoor production as well as supplemental plant growth lighting in greenhouses. The photon efficiency of LED lighting has increased since 2014 and the most efficient LED lighting is now more efficient than the best HPS technology (1000 W, double-ended). Although the cost per photon of LED fixtures for plant growth lighting is still high, payback times of 8 to 20 years can be achieved in applications where the lights are used for more than 4000 hours annually, compared to 1000 W HPS. If users can take advantage of the concentrated output of LED fixtures to increase radiation capture, the payback period could be shorter. The combination of an effective fixture and canopy photon capture results in the lowest lighting system costs (Bugbee, 2017).

Strawberry plants' biomass accumulation was considerably enhanced by LED blue light (400–500 nm), especially in the roots and crowns. When compared to control and red LED-treated plants, blue light-treated plants showed a 25% higher fruit set and a significantly higher final yield. In comparison to control fruits, blue and red LED-treated fruits displayed less saturated colors and lower levels of pelargonidin-3-glucoside anthocyanin, but other fruit characteristics stayed mostly the same. These findings imply that blue light can be successfully used to increase yield while preserving fruit quality in protected strawberry growing systems (Nadalini *et al.*, 2017).

In 2018, Magar *et al.* noticed that under 16°C conditions, LED lights with peak wavelengths of 470 nm (blue), 530 nm (green) and 640 nm (red) were used in a greenhouse. Flower clusters were produced in greater quantities by plants under blue LEDs than by those under red LEDs. Indicating the effectiveness of blue light in promoting flowering and fruiting, the total weight of flower clusters and fruits per plant was significantly higher under blue LED than red LED. According to their research, endogenous gibberellic acid (GA) and cytokinin (CK) levels may be modulated in response to blue LED light, which may have an impact on plant physiology and flowering patterns in strawberries that constantly bear fruit.

A study carried out on the response of strawberry plants as growth and yield under different spectral LEDs lights viz., white light, blue light, red light, red + blue light and control. It was observed the growth response was good under blue LED while reproduction growth was good under red LED (Uddin *et al.,* 2018). However red blue combination had dissolved in tesd best active and reproduction growth along with high yield (475.3g/plant and 16.6 ton / ha).

During in vitro growth, an increase in chlorophyll content and net photosynthetic rate is typically seen in dependence on the PPFD of LED light intensities. When used as a light source in strawberry plantlets in vitro, PPFD of LEDs light intensity is appropriate. We came to the conclusion that the strawberry can be successfully propagated in large numbers using the current protocol. To encourage the development of roots, leaves, fresh plant biomass, total dry plant biomass, photosynthetic rate, net photosynthetic rate, stomatal resistance, leaf chlorophyll a+ b content, plantlet height, elongation of axillary shoot length and axillary shoot regeneration in strawberries, an appropriate light source with a 75 molm-2 s-1 PPFD of LEDs light intensity can be used. In 2018, Kepenek studied that increases in photosynthetic parameters can result in higher PPFD of LED light intensities.

Light-emitting diode (LED)-based lighting not only uses less energy than conventional lighting but also offers better performance and control. With the ability to control lights colour, intensity and distribution with previously unheard-of precision, light can now be used to produce both fresh food and to signal specific physiological responses in both people and plants. Here, we demonstrate how a more thorough understanding of how the body reacts to light will enable greater energy savings and bring about previously unrecognized advantages for productivity and health (Pattison *et al.*, 2018).

The importance of photosynthetically active radiation (PAR) for urban agriculture was highlighted by Song *et al.,* (2018) as they investigated the spatiotemporal properties of PAR along building facades in Singapore. Their research emphasizes the necessity of adequate PAR in urban planning to guide choices about which plants to use for vertical farming. Micro gardening and building-integrated agriculture are two urban practices that can improve food self-sufficiency by complementing agricultural systems designed to maximize crop productivity per acre. For urban planners and designers looking for sustainable ways to produce food in densely populated areas, these findings offer insightful information.

Zheng *et al.,* (2019) combined varied light intensities (200-350 mol/(m^2·s)) and photoperiods (12 h/d and 16 h/d) to study the hydroponic growth of mother plants of Benihoppe strawberries under various LED lighting treatments. They discovered that runner length reduced linearly as daily light integral (DLI) increased, becoming noticeably shorter during a 16-hour photoperiod. The number of runners formed increased by 38.9% when the DLI was raised from 8.6 to 11.5 mol/(m^2·d). But beyond 11.5 mol/(m^2·d), no additional increase was noted. Elevated DLIs adversely affected photosynthetic capacity; an ideal DLI range of 11.5-17.3 mol/(m^2·d) improved the quality and efficiency of strawberry propagation. In LED plant factories, the ideal ratio for photon and energy yields during runner plant propagation was found to be 11.5 mol/(m^2·d).

Zhang *et al.,* 2018 had studied the sign in accumulation and gene expression in strawberry growth in supply of red and blue light. They have observed increase accommodation of colour imparting pigments viz., I am so sign in, pelargonidin 3- glucoside (80%) and pelargonidin 3- malonyl glucose and blue-red light combination. A comparative transcriptomic study in 3 pairs viz., red vs white, blue vs white and blue vs red reflected 1402, 5034 and 3764 differentially expressed gene respectively. The result confirms the significance of high expression of James under blue light white red light might have contributed in synthesis of proanthocyanidin.

In test greenhouses, flowering could increase by up to 300% without affecting the quality of the strawberries. Both the treated and control samples of the experiment saw a reduction in strawberry size. Similar procedures were followed in sizable commercial greenhouses. Díaz-Galian *et al.,* 2020 studied that to complete 13 hours of light, additional lighting was turned on an hour before sunset. In production greenhouses, fruit quality improved when exposed to more light, regardless of wavelength, as second-quality strawberries were of lower quality. Red and blue light enhance production and quality of strawberry is increased. Stumkey and Uchanski 2020 studied effect of LED on productivity and quality of strawberry fruits grown under greenhouse conditions. They have reported larger fruit size due to use of HB and LB LEDs during short the condition. Leaf area and crown number were increase in all LED condition provided viz., white-far-red, LB and HB. Under long day condition the stolen production was promoted in all the treatments with larger leaves in San Andreas. They observe large fruits with good quality and growth under short the condition with supply of LB and HB LEDs.

Wei *et al.,* 2020 reported significant effect of supplementary morning light or stomatal characteristics, where the stomatal opening, stomatal conductance and Quantum yield was promoted in comparison to control and other treatments. They have for the reported improvement in chlorophyll and carbohydrate accumulation in strawberry plants with supplementary morning light or blue light.

Numerous studies have assessed the use of high-energy radiation to improve lettuces nutritional value (Lactuca sativa). The majority of research, however, has been concentrated on maintaining a constant radiation quality or quantity over the course of the production cycle, which typically leads to decreased yields or higher production costs. End-of-production (EOP) radiation is a low-cost preharvest technique that enables growers to control product quality without adversely affecting plant growth. This technique can increase market value of lettuce. Plants total phenolic and carotenoid contents were generally unaffected by EOP treatments, but EOP-B and EOP-H had a positive effect on anthocyanin content and antioxidant capacity, while EOP-ultraviolet produced food with a similar nutritional quality to control. The results of this study suggest that high-energy EOP radiation, particularly EOP-B, has a significant potential to improve the nutritive value of red leaf lettuce grown under controlled conditions (Gómezand Jimenez, 2020).

Under long daylength conditions, the strawberry leaves total photosynthetic rate (Pn) response to varying light levels was comparable to that of plants grown in a closed conditions or polyhouses with added CO2. Though, the plants response to the S treatment was significantly less than that to the SA treatment because of the low intensity of light under short daylength conditions. Under short-day conditions, additional lighting that stabilized the intensity of light and enhances Pn. The strawberry plant demonstrated a high potential for flower and fruit production when grown under SPF that was comparable to that of productions carried out in other controlled environments. These findings imply that in subtropics using SPF strawberry production in the is feasible and the SPFs limitations can be reduced by using additional lighting (Le *et al.*, 2021).

A study on the photosynthetic characteristics and biochemical reactions in strawberry (*Fragaria ananassa* Duch.) leaves supplemented with LED lights was conducted by Lauria *et al.*, in 2021. The development of plants and/or the biosynthesis of specific metabolites are encouraged by certain light wavebands. This study reveals that supplemental LED lighting (red, green, blue and white in a 1:1:1 ratio) affects strawberry leaf physiochemical characteristics. At T1, light supplementation increased xanthophyll de-epoxidation and nonphotochemical quenching without altering the maximal photosynthetic rate (PNmax), regardless of the light spectrum. This suggests that while light quality influences certain physiological responses, it does not impact the overall photosynthetic capacity at this early stage. Only plants that received R-supplements had higher xanthophyll contents at T17. In general, W light increased photosynthesis, whereas R and Blight decreased PNmax values and aided in the formation of O_2 at T17. At T1 and T17, oxidative stress and variations in photosynthetic traits were not brought on by G light.

Fangfang *et al.*, 2021 studied that during winter and early spring, sunlight deficiency greatly influences the yield and quality of strawberry in Henan Province, mainly resulting from less sunshine weathers such as cloud, rain, snow, fog, haze and so on. In this study, the high-pressure sodium lamp and the LED lighting were selected for supplementary light test in a strawberry production base. The effects of various methods of supplement light on vegetative growth, chlorophyll content, yield and fruit sugar content of strawberry were observed. The finding displayed the two ways of supplement light effecting the temperature to increase in greenhouse and the effect of high-pressure sodium lamp was more obvious. On strawberry plant height, leaf length and leaf width no significant effect was observed with two light sources. Both light sources had significant effect on increasing the chlorophyll content of strawberry plants. The TSS content of strawberry was more than that of the control after light supplement with two light sources and the effect was more significant with high pressure sodium lamp.

Combination of red and blue light helps to promotes tomato fruit ripening and helps to improves quality by increasing melatonin content, according to an experiment conducted by Li *et al.,* in 2021. Red (R) and blue (B) light are essential elements of light for plant vegetative growth and their development. Impact of white (W, control), R, B and mixed Red and Blue (RB) light helps to change the endogenic level of melatonin and fruit quality during tomato ripening was examined (Yousef *et al.,*2021). The results showed that melatonin levels decreased as fruit ripened and this was escorted by increased levels of ethylene biosynthesis, fruit softening, respiration rate and carbohydrate conversion. Additionally, RB light significantly increased the melatonin content in tomato fruit when compared to monochromatic R and B light. This promoted tomato fruit ripening and enhanced the fruit softening, lycopene biosynthesis, respiration rate and antioxidant activity. It was found that increased ethylene production and endogenous melatonin may regulated by signalling from red blue light and promote the tomato ripening and improvement in quality. Similar results found by Yousef *et al.,* 2021.

Nguyen *et al.,* 2021 studied the impact of white LED with blue or green LED or lettuce production in the vertical farming. They have reported white light treatment better growth in lettuce in comparison to red blue light treatment which could be associated with accumulation of phenolics and flavonol. The results confirm the positive effect of white light supplementary with specific shorter blue light for better growth and quality of lettuce. Malekzadeh Shamsabad *et al.,* 2022 had reported the reduction in effect of salt steps in strawberry after supplementary blue and red spectra. They have observed increased in SPAD and RWC under salinity and alkaline it stress after supply of blue red light. This could be due to reversible in effect of salinity stress resulting in increased uptake of K, Ca, Mg and Fe white lower the uptake of Na.

Sidhu *et al.,* 2022, found that highest number of flower buds per plant, eight, were produced by plants grown under blue light supplied during night interruption. These conditions also encouraged flower production. According to the findings, lower wavelengths promote flowering while higher wavelengths support morphological traits, particularly during transplant production. According to findings, 1:5 combination of far-red and blue LEDs could be a viable light source for improving floral development and flower bud induction, which would increase fruit production. This combination offers a focused way to increase yields in horticultural practices by potentially favorably influencing plant growth processes that are essential for successful reproduction.

White LED, wide-spectrum fluorescent (WSF) and WSF+UV-B treatments had the lowest ratings for plant injury. Compared to plants exposed to all other light treatments, plants exposed to combinations of light emitting diode and red LED light experienced greater injury, lower vigor ratings and lower relative chlorophyll content values. After 18 weeks of exposure to light treatments following C. gloeosporioides inoculation of detached strawberry leaves, there was a significant impact of light treatments on disease severity ratings (DSRs), with the WSF+UV-B treatment having lower DSRs than all other treatments with the exception of red LED. This study demonstrated the impact of additional light on a number of strawberry plant growth parameters, as well as the negative effects of red LED irradiation at high intensities (Smith *et al.*, 2022).Plants treated with Red 10 LEDs showed the most damage but also had a noticeably higher chlorophyll content than plants treated with other treatments. Red 5 and red 10 LED treatments that were inoculated with *Colletotrichum gloeosporioides* exhibited the highest disease severity ratings (DSRs), while red 1 LED and WSF treatments displayed the lowest DSRs. Five days of additional lighting did not stop the growth of Colletotrichum isolates, even after high-intensity LED exposure, although WSF 1 UVB light treatment did slow their growth (Smith *et al.*, 2023). In a solar greenhouse, Wang *et al.*, (2023) investigated the advantages of supplementing red/blue light (R/B = 2:1) on Yanli strawberries. Throughout the course of two years, additional R/B light increased plant height by 13%–17%, crown diameter by 1.07–1.38 times and net photosynthetic rate by 19%. The fresh weight of strawberries increased by 18%–24%, while the total fruit weight per plant increased by 27%–33%. Fruit firmness increased by 1.05–1.21 fold and soluble solid content by 1.06–1.88 fold, respectively. Differentially expressed genes linked to light response and sucrose metabolism were found using RNA-seq, which shed light on how R/B light affects strawberry photosynthesis and fruit quality.

Zhang *et al.,* (2018) found that by increasing total anthocyanin content through enhanced gene expression, red light, blue light and a combination of both (RBL) accelerated fruit coloration. RBL significantly promotes anthocyanin and proanthocyanidin biosynthesis across both genotypes during fruit development, as evidenced by the a*, C* and h° values in Tokun at 28 DAF. It's interesting to note that in Toyonaka, BL and RL precisely increased anthocyanins and proanthocyanidins, respectively, indicating genotype-specific reactions to light quality. These results highlight the importance of taking genotype variations into account when making changes to light quality in strawberry cultivation, providing a way to manipulate levels of anthocyanin and proanthocyanidin to improve fruit health properties.

2.4 Photosynthetic activities in strawberry

Three UV-C dosages (0.43, 2.15 and 4.30 kJm−2) were tested by Erkan *et al.,* (2008). They observed that treatments lasting five and ten minutes considerably increased non-enzyme antioxidants like glutathione and significantly improved antioxidant capacity as indicated by oxygen radical absorbance capacity (ORAC) values. While storage, phenolic and total anthocyanin contents also increased; however, anthocyanin accumulation was not significantly affected by UV-C. When compared to the control, all UV-C treatments decreased decay; the greatest decay inhibition was observed during exposures of five and ten minutes. Overall, strawberries' antioxidant qualities were successfully enhanced and their deterioration was postponed during storage under UV-C illumination.

Red and blue LED treatments improved plant development, increased carbohydrate accumulation and enhanced pigment ratios, according to Samuolienė *et al.,* (2010) study, which was carried out in controlled chambers and greenhouses. Only red light induced the flowering stem to elongate, increasing the shoot-to-root ratio. The development of runners, inflorescence and crown was favorably impacted by both red and blue light. Red light alone produced smaller fruits, but these light treatments had no discernible impact on the total harvest. The results underline how crucial it is to combine red and blue LEDs for the best growth of frigo strawberries.

Supplemental UV or orange light increased phenolic compounds, UV or green light boosted α-carotene and green light enhanced anthocyanins, according to study by Samuoliene *et al*. 2013. Tocopherol and ascorbic acid levels, however, were adversely affected by all additional LED colors. LED and HPS lighting were ineffective because drops in important phytochemicals were not balanced by increases in some compounds. Tocopherols were only increased by brief exposure to 638 nm LEDs prior to harvest. They observed that although broader-spectrum lighting lessens the effects of narrow-bandwidth light, LED wavelength control has a significant impact on the production of secondary metabolites.

An investigation by Hidaka *et al.*, (2013) reported that LED lighting greatly boosted photosynthesis, resulting in increased leaf dry matter, leaf area and specific leaf weight. This was achieved with PPFD values exceeding 400 μmol m^2 s^{-1}. Therefore, in comparison to fluorescent lighting, there were more fruits overall, more of them on average and a marketable yield. Under LED illumination, the fruit's soluble solids content—which indicates sweetness—also increased. According to the results, growing strawberries under forced light with high irradiance LED lighting is a productive approach.

The blue light treatment significantly raised glucoraphanin in roots but decreased gluconapin, which gives shoots their bitter flavor. According to Qian *et al.*, (2015), sprouts grown in blue light had the highest levels of total phenolic compounds, anthocyanins and the strongest antioxidant capacity, while sprouts grown in white light had the highest vitamin C content. This implies that utilizing a colorful light spectrum can improve Chinese kale sprouts' nutritional phytochemical profile and consumer acceptance.

The assessment of fruit quality-related phytochemicals and growth traits under blue, red and combined blue and red LED light wavelengths was the main goal of Choi *et al.*, (2015). Fruits from the PG had higher levels of organic acid than those from the GC when they were harvested. Notably, adding blue or a combination of red and blue LED light to the PG's ambient light increased fruit production noticeably. Conversely, fruits grown in the PG accumulated more organic acids and phenolic compounds when exposed to red LED lights, or to red LED lights combined with blue ones. These results imply that in strawberry growing environments, LED light supplementation can affect phytochemical composition and fruit yield.

Sabine *et al.,* (2015) emphasized the significance of comprehending how phytochromes, which control a variety of physiological processes, enable plants to perceive R and FR wavelengths as well as the R ratio. The review made clear that different species and growing environments can exhibit different phenotypic reactions to light and that research is still being done to determine the underlying molecular mechanisms of these variations. With the use of technologies like photo-selective films and LEDs, horticulturists are able to manipulate light quality and increase crop yield and quality.

The differences in experimental designs present comparison problems, according to Ouzonuis *et al.,* (2015), which makes it hard to apply knowledge from controlled settings directly to greenhouses. When designing light modules for enclosed spaces, dynamic light levels and the spectral composition of the light throughout the day must be taken into account. High-efficiency LEDs, in contrast to traditional HPS lamps, can save energy and benefit plants by providing a higher percentage of blue light. For plants to grow, perform well after harvest and produce certain metabolites, this strategy is essential.

According to Pandey *et al.,* (2015), comparing the fruits from the polyhouse to those from the open field, the former displayed higher total chlorophyll content (2.02 mg/g), root weight (Y), number of roots/plant (Z) and root volume (X). Contrarily, the strawberries grown in the polyhouse showed higher levels of anthocyanin content (45.51 mg per 100 g), fruit yield (242.77 g/plant), number of fruits/plant (29.00) and crown height (A) and plant spread (B). Higher total and reducing sugar content (C), vitamin C content (50.32 mg per 100 g) and sensory scores (8.35 out of 10) were observed in fruits from the open field, suggesting that growth and quality of strawberries were supported in both settings.

In light of the urgent concerns surrounding food security and climate change, Rouphael *et al.,* (2018) investigated methods for enhancing the quality of vegetables grown in controlled environments. They emphasized the benefits of indoor and greenhouse growing systems in terms of yield optimization, out-of-season production and crop quality manipulation. The review underscored the importance of genotype selection, microclimate management, nutrient solution strategies, biofortification techniques and the use of plant biostimulants in improving the chemical composition and bioactive profile of greenhouse crops. Finally, the authors suggested future research directions aimed at further improving the quality of vegetables grown in controlled environments.

Bantis *et al.,* (2018) conducted a review that covers a wide range of applications in climate rooms, vertical farming and greenhouse environments. The review provides insightful information for both researchers and growers. The overview emphasizes how LED technology can improve crop yield, as well as pre- and post-harvest product quality, phytochemical content, nutritional value, flowering control, transplant success and regeneration material production. The study ends with recommendations for future opportunities and paths in this quickly developing field.

The results of Xu *et al.,* (2023) demonstrated significant improvements in fruit quality attributes: extra light boosted polyphenol concentrations by 15.5% early in the season and total sugar, glucose and fructose concentrations by approximately 10% in the late season. Early in the growing season, deficit irrigation significantly increased fruit glutamate concentrations by 12.3% and anthocyanins by 25%. Incorporating silicon (Si) spray early in the season resulted in a significant increase in anthocyanins, polyphenols and citrate concentrations of up to 41.7%, 14.7% and 8.2%, respectively. Later in the season, there was also an 8.8% increase in single fruit mass. It is recommended that growers consider deficit irrigation as a water-saving technique and combine silicate spray with additional lighting for high-quality strawberry production.

Victor *et al.,* (2023) noticed that the best results for plant growth and productivity were obtained when 20% GL, 20% BL and 60% red light (RL) were combined. Fruit quality attributes, net photosynthesis rate and water-use efficiency were all improved by this blend. Nevertheless, the effects became negative or similar to using only 6% GL with 36% BL and 58% RL when the GL proportion rose to 27%, which included 12% BL and 61% RL. The aforementioned results underscore the importance of maximizing light spectra, particularly GL, in indoor farming systems to attain ideal growth and yield parameters in strawberries and possibly other premium crops appropriate for these kinds of conditions.

CHAPTER-III

MATERIALS AND METHODS

The research entitles **“Effect of Full Spectrum Supplementary Light on Growth, Yield and Quality Attributes of Strawberry (*Fragaria X ananassa* Duch.) Under Vertical Farming System”**. The study of physical attributes was initiated in Month of December at Agricultural Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab during 2020-2023. The study of chemical attributes was carried in Laboratories of Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab. The details have been described below:

3.1 Vertical Farming System: Growing food in vertically stacked layers is known as vertical farming. The procedure can make use of hydroponic and sand growing techniques. It consists of iron rack of 2 feet wide and 4 feet long having four layers (levels) Each level is 2 feet apart vertically. Full spectrum grow light of 22 W (length 2 feet) is installed just below every level. Grow light is provided to plants for different hours according to need of plant.

Parameters	**Frame 2**	**Method of analysis**
pH	6.4	Digital pH meter
Electrical Conductivity	830-870mg/L	Digital EC meter

In Punjab region, only few areas are suitable for the cultivation of strawberry because it is a subtropical area with humid and hot condition. Maximum temperature recorded is in between 21-24^{o}C. Punjab receives monsoons from both south-west and north-east direction from August to February.

3.2 Selection of variety of strawberry:

The variety mentioned below has been taken from *Gunjan Strawberry, Solan. The germplasms Winter Dawn has been identified for evaluation.

The details of materials used and methodology opted has been described below:

- **Location:** Horticulture farms, Department of Horticulture, Lovely professional University.
- **Crop:** Strawberry
- **Variety**: Winter Dawn
- **Total number of Treatments**: 13
- **Replication:** 3

- **Design:** Randomized block design (RBD)
- **Conditions**
  - Outdoor conditions (OC)
  - Indoor conditions (IC)
- **Base Material:** Cocopeat, Vermicompost and Soil (3:2:1)
- **Spacing:** 20 X 25 cm
- **N:P:K:** 80:40:40 (Kg/ha)
- **Light Intensity:**
  - **Open condition:** 6646.40 - 9128.68 lux
  - **Indoor condition:** 4320.12 - 6197.78 lux

Weather Information

Months	Max Temp (°C)	Min Temp (°C)	RH (%)	Rain (mm)	Evaporation (mm)
Dec-21	21.78	9.87	90.34	0.18	0.86
Jan-22	15.97	10.29	75.90	91.35	0.09
Feb-22	16.29	9.04	73.07	0.59	0.99
Mar-22	27.00	17.84	53.74	0.00	2.72
Apr-22	38.70	27.20	42.03	0.02	6.01
Dec-22	24.84	10.26	90.16	0.06	0.95
Jan-23	15.58	7.07	91.55	1.58	0.91
Feb-23	25.43	11.94	81.18	0.00	2.51
Mar-23	27.45	14.99	73.09	1.79	1.95
Apr-23	33.07	16.41	72.43	0.39	4.27

Treatments

1. **Four Levels**

   a. First Layer (ground) (L1)
   b. Second Layer (L2)
   c. Third Layer (L3)
   d. Fourth Layer (top) (L4)

2. **Types of Light**
   a. Natural light: LT1
   b. Full spectrum light:LT2
3. **Duration of the light**
   a. 2 hours: D1
   b. 4 hours: D2
   c. 6 hours: D3
   d. 8 hours: D4

There are two experiment

- **Treatment Combination of first experiment:**

Outdoor Condition

Treatment	**Details**
T1	LT1+ L4+OC (Natural light+ Fourth Level)
T2	LT1+L3+OC (Natural light+ Third Level)
T3	LT1+L2+OC (Natural light+ Second Level)
T4	LT1+L1+OC (Natural light+ First Level)
T5	LT1+LT2D1+L3 (Natural light +Full spectrum light for 2 hours+ Third Level)
T6	LT1+LT2D2+L2 (Natural light+ Full spectrum light for 4 hours + Second

	layer)
T7	LT1+LT2D3+L1 (Natural light+ Full spectrum light for 6 hours + First Level)

- **Treatment Combination of Second experiment:**

Indoor Condition

Treatment	**Details**
T1	LT1+L4 (Natural light+ Fourth Level)
T2	LT1+LT2D2+L3 (Natural light + Full spectrum light for 4hours + Third Level)
T3	LT1+LT2D3+L2 (Natural light + Full spectrum light for 6hours + Second Level)
T4	LT1+LT2D4+L1 (Natural light + Full spectrum light for 8hours + First Level)
T5	LT1+LT2D3+L3 (Natural light + Full spectrum light for 6hours + Third Level)
T6	LT1+LT2D4+L2 (Natural light + Full spectrum light for 8hours + Second Level)

Observations Recorded:-

Sr.No.	**Quantitative Parameters**	**Sr.No.**	**Quantitative Parameters**
1	Plant height (cm)	**8**	Days to flowering
2	Plant spread (cm)	**9**	Days to maturity
3	Petiole length (cm)	**10**	Number of bud formation
4	Number of leaves	**11**	Number of Flowers
5	Leaf area (sq cm)	**12**	Number of Fruiting

6	Chlorophyll content index	**13**	Fruit Set (%)
7	Days to bud formation	**14**	Average berry weight(g)

Sr.No.	Qualitative Parameters	Sr.No.	Qualitative Parameters
1	Fruit volume (cm^3)	**10**	Total Sugars (%)
2	Average berry weight(g)	**11**	Total flavonoids content **(**mg of QE per g)
3	Yield (g/plant)	**12**	Total phenols content **(**mg of GAE per g)
4	Estimated Yield (kg per 1000 sqm)	**13**	Antioxidants (%)
5	Total soluble solids (˚Brix)	**14**	Chlorophyll a **(**mg per g)
6	Titratable acidity (%)	**15**	Chlorophyll b **(**mg per g)
7	Ascorbic acid (mg per 100g pulp)	**16**	Total Chlorophyll content **(**mg per g)
8	Reducing sugar (%)	**17**	Total Anthocyanin Content (mg per g)
9	Non-Reducing Sugar (%)	**18**	Total Caretenoids Content **(**mg/g)

3.3 Parameters Details:

A. Quantitative Traits

The quantitative traits are usually multigenic traits which show a continuous variation and are greatly influenced by environmental factors. The common quantitative traits are:

3.3.1 Vegetative parameters:

3.3.1.1 Average plant height (cm): The length of plant was recorded by measuring the distance between the level of crown to tip of primary leaf using the measuring tape. The measurement was taken after 30, 60 days and 90 days of planting and mean was presented in centimeters (cm).

3.3.1.2 Average plant spread (cm): The growth of the plant was determined in North-South (N-S) as well as in East West (E-W) direction after 30, 60 days and 90 days of planting and mean was presented in centimeters (cm).

3.3.1.3 Petiole length: The length of petiole was recorded by measuring the distance between the stem and the leaf base using the measuring scale. The measurement was taken after 30, 60 days and 90 days of planting and mean was presented in centimeters (cm).

3.3.1.4 Average number of leaves: The leaves present on plants were counted after 30, 60 days and 90 days of planting and mean value was presented.

3.3.1.5 Leaf Area: The leaf area was measured using leaf area meter. It was measured at 30 and 60 days of planting. The mean was presented in cm^2.

3.3.1.6 Chlorophyll Content Index (CCI): Chlorophyll is the pigment that gives plants their characteristics green colour. The contents of chlorophyll are usually three times than chlorophyll b in the leaf tissue. Chlorophyll index was measured by SPAD meter at 90 days after planting. The model SPAD-502^+ (Konica Minolta Sensing, Inc., Sakai, Osaka, Japan) which work on the ration of transmission of two closely related wavelength viz., 940 and 650 nm (Cerovic *et al.*, 2012) & Markwell *et al.*, 1995).

$$\mathrm{CCI} = \log \frac{\%\ \text{transmission of } 940\text{nm}}{\%\ \text{transmission of } 650\text{nm}}$$

3.3.1.7 Days to bud formation, flowering and fruiting: From the date of planting the days to bud formation, flowering and fruiting were counted.

3.3.2 Flowering and fruiting parameters

3.3.2.1 Average number of flowers and floral buds per plant: The floral buds and flowers present on plants were counted after 60 days of planting to till last flowering and sum of this value was presented. The flowers count on randomly selected plants of each replication was counted at the different time interval and the finding was expressed as average number of flowers per plant.

3.3.2.2 Percentage of buds developed as flowers: Many of the buds were reported to get deformed under hydroponic solution and same was noticed and counted. The percentage of buds opened to a flower were expressed as percentage.

3.3.2.3 Average number of fruits per plant: The fruits count on randomly selected plants of each replication was done at the time of harvesting and the sum of each harvesting was taken as average number of fruits.

3.3.2.4 Fruit set (%): The fruit set percent was estimated by using the formula given herewith.

$$\text{Fruit set (\%)} = \frac{\text{Average number of fruits harvested at maturity x 100}}{\text{Average number of flowers count per}}$$

3.3.3 Yield and quality parameters of strawberry fruits

3.3.3.1 Average berry or fruit weight (g): The weight of ten randomly selected fruits from each plot was measured by using electronic balance and the average berry weight was estimated and presented in grams (g).

3.3.3.2 Average fruit yield per plant (g): The weight of fruit harvested from randomly selected plants at different interval was summed up and mean was calculated to determine the average yield per plant and was expressed in grams.

3.3.3.3 Estimated Yield (kg per 1000 sq. m.): The average fruit weight per plant was used to calculate the fruit yield from 1000 sq. m. of vertical farming system using the given formula and the estimated yield was expressed in kg per 1000 sq.m. (there were 15 plants in the experimental area [0.743 sq.m.] of vertical rack).

$$\text{Yield (quintal per 1000 sq. m.)} = \frac{\text{Average fruit yield per plant (g) x 15}}{0.743} x \frac{1000}{100}$$

3.3.3.4 Total soluble solids (˚Brix): The TSS of ripe fruit juice was determined with the help of a digital refractometer by placing a few drops of juice on the prism. The total soluble solids are expressed in ^{0}Brix.

3.3.3.5 Titratable acidity (%): Titratable acidity of a fruit is the quantity of acids present in the fruit juice which can be estimated by titrating it against a standard NaOH solution. When NOH solution is added to fruit juice neutralization process is started. The known quantity of NaOH solution used to bring complete neutralization of organic acids present in juice is used to determine the quantity of acidity of fruit juice. A 100 ml volumetric flask was filled with a predetermined amount of crushed fruit sample. A 100 ml volume was achieved by adding distilled water. Following filtration, 10 ml of the resultant solution was moved to a different conical flask and used to titrate 0.1N (4g/1000g) sodium hydroxide using phenolphthalein. The endpoint was indicated by a faint pink color. Note the readings and calculate using the formula.

3.3.3.6 Ascorbic acid or Vitamin-C (mg per 100g):

Ascorbic acid is a good reducing agent which reduces 2, 6-dichlorphenol-indophenol (DCPIP) dye and itself gets oxidized. Thus, in absence of any reducing or oxidizing substance as contaminant the amount of standard dye solution reduced during titration is directly proportional to the ascorbic acid content. The vitamin-C level of strawberry fruit was estimated as per the guidelines of AOAC (Horwitz and Latimer, 2000).

Reagents used:

1. 3% Metaphosphoric acid [$(HPO_3)_n$] solution.
2. Dye solution: 50 mg of DCPIP dissolved in 150 ml of hot distilled water to make the volume 200 ml. Prepared freshly before every titration.
3. Standard ascorbic acid solution: 100 mg of L- ascorbic acid dissolved in desirable volume of 3% metaphosphoric acid solution and volume was made up to 100 ml. 10 ml of stock solution was diluted by 3% metaphosphoric acid to make the concentration as 0.1mg ascorbic acid per ml.

Procedure followed:

Standardization of dye: 5 ml of standard ascorbic acid solution was diluted with 5 ml of 3% metaphosphoric acid. Titration of ascorbic acid solution was done with dye solution till pink colour persists for 10 second. The dye factor (mg of ascorbic acid per ml of dye) was calculated as follows:

$$\text{Dye factor} = \frac{0.5}{\text{titer value}}$$

Preparation of sample and titration

10 ml of fruit juice sample was taken and volume was made up to 100 ml by using 3% HPO_3solution and filtered. A quantity of 10 ml from filtrate was taken out through pipette in a conical flask and titration was carried out against the standard dye till pink end point. Ascorbic acid or vitamin C content was calculated as below:

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre value x Dye factor x Volume made up x 100}}{\text{Volume of filtrate taken x Volume of sample taken}}$$

3.3.3.7 Total soluble solids: acid ratio: The TSS / acidity ratio of fruit is essentially a measure of the sugar content versus acidity which gave fruits characteristics taste and flavour. The TSS or sugar content is usually obtained from assessing the Brix of the fruit**.** It was worked out by dividing the TSS to titratable acidity.

3.3.3.8 Total sugars (%): 4ml of anthrone reagent was added to 1ml of juice. Water bath at 100^0C for 8 minutes and check the O.D. at 630nm.

3.3.3.9 Reducing sugars (%): It was done by using Nelson – Somogyi method. Take 1ml of strawberry juice and make the volume to 3ml by adding distilled water. Add 3ml of the DNS reagent. Keep in water bath at 100^0C for five minutes. Afterwards add 1ml of 40% Rochelle salt. Allow it to cool and take O.D.at 510nm.

3.3.3.10 Non- Reducing sugars (%): It was calculated by subtracting reducing sugars from total sugars.

3.3.3.11 Antioxidants (%): Ferric reducing ability of plasma (FRAP) assay, proposed by Benzie and Strain (1996), was adopted to evaluate the antioxidant capacity of sprouts. The sample extracts were prepared in the same way as described in total phenolic content assay above. Then, 0.3 ml of the extracts were added to 2.7 ml of FRAP working solution, composed of 300 mM acetate buffer (pH 3.6), 10 mM 2,4,6-tripyridyl-S-triazine in 40mM HCl and 20 mM FeCl3.6H2O with the ratio of 25:1:1. The mixture was vortexed and incubated at 37 °C for 10 min. The absorbance was recorded at 593 nm. FRAP values were calculated against FeSO4.7H2O standard curves and expressed as μmol g–1 FW.

3.3.3.12 Total Flavonoids Content (%): Flavonoids were determined according to the Woisky and Salatino (1998) method. An extract was prepared with 1 g of strawberry fruit tissue and adding 10 mL of methanol and the mixture homogenized for 20 s and filtered. From the filtered mixture, a 2 mL sample was mixed with 2 mL of aluminum trichloride at 2% (w/v) and left for 15 min in the dark. The absorbance was recorded at 415 nm in a spectrophotometer and the results were expressed as equivalent mg of quercetin per 100 g of fresh mass (mg EQ/1000 gfw).

3.3.3.13 Total Phenols Content (%): The total phenolic content was estimated by Folin Ciocalteau Reagent as described by McDonald *et al.*, 2001. The extract of samples of leaf was mixed with Folin Ciocalteau Reagent (5ml, 1:10 diluted with distilled water) and aqueous Na2CO3(4ml, 1M). The mixture was then kept still for about 15 minutes and phenols were determined by colorimetry at 765nm. Total Phenols will be expressed as gallic acid equivalent per gram (mg GAE g-1 DW).

3.3.3.14 Chlorophyll a: The Chl a, Chl b and total carotenoids were determined by the different methods. The acetone-water mixture (4:1) was used as a solvent. The absorbance maxima were read at 663 nm for Chl a, 645 nm for Chl b and 480.0 nm for carotenoids. Contents of Chl a, Chl b and total carotenoids were calculated from the following equations:

$$Chlorophyll\ a = 12.7 \times A663 - 2.69 \times A645 \times \frac{V}{1000 \times W}\ [\frac{mg}{g}]$$

$$Chlorophyll\ b = 22.9 \times A645 - 4.68 \times A663 \times \frac{V}{1000 \times W}\ [\frac{mg}{g}]$$

$$Total\ Chlorophyll = 20.2 \times A645 + 8.02 \times A663 \times \frac{V}{1000 \times W}\ [\frac{mg}{g}]$$

$$Total\ Caretenoids = 1000 \times (A480 - 1.29 \times A663 - 0.064 \times A645) \times \frac{V}{1000 \times W}[\frac{mg}{g}]$$

The results were expressed as micrograms per gram fresh weight of sample (Holm, 1954 and Ewais *et al.,* 2022)

3.3.3.15 Total Anthocyanin Content: The total anthocyanin content was determined using different methods. Two buffer solution were prepared. In first buffer solution (a) 1M anhydrous sodium acetate and (B) 1N HCl dissolved in distilled water for making 100ml both solution seperately at pH 4.5. Take 40 ml of A and 24 ml of B up to 100ml with distilled water and mix well. In second buffer solution (A) 0.2 N KCl were taken in 100 ml distilled water and (B) 0.2 HCl were taken in distilled water upto volume 100ml. Then 24 ml of A and 76 ml of B solution taken in separate beaker and mix well. pH should be 1.

Procedure:

1. Take 3.5 ml of buffer solution 1, 4.5 ml of buffer solution second in 2 separate test tubes and add 0.5 ml of extract in the test tubes.
2. If turbidity (cloudiness) appears then centrifuge extract 2 times.
3. Note readings at 520nm and 700nm (Reading of pH1>pH 4.5).
4. Take 4 ml of distilled water for blank solution.

Calculation:

$$TAC = (A520 - A700)pH\ 1 - (A520 - A700)pH4.5$$

$$Total\ anthocyanin\ \left(\frac{mg}{L}\right) = A \times MW \times DF \times \frac{10^3}{E \times L}$$

Where, E=Molar extinction coefficient

MW= Molecular weight of predominant anthocyanin

DF= Dilution factor

L= path length of cuvette

3.4 Statistical analysis

The data was statistically analysed by using MS-Excel and OPSTAT software. The mean values of observations were subjected to analysis for Randomized Complete Block Design (RCBD) for comparing means and to evaluate the statistical significance for variation due to genotypes as explained by Gomez and Gomez (1976, 1984). The analysis was done for following parameters:

3.4.2 Analysis of variance (ANOVA)

3.4.3 Mean performance

3.4.1. Analysis of variance (ANOVA): The recorded mean of all the quantitative traits for each replication was exposed to statistical analysis for testing the significance of variation among different genotypes by F-test (Panse and Sukhatme, 1967).

$$Y_{ij} = \mu + g_i + r_j + e_{ij}$$

Where,

Y_{ij} = Phenotypic observations of i^{th} genotype grown in j^{th} replication

μ = General population mean

g_i = Influence of i^{th} genotype

r_j = Influence of j^{th} replication

e_{ij} = Error component

The estimation of degrees of freedom, mean sum of squares and ‘F’ value were done as per the table given below:

Source of variance	**Degree of freedom**	**Sum of squares**	**Mean sum of Squares**	**F-value**
Replication(r)	$\boldsymbol{r-1=2}$	$\boldsymbol{SSR=\frac{1}{t}\sum_{j} Y_j^2 - C.F.}$	$\boldsymbol{MSR=\frac{SSR}{(r-1)}}$	$\boldsymbol{\frac{MSR}{MSE}}$
Genotypes(g)	$\boldsymbol{g-1=11}$	$\boldsymbol{SSG=\frac{1}{r}\sum_{i} Y_i^2 - C.F.}$	$\boldsymbol{MSG=\frac{SSG}{(r-1)}}$	$\boldsymbol{\frac{MSG}{MSE}}$
Error(e)	$\mathbf{(r-1)(g-1)}$	$\mathbf{SSE = SST - SSG}$	$\boldsymbol{MSE=\frac{SSE}{(r-1)(g-1)}}$	
Total	$\boldsymbol{gr-1}$	$\boldsymbol{SST=\sum_{i}.\sum_{j} Y_{ij}^2 - C.F.}$		

Where,

r : Number of replications

g : Number of genotypes

SSR : Sum of squares due to replications

SSG : Sum of squares due to genotypes

SSE : Sum of squares due to error

SST : Total Sum of squares

MSR : Mean sum of squares due to replications

MSG : Mean sum of squares due to genotypes

MSE : Mean sum of squares due to error

$$\text{C. F. (Correction Factor)} = \frac{1}{rt}\left(\sum_i . \sum_j Y_{ij}^2\right)^2$$

If $F_{calculated} < F_{tablevalue}$, result was not siginifcant

If $F_{calculated} \geq F_{tablevalue}$, result was siginifcant and CD is calculated

The standard error of the difference between any two genotype means was expressed as:

SE (m) ± = $\sqrt{MSE/r}$

SE (d) ± = $\sqrt{2MSE/r}$

Where,

S.E. (m) ± = Standard error of mean

S.E. (d) ± = Standard error of difference

The significance of differences between two genotypes for a trait was done by using t-test. The CD was calculated as:

$$CD_{0.05} = \text{S. E. (d) x } t_{(0.05\ anderrorDF)}$$

Where,

$CD_{0.05} =$ Critical difference at $p \leq 0.05$

$t_{(0.05\ anderrorDF)}$ = t value at 5% significance level and error DF

3.4.2. Mean performance: Mean performance of each parameter was calculated by using the formula as given below:

$$\bar{X} = \frac{\sum X_i}{n}$$

Where,

$\bar{X} = mean$

$X_i = value of i^{th} plant for a trait$

n = total number of plants

CHAPTER-IV

RESULT AND DISCUSSION

The present research work entitled **Effect of full spectrum supplementary light on growth yield and quality attributes of strawberry under vertical farming system**, is a field experiment that has been carried out under indoor and outdoor conditions near polyhouse at Horticultural Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab during 2022-2023. The research was divided into two experiments according to indoor and outdoor conditions under various traits. The experimental studies are the following:

4.1 EXPERIMENT 1: OUTDOOR CONDITIONS

In this experiment, two structures were placed outside. In one structure all the treatments (levels) were placed under natural light while in other structures according to level full spectrum light was provided for 2,4 and 6 hours.

4.1.1 Plant height (cm) (30, 60 and 90 DAP)

The data pertaining to plant height (cm) of strawberry plants, presented in Table 4.1, confirms significant variation among different treatments grown under outdoor conditions at 30, 60 and 90 days after planting (DAP). At 30 DAP, treatment T2 (natural light + third level) has the highest plant height (13.09, 14.25 and 13.67 cm) followed by T1 (natural light + fourth level) (13.19, 13.82 and 13.50 cm) and T4 (natural light + first level) (12.05, 13.03 and 12.54 cm) in the year 2022, 2023 and pooled data. In additional full spectrum light (AFSL), the highest plant height (12.81, 14.12 and 13.46 cm) was observed in treatment T7 (natural light + full spectrum (6 hours) + first level) in year 2022, 2023 and in pooled data followed by T5 (natural light + full spectrum (2 hours) + third level) (13.14, 13.58 and 13.36 cm) and T6 (natural light + full spectrum (4 hours) + second level) (13.03, 13.43 and 13.23 cm). Treatments T1, T2 and T7 were at par throughout the year of observations and in pooled data.

After 60 DAP, the highest plant height (22.81, 23.49 and 23.15 cm) in the year 2022, 2023 and pooled data were observed in T1 (natural light + fourth level) under natural light followed by T2 (natural light + third level) (18.37, 19.48 and 18.93 cm) and T3 (natural light + second level) (17.43. 18.89 and 18.16 cm). In artificial full spectrum light, treatment T5 (natural light + full spectrum (2 hours) + third level) has (21.59, 21.12 and 21.36 cm) highest plant height followed by T6 (natural light + full spectrum (4 hours) + second level) (17.39, 18.52 and 17.95 cm) and T7 (natural light + full spectrum (6 hours) + first level) (16.61, 18.20 and 17.40 cm) in year 2022, 2023 and pooled data. In the overall study, it was observed that T1 was superior and T3 was inferior.

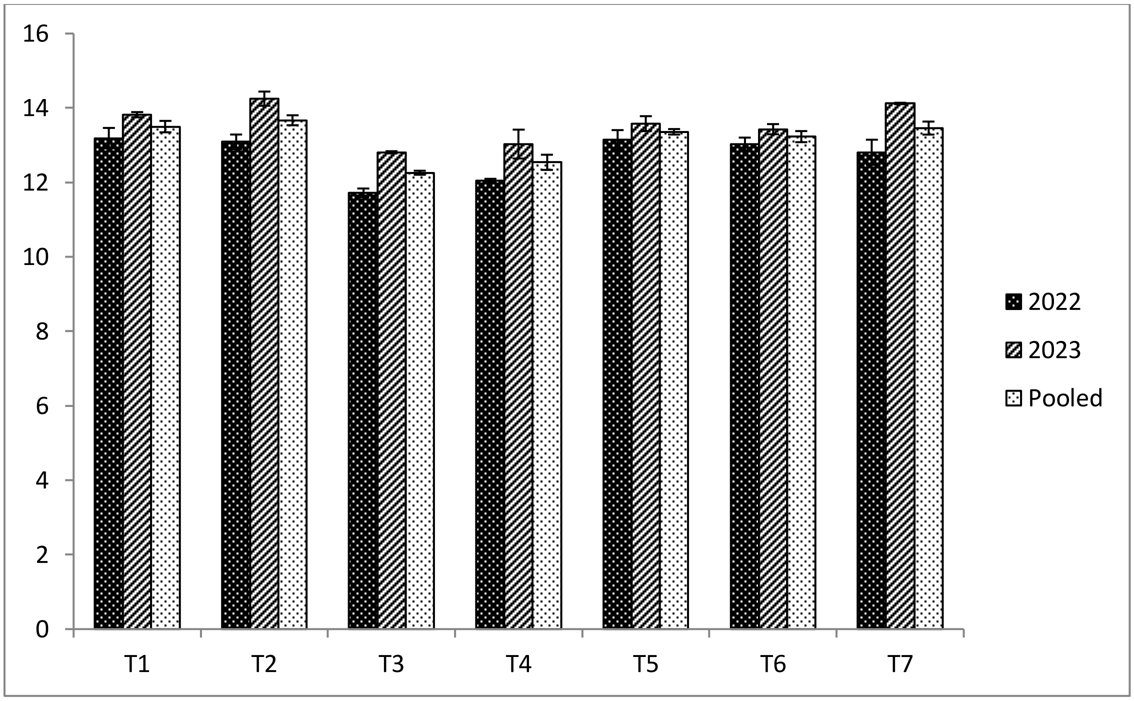

Fig 4.1. Effect of full spectrum light on plant height at 30 DAP under vertical farming system in outdoor conditions

Table 4.1: Effect of full spectrum light on plant height under vertical farming system in outdoor conditions.

	Plant Height 30 days (cm)			**Plant Height 60 days (cm)**			**Plant Height 90 days (cm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	13.19 ± 0.274^{a}	13.82 ± 0.069^{ab}	13.50 ± 0.153^{ab}	22.81 ± 0.370^{a}	23.49 ± 0.468^{a}	23.15 ± 0.410^{a}	17.67 ± 0.285^{b}	17.97 ± 0.384^{bc}	17.82 ± 0.330^{b}
T2	13.09 ± 0.197^{a}	14.25 ± 0.191^{a}	13.67 ± 0.134^{a}	18.37 ± 0.154^{c}	19.48 ± 0.183^{c}	18.93 ± 0.168^{c}	14.55 ± 0.222^{d}	15.67 ± 0.285^{c}	15.11 ± 0.251^{c}
T3	11.72 ± 0.117^{b}	12.8 ± 0.029^{c}	12.26 ± 0.054^{c}	17.43 ± 0.439^{d}	18.89 ± 0.254^{cd}	18.16 ± 0.342^{cd}	15.62 ± 0.090^{c}	16.73 ± 0.019^{c}	16.18 ± 0.037^{c}
T4	12.05 ± 0.047^{b}	13.03 ± 0.388^{c}	12.54 ± 0.204^{c}	17.09 ± 0.044^{de}	18.33 ± 0.094^{d}	17.71 ± 0.046^{d}	14.70 ± 0.234^{cd}	15.57 ± 0.110^{c}	15.13 ± 0.169^{c}
T5	13.14 ± 0.266^{a}	13.58 ± 0.200^{b}	13.36 ± 0.074^{ab}	21.59 ± 0.167^{b}	21.12 ± 0.164^{b}	21.36 ± 0.164^{b}	18.10 ± 0.522^{b}	18.26 ± 0.784^{b}	18.18 ± 0.604^{b}
T6	13.03 ± 0.174^{a}	13.43 ± 0.137^{bc}	13.23 ± 0.149^{b}	17.39 ± 0.041^{de}	18.52 ± 0.358^{d}	17.95 ± 0.166^{d}	19.19 ± 0.205^{a}	21.16 ± 0.707^{a}	20.17 ± 0.455^{a}
T7	12.81 ± 0.337^{a}	14.12 ± 0.020^{a}	13.46 ± 0.175^{ab}	16.61 ± 0.221^{e}	18.20 ± 0.081^{d}	17.40 ± 0.071^{d}	19.49 ± 0.205^{a}	20.47 ± 0.318^{a}	19.98 ± 0.260^{a}
SEM±	0.23	0.16	0.12	0.26	0.28	0.25	0.30	0.46	0.36
CD at 5%	0.71	0.49	0.38	0.79	0.85	0.77	0.91	1.42	1.12
CV%	3.12	2.04	1.64	2.36	2.43	2.25	3.01	4.46	3.60

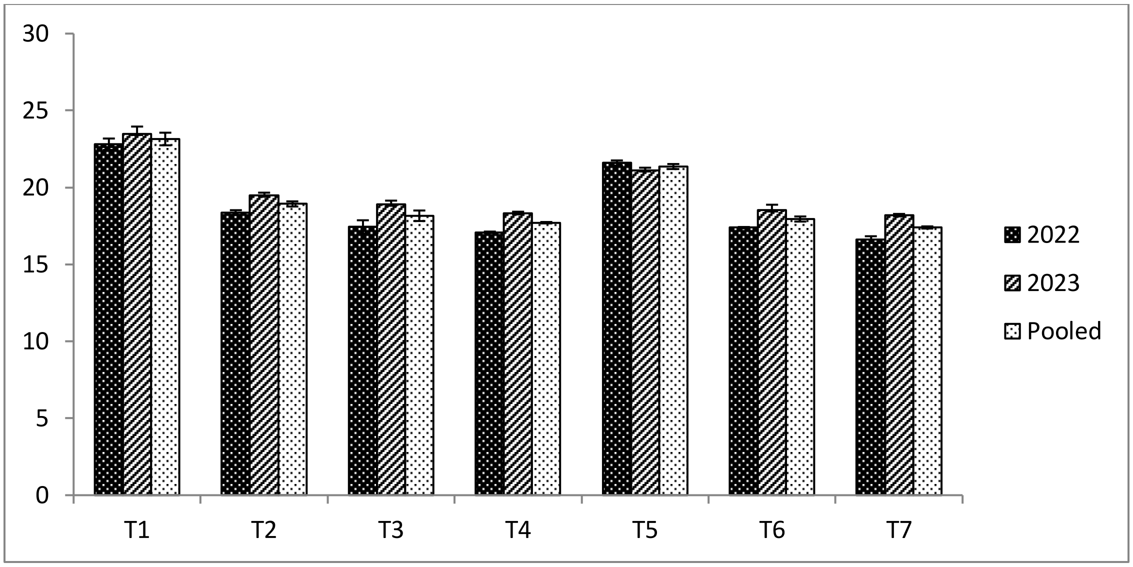

Fig 4.2. Effect of full spectrum light on plant height at 60 DAP under vertical farming system in outdoor conditions

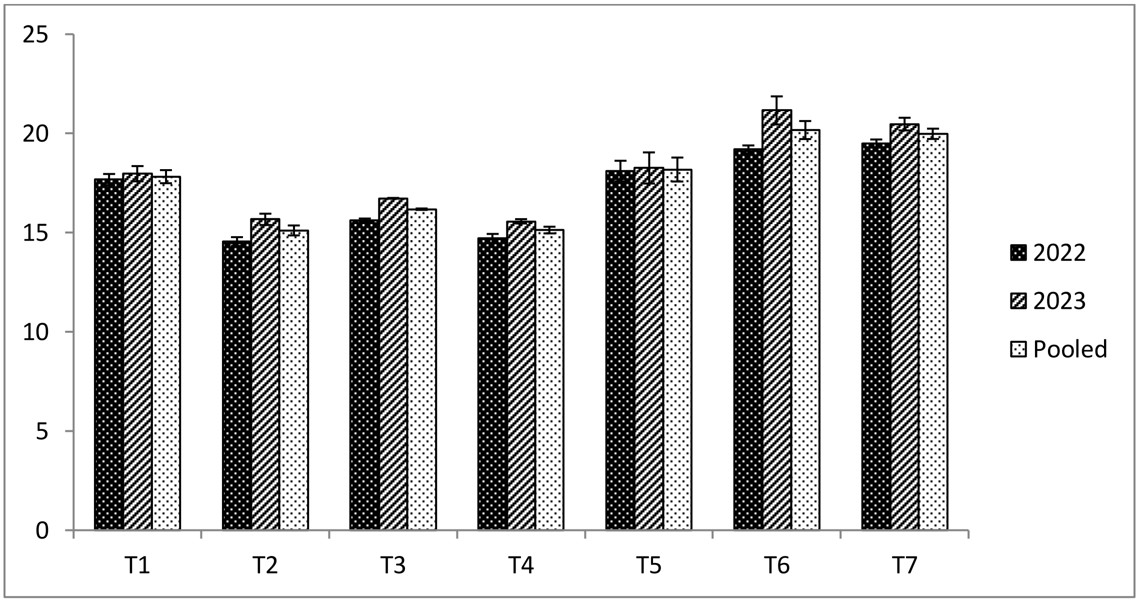

Fig 4.3. Effect of full spectrum light on plant height at 90 DAP under vertical farming system in outdoor conditions

Table 4.1, the recorded data of plant height (cm) and confirms significant variation along with different treatments grown under outdoor conditions. After 90 DAP treatment T1 (natural light + fourth level) performs superior (17.67, 17.97 and 17.82 cm) in plant height followed by T3 (natural light + second level) (15.62, 16.73 and 16.18 cm) and T4 (natural light + first level) (14.70, 15.57 and 15.13 cm) in the year 2022, 2023 and pooled data. In artificial full spectrum light, treatment T6 (natural light + full spectrum (4 hours) + second level) performs better (19.19, 21.16 and 20.17 cm) and followed by T7 (natural light + full spectrum (6 hours) + first level) (19.49, 20.47 and 19.98 cm) and T5 (natural light + full spectrum (2 hours) + third level) (18.10, 18.26 and 18.18 cm) in year 2022, 2023 and in pooled data. In the overall study, treatment T6 has the highest plant height and T2 has the lowest plant height. Treatment T6 and T7 were at par in the year 2022, 2023 and pooled data.

4.1.2 Petiole length (cm) (30, 60 and 90 DAP)

In Table 4.2, petiole length at 30 days of planting shows a significant variation among the treatments. Treatment T2 (natural light + third level) has the highest petiole length (12.83, 13.30 and 13.06 cm) in 2022, 2023 and pooled data followed by T1 (natural light + fourth level) (12.96, 12.57 and 12.77 cm) and T4 (natural light + first level) (11.81, 11.87 and 11.84 cm). Treatment T7 (natural light + full spectrum (6 hours) + first level) has the highest petiole length (12.53, 13.27 and 12.90 cm) under additional full spectrum light in year 2022, 2023 and pooled data followed by T5 (natural light + full spectrum (2 hours) + third level) (12.84, 12.85 and 12.84 cm) and T6 (natural light + full spectrum (4 hours) + second level) (12.71, 12.69 and 12.70 cm) at 30 days of planting. In the overall study, T2 performed superior while T3 was inferior. T1, T2, T5, T6 and T7 were at par in 2022 and 2023 and in pooled data (Table 4.2).

Further, after 60 DAP treatments T1 (natural light + fourth level) performs superior (22.33, 17.73 and 20.03 cm) in petiole length under natural light followed by T2 (natural light + third level) (18.11, 15.34 and 16.72 cm) and T3 (natural light + second level) (17.15, 16.25 and 16.70 cm) in year 2022, 2023 and in pooled data. With artificial full spectrum light, treatment T5 (natural light + full spectrum (2 hours) + third level) has highest petiole length (21.33, 17.93 and 19.63 cm) followed by T6 (natural light + full spectrum (4 hours) +

second level) (17.07, 20.85 and 18.96 cm) and T7 (natural light + full spectrum (6 hours) + first level) (16.30, 20.17 and 18.24 cm) in year 2022, 2023 and in pooled data. In overall performance T1 has highest petiole length and T4 has lowest petiole length. T6 and T7 were at par in year 2022, while T1 and T5 were at par in pooled data.

At 90 days of planting highest petiole length was observed in T1 (natural light + fourth level) (17.27, 13.25 and 15.26 cm) followed by T2 (natural light + third level) (14.27, 15.31 and 14.79 cm) and T3 (natural light + second level) (15.23, 14.25 and 14.74 cm) under natural light in year 2022, 2023 and in pooled data. When additional full spectrum light was provided than treatment T6 (natural light + full spectrum (4 hours) + second level) has highest petiole length (18.87, 16.08 and 17.47 cm) in year 2022, 2023 and in pooled data followed by T7 (natural light + full spectrum (6 hours) + first level) (19.13, 14.07 and 16.60 cm) and T5 (natural light + full spectrum (2 hours) + third level) (17.70, 13.85 and 15.78 cm). T6 was superior in overall performance and T3 was inferior. In 2022, T6 and T7 were at par, further T2, T4 and T6 were also at par in 2023.

The average plant height of strawberry grown under outdoor condition with additional supply of light and natural light was significantly affected by the levels of verticals and the duration of full spectrum light provided at all days of observations (30, 60 and 90 days after planting). The plants subjected with natural light have grown better when plants were at third and fourth level (T_1 and T_2) at 30 and 90 DAP and was superior in comparison to other treatments but at 60 days in T_6 where additional full spectrum light was provided for 4 hours performs better than others. Similarly, the petiole length of the plants that have been exposed to full spectrum light for 2 hours have maximum petiole length when plants were at third level (T_5) and were superior in comparison to other treatments at 30 and 60 DAP but T_1 performs superior at 60DAP. Thus, the plant height and petiole length of strawberries were significantly influenced by the length of the full spectrum light in an outdoor vertical farming system where longer exposure times to full spectrum light encouraged taller plants and longer petioles. This could be associated with the efficient utilization of nutrients provided to the plants and balanced metabolic processes under higher lux value.

Strawberry plants grown under full spectrum light demonstrated noticeable improvements in their growth compared to those subjected to NL conditions only. The optimized light spectrum provided by full spectrum LEDs facilitated photosynthesis and stimulated overall plant development, resulting in increased height and a wider plant spread (Cervantes *et al.*, 2019). Uddin *et al.*, 2018 found that LED lights improved the plant height which is somehow similar to our study. Plants exposed to full-spectrum light exhibited longer petioles, indicating enhanced nutrient absorption and transport within the plants (Peng *et al.*, 2020). Moreover, full-spectrum LEDs encouraged the initiation and expansion of leaves, thereby increasing the available leaf area for efficient photosynthesis (Shamsabad *et al.*, 2022). Additionally, the influence of full-spectrum light positively affected petiole length, which plays a vital role in nutrient uptake and leaf development.

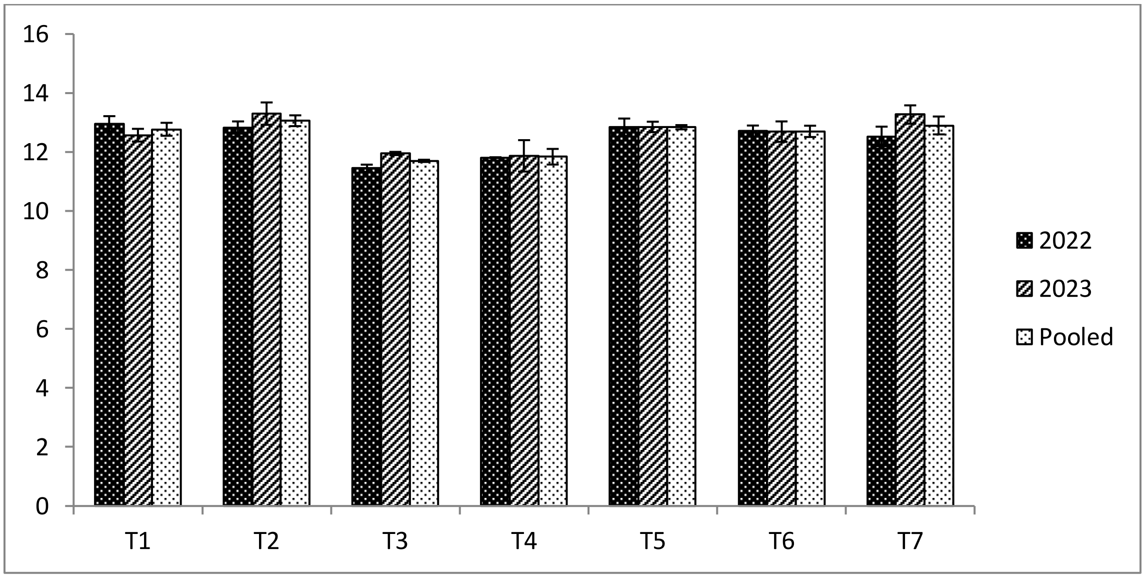

Fig 4.4. Effect of full spectrum light on petiole length at 30 DAP under vertical farming system in outdoor conditions

Table 4.2: Effect of full spectrum light on petiole length under vertical farming system in outdoor conditions.

	Petiole Length 30 days (cm)			**Petiole Length 60 days (cm)**			**Petiole Length 90 days (cm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	12.96 ± 0.255^{a}	12.57 ± 0.215^{ab}	12.77 ± 0.220^{a}	22.33 ± 0.347^{a}	17.73 ± 0.384^{b}	20.03 ± 0.205^{a}	17.27 ± 0.262^{b}	13.25 ± 0.685^{b}	15.26 ± 0.356^{cd}
T2	12.83 ± 0.207^{a}	13.30 ± 0.380^{a}	13.06 ± 0.183^{a}	18.11 ± 0.184^{c}	15.34 ± 0.305^{cd}	16.72 ± 0.245^{c}	14.27 ± 0.224^{d}	15.31 ± 0.773^{ab}	14.79 ± 0.276^{d}
T3	11.45 ± 0.122^{b}	11.95 ± 0.055^{b}	11.70 ± 0.038^{b}	17.15 ± 0.406^{d}	16.25 ± 0.129^{c}	16.70 ± 0.157^{c}	15.23 ± 0.082^{c}	14.25 ± 0.387^{b}	14.74 ± 0.191^{d}
T4	11.81 ± 0.013^{b}	11.87 ± 0.532^{b}	11.84 ± 0.265^{b}	16.85 ± 0.047^{d}	15.23 ± 0.122^{d}	16.04 ± 0.054^{c}	14.41 ± 0.262^{cd}	14.83 ± 0.325^{ab}	14.62 ± 0.28^{d}
T5	12.84 ± 0.295^{a}	12.85 ± 0.177^{ab}	12.84 ± 0.072^{a}	21.33 ± 0.184^{b}	17.93 ± 0.765^{b}	19.63 ± 0.408^{ab}	17.70 ± 0.472^{b}	13.85 ± 0.218^{b}	15.78 ± 0.262^{c}
T6	12.71 ± 0.188^{a}	12.69 ± 0.347^{ab}	12.70 ± 0.191^{a}	17.07 ± 0.041^{d}	20.85 ± 0.697^{a}	18.96 ± 0.334^{b}	18.87 ± 0.175^{a}	16.08 ± 0.262^{a}	17.47 ± 0.212^{a}
T7	12.53 ± 0.330^{ab}	13.27 ± 0.312^{a}	12.90 ± 0.303^{a}	16.30 ± 0.219^{d}	20.17 ± 0.299^{a}	18.24 ± 0.117^{b}	19.13 ± 0.238^{a}	14.07 ± 0.349^{b}	16.60 ± 0.278^{b}
SEM±	0.24	0.30	0.19	0.25	0.32	0.25	0.28	0.47	0.26
CD at 5%	0.73	0.91	0.57	0.78	0.99	0.76	0.87	1.44	0.81
CV%	3.28	4.07	2.58	2.38	2.87	2.36	2.93	4.58	2.93

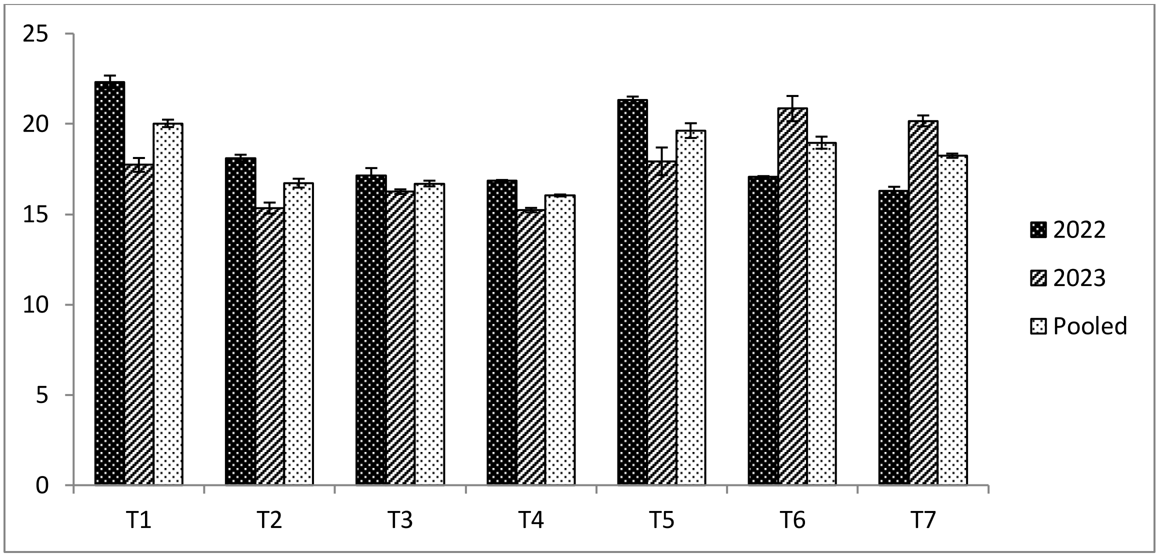

Fig 4.5. Effect of full spectrum light on petiole length at 60 DAP under vertical farming system in outdoor conditions

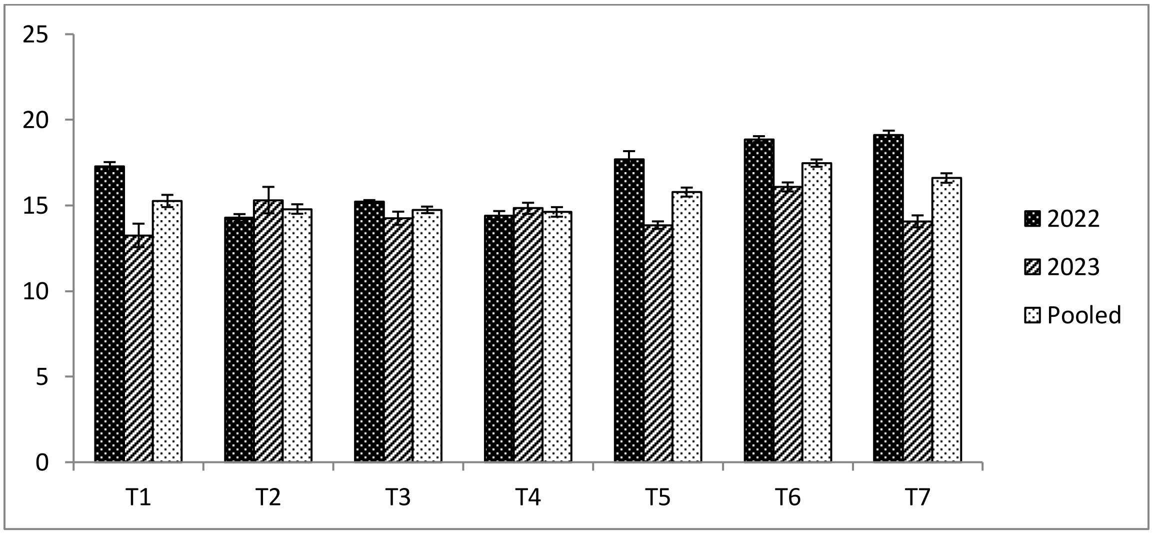

Fig 4.6. Effect of full spectrum light on petiole length at 90 DAP under vertical farming system in outdoor conditions

4.1.3 Plant spread (E-W) cm (30, 60 and 90 DAP)

The data pertaining to plant spread (E-W) at 30 DAP of strawberry plants, presented in Table 4.3, confirms significant variation among different treatments grown under outdoor conditions. T1 (natural light + fourth level) performs superior (7.06, 8.21 and 7.63 cm) under natural light in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (6.83, 8.26 and 7.55 cm) and T3 (natural light + second level) (7.17, 7.63 and 7.40 cm) at 30 DAP. In case of full spectrum light maximum plant spread (E-W) observed in T6 (natural light + full spectrum (4 hours) + second level) (6.75, 7.39 and 7.07 cm) followed by T5 (natural light + full spectrum (2 hours) + third level) (6.15, 8.07 and 7.11 cm) and T7 (natural light + full spectrum (6 hours) + first level) (8.13, 7.04 and 7.58 cm) in year 2022, 2023 and in pooled data. T1 and T3 were at par in year 2022, 2023 and in pooled data.

After 60 days of planting maximum plant spread (E-W) was noticed in T1 (natural light + fourth level) (15.19, 17.32 and 16.26 cm) under natural light followed by T3 (natural light + second level) (12.93, 13.87 and 13.40 cm) and T4 (natural light + first level) (12.45, 13.30 and 12.88 cm) in year 2022, 2023 and in pooled data. When artificial full spectrum light was provided than T6 (natural light + full spectrum (4 hours) + second level) was superior (17.68, 16.83 and 17.25 cm) and followed by T5 (natural light + full spectrum (2 hours) + third level) (14.89, 18.01 and 16.45 cm) and T7 (natural light + full spectrum (6 hours) + first level) (14.26, 14.41 and 14.33 cm) in year 2022, 2023 and in pooled data at 60 DAP. Treatment T5 and T6 were at par in year 2023.

Table.4.3, shows maximum plant spread (E-W) after 90 days of planting in treatment T1 (natural light + fourth level) (16.83, 20.99 and 18.91 cm) followed by T3 (natural light + second level) (13.52, 17.31 and 15.41 cm) and T2 (natural light + third level) (11.85, 17.91 and 14.88 cm) under natural light in year 2022, 2023 and in pooled data. In case of full spectrum light T5 (natural light + full spectrum (2 hours) + third level) performs better (16.38, 19.14 and 17.76 cm) and followed by T7 (natural light + full spectrum (6 hours) + first level) (15.70, 17.75 and 16.72 cm) and T6 (natural light + full spectrum (4 hours) + second level) (15.11, 18.25 and 16.68 cm) in year 2022, 2023 and in pooled data. T1 and T5 were at in year both year 2022 and 2023 (Table 4.3).

Table 4.3: Effect of full spectrum light on plant spread (E-W) under vertical farming system in outdoor conditions.

	Plant spread (E-W) 30 days (cm)			**Plant spread (E-W) 60 days (cm)**			**Plant spread (E-W) 90 days (cm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	7.06 ± 0.512^{ab}	8.21 ± 0.097^{a}	7.63 ± 0.294^{a}	15.19 ± 0.098^{b}	17.32 ± 0.311^{a}	16.26 ± 0.189^{b}	16.83 ± 0.274^{a}	20.99 ± 0.635^{a}	18.91 ± 0.293^{a}
T2	6.83 ± 0.394^{b}	8.26 ± 0.326^{a}	7.55 ± 0.191^{a}	11.53 ± 0.478^{d}	13.31 ± 0.911^{b}	12.42 ± 0.307^{e}	11.85 ± 0.344^{d}	17.91 ± 0.268^{b}	14.88 ± 0.161^{d}
T3	7.17 ± 0.474^{ab}	7.63 ± 0.294^{ab}	7.40 ± 0.365^{a}	12.93 ± 0.408^{c}	13.87 ± 0.291^{b}	13.40 ± 0.081^{d}	13.52 ± 0.261^{c}	17.31 ± 1.1^{b}	15.41 ± 0.507^{d}
T4	5.60 ± 0.3^{b}	6.75 ± 0.074^{b}	6.18 ± 0.149^{b}	12.45 ± 0.326^{cd}	13.30 ± 0.503^{b}	12.88 ± 0.182^{de}	12.42 ± 0.25^{d}	17.20 ± 0.27^{b}	14.81 ± 0.255^{d}
T5	6.15 ± 0.308^{b}	8.07 ± 0.294^{ab}	7.11 ± 0.299^{a}	14.89 ± 0.358^{b}	18.01 ± 0.396^{a}	16.45 ± 0.11^{ab}	16.38 ± 0.372^{ab}	19.14 ± 0.269^{ab}	17.76 ± 0.095^{b}
T6	6.75 ± 0.314^{b}	7.39 ± 0.299^{b}	7.07 ± 0.198^{ab}	17.68 ± 0.405^{a}	16.83 ± 0.667^{a}	17.25 ± 0.428^{a}	15.11 ± 0.14^{b}	18.25 ± 0.375^{b}	16.68 ± 0.213^{c}
T7	8.13 ± 0.415^{a}	7.04 ± 0.266^{b}	7.58 ± 0.327^{a}	14.26 ± 0.31^{b}	14.41 ± 0.701^{b}	14.33 ± 0.402^{c}	15.70 ± 0.099^{b}	17.75 ± 1.373^{b}	16.72 ± 0.638^{bc}
SEM±	0.41	0.25	0.28	0.37	0.61	0.29	0.28	0.64	0.34
CD at 5%	1.26	0.79	0.88	1.15	1.88	0.89	0.87	1.97	1.05
CV%	10.36	5.79	6.84	4.56	6.92	3.41	3.37	6.00	3.57

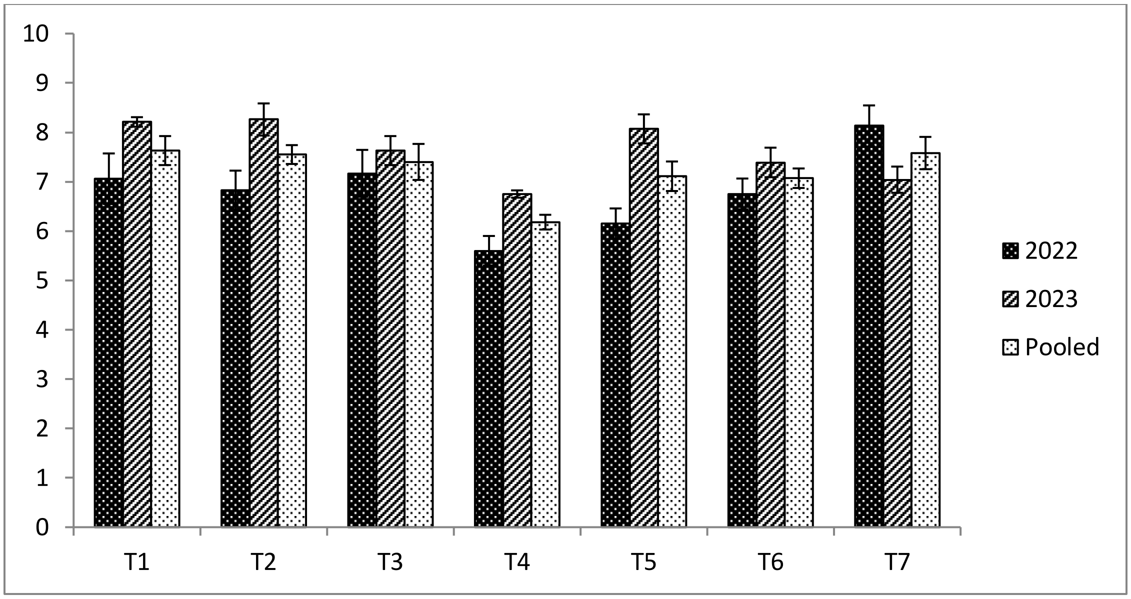

Fig 4.7. Effect of full spectrum light on plant spread (E-W) at 30 DAP under vertical farming system in outdoor conditions

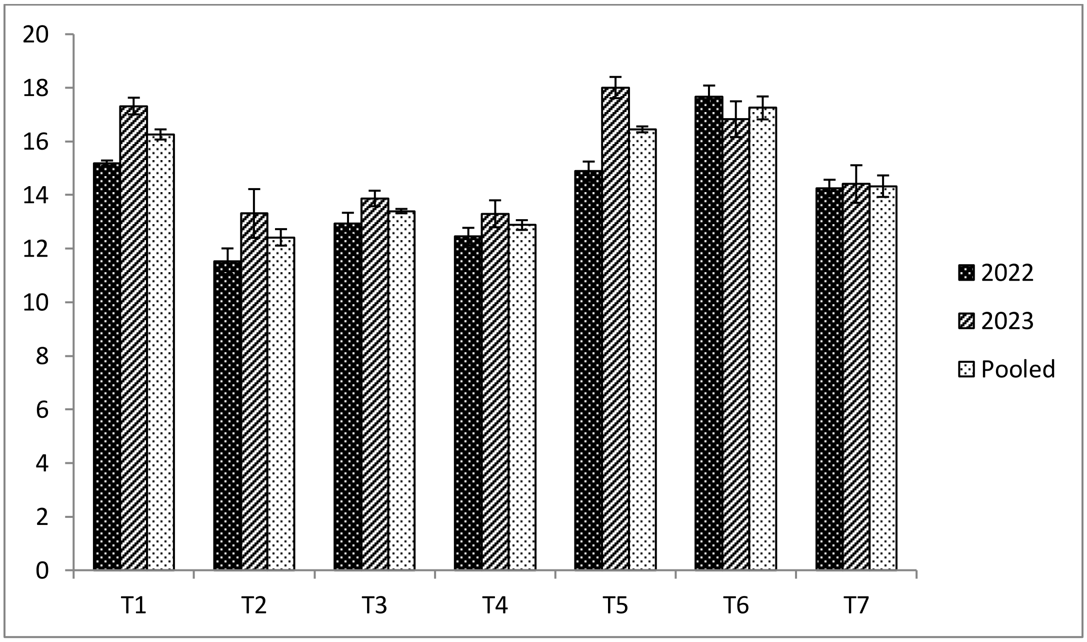

Fig 4.8. Effect of full spectrum light on plant spread (E-W) at 60 DAP under vertical farming system in outdoor conditions

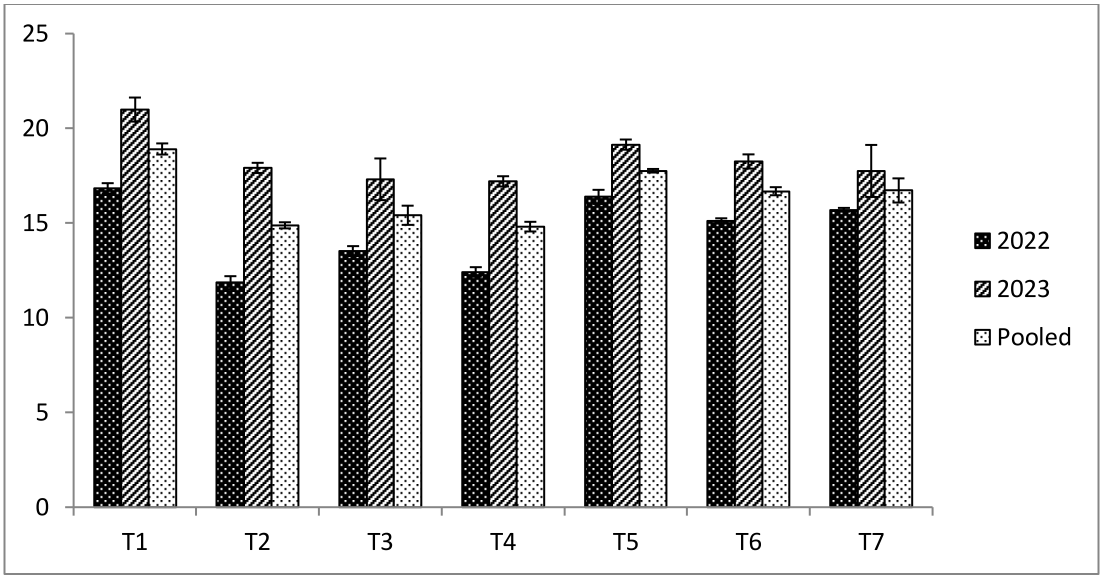

Fig 4.9. Effect of full spectrum light on plant spread (E-W) at 90 DAP under vertical farming system in outdoor conditions

4.1.4 Plant spread (N-S) cm (30, 60 and 90 DAP)

After 30 days of planting plant spread (N-S) showed significant variations among the treatments in outdoor conditions. Treatment T1 (natural light + fourth level) has maximum spread (N-S) (7.42, 6.45 and 6.94 cm) under natural light in year 2022, 2023 and in pooled data followed by T4 (natural light + first level) (5.17,6.81 and 5.99 cm) and T2 (natural light + third level) (7.38, 4.53 and 5.95 cm). With artificial full spectrum light, treatment T5 (natural light + full spectrum (2 hours) + third level) has higher (8.00, 7.35 and 7.68 cm) plant spread (N-S) followed by T6 (natural light + full spectrum (4 hours) + second level) (5.95, 6.39 and 6.17 cm) and T7 (natural light + full spectrum (6 hours) + first level) (6.18, 4.59 and 5.38 cm) in year 2022, 2023 and in pooled data. In overall performance T5 has maximum spread (N-S) and minimum in treatment T7.

Table 4.4, shows maximum plant spread (N-S) at 60 DAP under natural light in T1 (natural light + fourth level) (13.27, 15.62 and 14.44 cm) in year 2022, 2023 and in pooled data followed by T4 (natural light + first level) (12.93, 11.06 and 12.00 cm) and T2 (natural light + third level) (11.51, 11.34 and 11.42 cm). In addition of full spectrum light T6 (natural light + full spectrum (4 hours) + second level) has maximum plant spread (N-S) (16.62, 15.59 and 16.11 cm) followed by T5 (natural light + full spectrum (2 hours) + third level) (14.27, 16.93 and 15.60 cm) and T7 (natural light + full spectrum (6 hours) + first level) (14.28, 14.75 and 14.52 cm). T6 has maximum plant spread and T3 has minimum plant spread in overall performance. In 2023 and in pooled data, treatment T5 and T6 were at par.

Moreover, T1 (natural light + fourth level) has maximum plant spread (N-S) (11.21, 22.22 and 16.71 cm) under natural light in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (11.14, 16.51 and 13.82 cm) and T4 (natural light + first level) (9.34, 16.06 and 12.70 cm) after 90 days of planting. With artificial full spectrum light maximum plant spread observed under treatment T5 (natural light + full spectrum (2 hours) + third level) (13.15, 21.67 and 17.41 cm) followed by T6 (natural light + full spectrum (4 hours) + second level) (12.18, 16.01 and 14.10 cm) and T7 (natural light + full spectrum (6 hours) + first level) (10.71, 16.93 and 13.82 cm) in year 2022, 2023 and in pooled data (Table 4.4). When overall result discussed it was noticed that treatment T5 has maximum north-south plant spread after 90 days of planting and T3 has minimum spread of plant.

The treatments significantly affected the plant spread on all observation days (30, 60 and 90 days after planting, Table 4.3 and 4.4) which supports dependence of plant spread on light duration and levels of verticals under indoor condition. The plants subjected with natural light have wider spread of plant (E-W) at fourth level (T_1) in comparison to other treatments. In case of north- south spread treatment under full spectrum light T_5 (30DAP) and T_6 (at 60 DAP) performs superior except 90 days after planting. In T_1 after 45 days the plants die due to insufficient light. The duration of full spectrum light in a vertical farming system can significantly affect the spread of plants and the number of leaves in strawberries.

AFSLs consist of visible spectra predominantly consisting of blue light, green light and red light. The red light stimulates the photosynthetic apparatus and phytochromes (Kochetova *et al.,* 2018) which regulates the photosynthesis and biomass accumulation (Chen *et al.,*

2017) whereas the blue component of LED light effectively stimulates phytochromes as well as cryptochromes and phototropins (Kochetova *et al.*, 2018) which regulates photomorphogenesis, stomatal movement, biosynthesis of chlorophyll and anthocyanin as well as biomass accumulation. Longer durations of full spectrum light exposure can promote plant growth and increase the spread of plants in each direction, resulting in larger overall plant growth (Madhavi *et al.*, 2023). The dependence of plant spread on light intensity at different levels of verticals could be associated with alteration in water use efficiency and stomatal conductance of strawberry plants (Pennisi *et al.*, 2019) or the activation of phytochrome by different light duration resulting in regulation of activities of transcription factors (Helizon *et al.*, 2018).

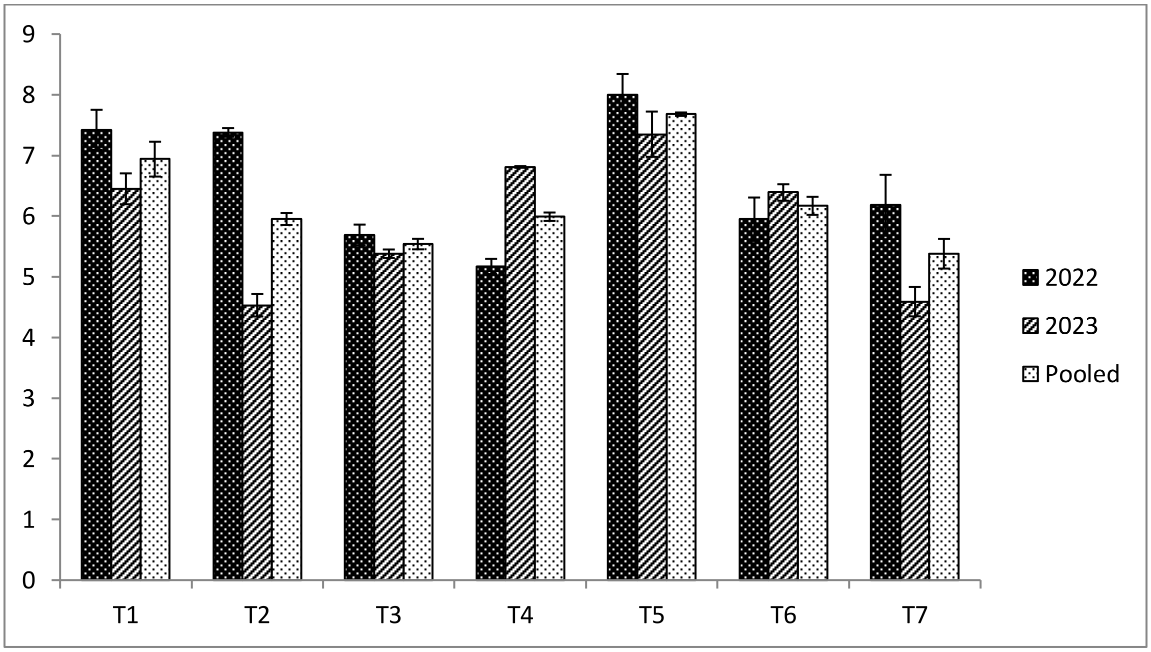

Fig 4.10. Effect of full spectrum light on plant spread (N-S) at 30 DAP under vertical farming system in outdoor conditions

Table 4.4: Effect of full spectrum light on plant spread (N-S) under vertical farming system in outdoor conditions.

	Plant spread (N-S) 30 DAP (cm)			**Plant spread (N-S) 60 DAP (cm)**			**Plant spread (N-S) 90 DAP (cm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	7.42 ± 0.332^{a}	6.45 ± 0.255^{b}	6.94 ± 0.287^{b}	13.27 ± 0.301^{bc}	15.62 ± 0.338^{ab}	14.44 ± 0.131^{b}	11.21 ± 0.318^{b}	22.22 ± 1.084^{a}	16.71 ± 0.540^{a}
T2	7.38 ± 0.070^{a}	4.53 ± 0.185^{d}	5.95 ± 0.099^{cd}	11.51 ± 0.221^{d}	11.34 ± 1.046^{c}	11.42 ± 0.536^{c}	11.14 ± 0.397^{b}	16.51 ± 0.166^{b}	13.82 ± 0.281^{b}
T3	5.69 ± 0.171^{bc}	5.38 ± 0.070^{c}	5.54 ± 0.088^{d}	12.07 ± 0.341^{cd}	10.68 ± 0.175^{c}	11.38 ± 0.09^{c}	8.79 ± 0.376^{c}	16.57 ± 1.587^{b}	12.68 ± 0.850^{b}
T4	5.17 ± 0.128^{c}	6.81 ± 0.013^{ab}	5.99 ± 0.070^{cd}	12.93 ± 0.445^{c}	11.06 ± 0.671^{c}	12.00 ± 0.531^{c}	9.34 ± 0.262^{c}	16.06 ± 1.250^{b}	12.70 ± 0.521^{b}
T5	8.00 ± 0.342^{a}	7.35 ± 0.374^{a}	7.68 ± 0.029^{a}	14.27 ± 0.358^{b}	16.93 ± 0.229^{a}	15.60 ± 0.215^{ab}	13.15 ± 0.467^{a}	21.67 ± 0.453^{a}	17.41 ± 0.457^{a}
T6	5.95 ± 0.357^{bc}	6.39 ± 0.135^{b}	6.17 ± 0.149^{c}	16.62 ± 0.428^{a}	15.59 ± 0.682^{ab}	16.11 ± 0.497^{a}	12.18 ± 0.456^{ab}	16.01 ± 0.096^{b}	14.10 ± 0.274^{b}
T7	6.18 ± 0.501^{b}	4.59 ± 0.243^{d}	5.38 ± 0.244^{d}	14.28 ± 0.420^{b}	14.75 ± 0.631^{b}	14.52 ± 0.226^{b}	10.71 ± 0.297^{bc}	16.93 ± 0.540^{b}	13.82 ± 0.254^{b}
SEM±	0.29	0.22	0.17	0.36	0.63	0.39	0.40	0.86	0.47
CD at 5%	0.90	0.69	0.51	1.12	1.95	1.20	1.24	2.65	1.46
CV%	7.72	6.55	4.63	4.62	8.00	4.93	6.39	8.29	5.68

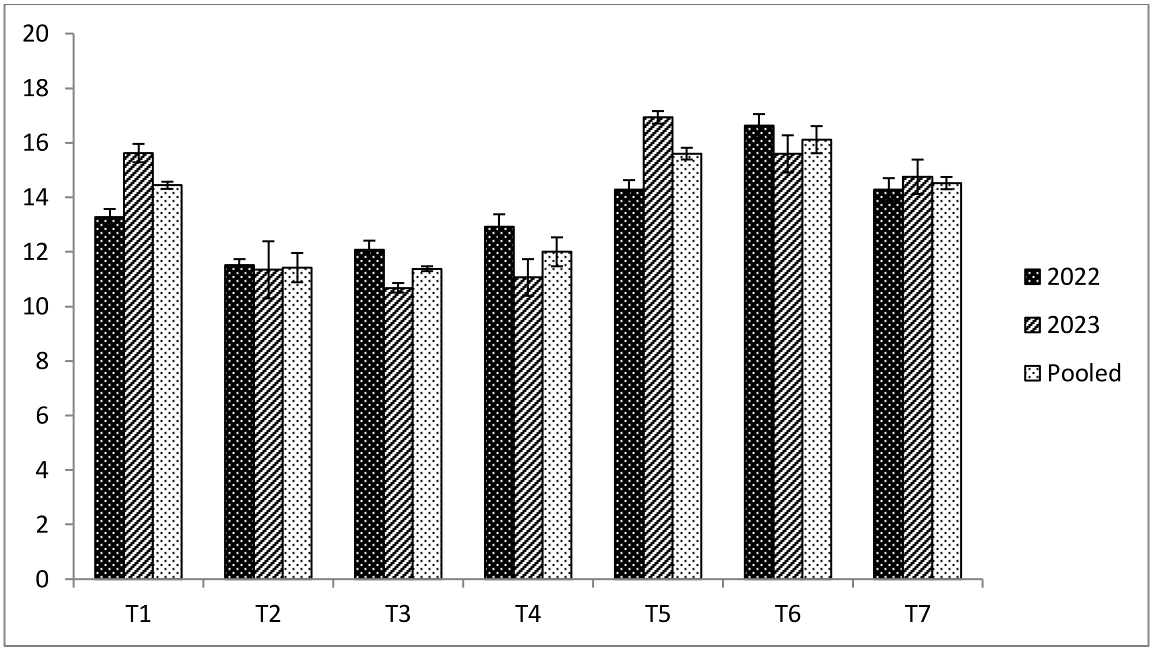

Fig 4.11. Effect of full spectrum light on plant spread (N-S) at 60 DAP under vertical farming system in outdoor conditions

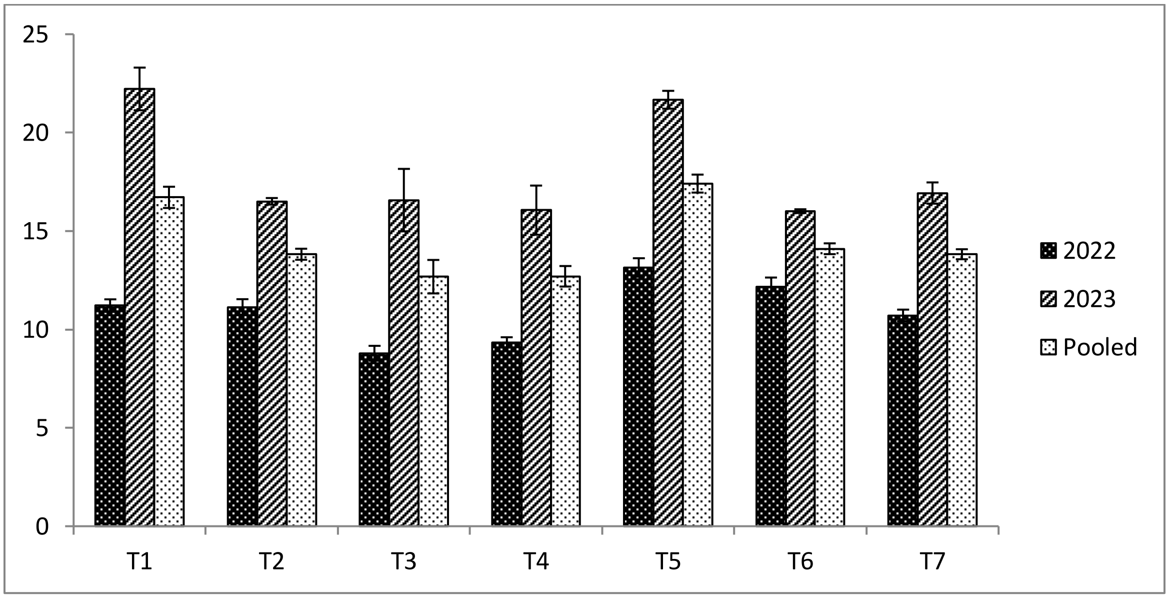

Fig 4.12. Effect of full spectrum light on plant spread (N-S) at 90 DAP under vertical farming system in outdoor conditions

4.1.5 Number of leaves (30, 60 and 90 DAP)

The data pertaining to number of leaves (30 DAP) of strawberry plants, presented in Table 4.5, confirms significant variation among different treatments grown under outdoor conditions. Treatment T1 (natural light + fourth level) has maximum number of leaves (10.67, 15.93 and 13.30) at 30 DAP followed by T3 (natural light + second level) (12.87, 13.53 and 13.20) and T2 (natural light + third level) (10.67, 13.27 and 11.97) in year 2022, 2023 and in pooled data. In addition of full spectrum light, T5 (natural light + full spectrum (2 hours) + third level) has maximum number of leaves (12.93, 16.53 and 14.73) followed by T6 (natural light + full spectrum (4 hours) + second level) (12.87, 13.80 and 13.33) and T7 (natural light + full spectrum (6 hours) + first level) (11.93, 14.47 and 13.20) in year 2022, 2023 and in pooled data. In overall performance T5 has maximum number of leaves and T4 has minimum number of leaves. T5, T6 and T7 were at par in 2022, 2023 and in pooled data.

In Table 4.5, T1 (natural light + fourth level) has maximum number of leaves (14.47, 19.40 and 16.93) at 60 days of planting under natural light followed by T2 (natural light + third level) (11.73, 15.13 and 13.43) and T3 (natural light + second level) (13.47, 13.20 and 13.33) in year 2022, 2023 and in pooled data. When artificial full spectrum light was provided than T6 (natural light + full spectrum (4 hours) + second level) (16.80, 13.87 and 15.33) and T7 (natural light + full spectrum (6 hours) + first level (16.53, 14.13 and 15.33) has maximum number of leaves followed by T5 (natural light + full spectrum (2 hours) + third level) (14.27, 15.93 and 15.10) in year 2022, 2023 and in pooled data. T1 performs superior whileT4 was inferior in overall performance. In 2022, T6 and T7 were at par.

At 90 DAP, maximum number of leaves was found in T1 (natural light + fourth level) (17.20, 17.00 and 17.10) under natural light in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (14.60, 13.47 and 14.03) and T3 (natural light + second level) (15.73, 12.13 and 13.93). When full spectrum light was added than T6 (natural light + full spectrum (4 hours) + second level) performs superior (19.80, 16.60 and 18.20) in year 2022, 2023 and in pooled data followed by T5 (natural light + full spectrum (2 hours)

+ third level) (17.13, 15.80 and 16.47) and T7 (natural light + full spectrum (6 hours) + first level) (19.27, 12.60 and 15.93). When overall result was discussed, it was observed that T6 has maximum number of leaves and T4 has minimum number of leaves (Table 4.5).

The observations recorded for average number of leaves was significantly affected by treatments given at all days of observations (30, 60 and 90 days after planting where the plants subjected to full spectrum light for 2 hours have grown a greater count of leaves when plants were at third level (T_5) and were superior in comparison to other treatments at 30 DAP and T_6 (use of additional full spectrum light for 4 hours) at 90 DAP. At 60 DAP plants under natural light on fourth level (T_1) performs better than other treatments. Plants grown with addition full spectrum light gave more significant number of leaves than natural light. Somewhat Similar results were observed in the study of Uddin et al. (2018) which showed an increased number of leaves (25.3) with the effect of LED lights. Additionally, extended exposure to full spectrum light might have stimulated leaf production, leading to an increased number of leaves in strawberry plants (Peng *et al.,* 2020). Improvement in water use efficiency could be associated with increased biomass production due to reduced stomatal conductance and controlled leaf transpiration (Baroli *et al.,* 2008). A greater fraction of red light is responsible for the impaired development of leaves, i.e., long petioles and thin wide leaves with reduced chlorophyll content, resembling to shade avoidance response under low light; however, the presence of blue light in AFSL could be accountable to counteract the red-light effect to ensure healthy development leaves under vertical farming system (Wong *et al.,* 2020).

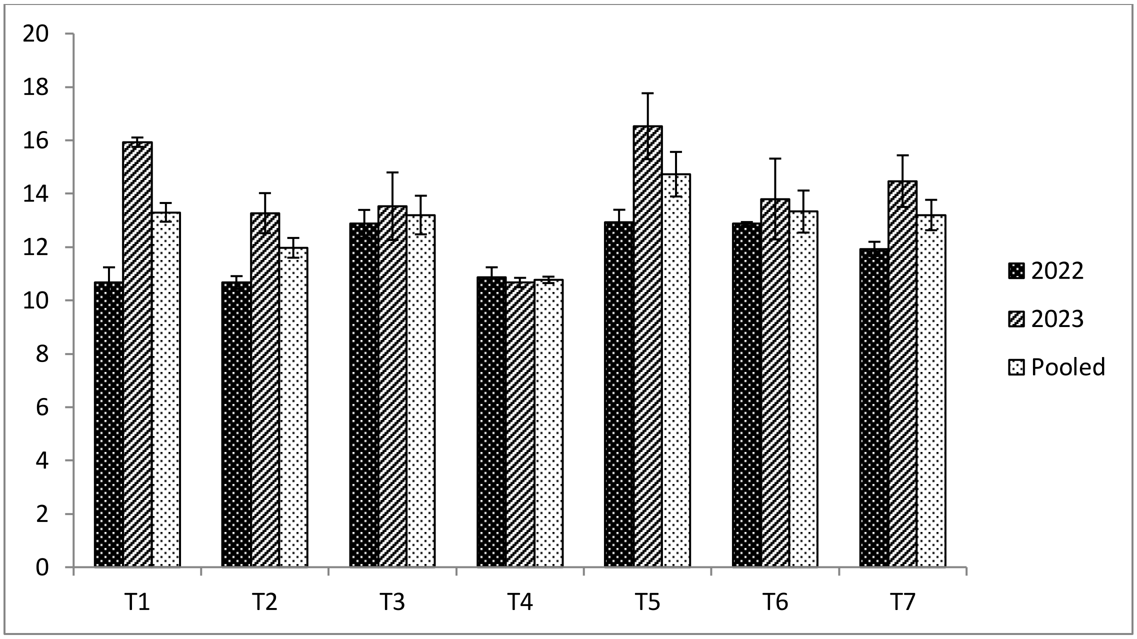

Fig 4.13. Effect of full spectrum light on number of leaves at 30 DAP under vertical farming system in outdoor conditions

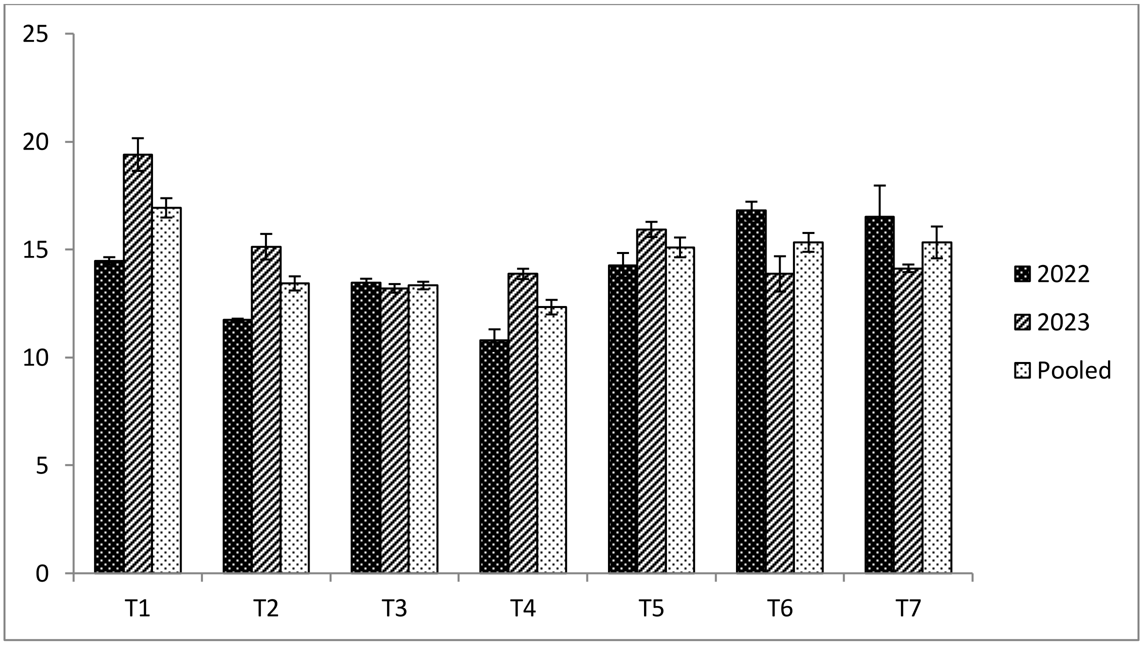

Fig 4.14. Effect of full spectrum light on number of leaves at 60 DAP under vertical farming system in outdoor conditions

Table 4.5: Effect of full spectrum light on number of leaves under vertical farming system in outdoor conditions.

	Number of Leaves 30 DAP			**Number of Leaves 60 DAP**			**Number of Leaves 90 DAP**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	10.67 ± 0.570^{b}	15.93 ± 0.176^{ab}	13.30 ± 0.351^{ab}	14.47 ± 0.176^{b}	19.40 ± 0.757^{a}	16.93 ± 0.448^{a}	17.20 ± 0.231^{b}	17.00 ± 1.206^{a}	17.10 ± 0.603^{ab}
T2	10.67 ± 0.240^{b}	13.27 ± 0.751^{b}	11.97 ± 0.371^{b}	11.73 ± 0.067^{c}	15.13 ± 0.593^{bc}	13.43 ± 0.328^{c}	14.60 ± 0.231^{d}	13.47 ± 1.954^{b}	14.03 ± 0.949^{c}
T3	12.87 ± 0.521^{a}	13.53 ± 1.267^{b}	13.20 ± 0.723^{ab}	13.47 ± 0.176^{bc}	13.20 ± 0.200^{c}	13.33 ± 0.176^{c}	15.73 ± 0.533^{c}	12.13 ± 0.706^{b}	13.93 ± 0.481^{c}
T4	10.87 ± 0.371^{b}	10.67 ± 0.176^{b}	10.77 ± 0.12^{b}	10.80 ± 0.503^{c}	13.87 ± 0.24^{c}	12.33 ± 0.338^{c}	13.27 ± 0.176^{e}	13.73 ± 0.570^{b}	13.50 ± 0.305^{c}
T5	12.93 ± 0.467^{a}	16.53 ± 1.235^{a}	14.73 ± 0.835^{a}	14.27 ± 0.570^{b}	15.93 ± 0.353^{b}	15.10 ± 0.458^{b}	17.13 ± 0.24^{b}	15.80 ± 0.416^{ab}	16.47 ± 0.088^{b}
T6	12.87 ± 0.067^{a}	13.80 ± 1.514^{ab}	13.33 ± 0.788^{ab}	16.80 ± 0.416^{a}	13.87 ± 0.819^{c}	15.33 ± 0.437^{b}	19.80 ± 0.116^{a}	16.60 ± 0.346^{ab}	18.20 ± 0.115^{a}
T7	11.93 ± 0.267^{ab}	14.47 ± 0.968^{ab}	13.20 ± 0.569^{ab}	16.53 ± 1.434^{a}	14.13 ± 0.176^{c}	15.33 ± 0.736^{b}	19.27 ± 0.291^{a}	12.60 ± 0.503^{b}	15.93 ± 0.291^{b}
SEM±	0.39	0.99	0.59	0.61	0.55	0.45	0.29	0.96	0.49
CD at 5%	1.22	3.05	1.82	1.88	1.69	1.38	0.89	2.95	1.49
CV%	5.78	12.23	7.89	7.53	6.30	5.34	3.00	11.44	5.39

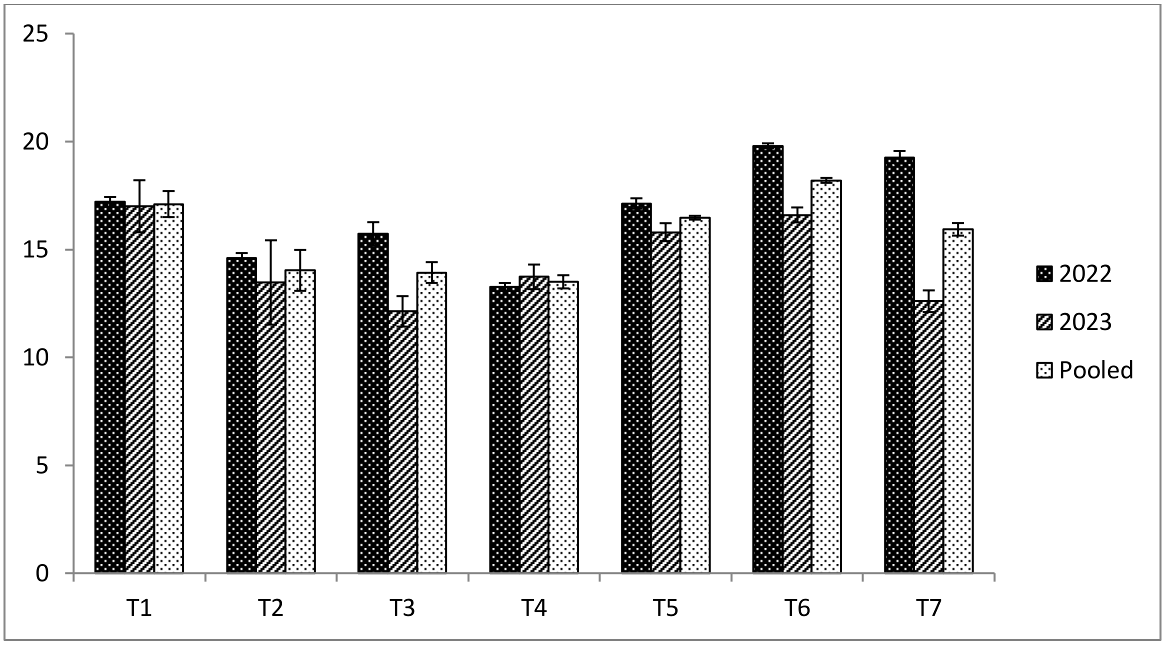

Fig 4.15. Effect of full spectrum light on number of leaves at 90 DAP under vertical farming system in outdoor conditions

4.1.6 Leaf area (sq cm)

As shown in Table 4.6, leaf area shows a significant variation among the treatments under outdoor conditions. T3 (natural light + second level) showed maximum leaf area (190.90, 191.43 and 191.17 sq cm) under natural light in year 2022, 2023 and in pooled data followed by T4 (natural light + first level) (191.03, 191.00 and 191.02 sq cm) and T2 (natural light + third level) (191.00, 190.67 and 190.83 sq cm). When artificial full spectrum light was provided than T5 (natural light + full spectrum (2 hours) + third level) has maximum leaf area (191.20, 191.63 and 191.42 sq cm) followed by T7 (natural light + full spectrum (6 hours) + first level) (190.70, 190.87 and 190.78 sq cm) and T6 (natural light + full spectrum (4 hours) + second level) (190.93, 190.33 and 190.63 sq cm) in year 2022, 2023 and in pooled data. T5 (natural light + full spectrum (2 hours) + third level) was superior and T6 was inferior in overall performance. In 2022, 2023 and in pooled data T3, T4 and T5 were at par.

4.1.7 Chlorophyll content index

In chlorophyll content index T2 (natural light + third level) has maximum content (54.22, 53.40 and 53.81) followed by T1 (natural light + fourth level) (52.85, 53.93 and 53.39) and T3 (natural light + second level) (51.93, 49.95 and 50.94) under natural light in year 2022, 2023 and in pooled data. In case of additional full spectrum light T6 (natural light + full spectrum (4 hours) + second level) has maximum chlorophyll content index (58.45, 50.35 and 54.40) in year 2022, 2023 and in pooled data followed by T5 (natural light + full spectrum (2 hours) + third level) (55.02, 52.63 and 53.83) and T7 (natural light + full spectrum (6 hours) + first level) (52.00, 53.60 and 52.80). When overall result was discussed, it was noticed that T6 has maximum chlorophyll content index while T4 has minimum index. Treatment T2 and T5 were at par in year 2022 2023 and in pooled data (Table 4.6).

Under outdoor conditions the variation in leaf area was at par when only natural light was given which could be due to fact that the light variation was not significant at all levels of vertical layers. However, the LED lighting as supplementary light can influence leaf area development in strawberry plants grown in vertical systems which could be accountable to significant variation (Nadilini *et al.*, 2017). Leaf area is an important morphological characteristic that influences leaf performance, including the light-saturated photosynthetic rate per unit of leaf mass, leaf mechanical strength, and leaf longevity (Li *et al.*, 2022). Chlorophyll synthesis and accumulation can be affected by the various light spectra that LEDs can provide. It has been shown that strawberry plants produce more chlorophyll when exposed to red and blue light spectrum (Samuolienė *et al.,* 2010). By effectively absorbing this spectrum, chlorophyll pigments their synthesis is stimulated which could be responsible for increasing the chlorophyll content of leaves.

Table 4.6: Effect of full spectrum light on leaf area and chlorophyll content index under vertical farming system in outdoor conditions.

	Leaf Area (sq cm)			**Chlorophyll content index**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	190.37 ± 0.155^{b}	191.00 ± 0.265^{ab}	190.68 ± 0.093^{b}	52.85 ± 1.935^{b}	53.93 ± 1.008^{a}	53.39 ± 1.460^{ab}
T2	191.00 ± 0.095^{ab}	190.67 ± 0.316^{b}	190.83 ± 0.205^{b}	54.22 ± 1.965^{ab}	53.40 ± 0.831^{ab}	53.81 ± 1.387^{ab}
T3	190.90 ± 0.037^{ab}	191.43 ± 0.370^{ab}	191.17± 0.210^{ab}	51.93 ± 0.916^{b}	49.95 ± 0.843^{b}	50.94 ± 0.762^{b}
T4	191.03 ± 0.094^{ab}	191.00 ± 0.153^{ab}	191.02± 0.117^{ab}	45.43 ± 1.543^{c}	51.78 ± 0.460^{b}	48.61 ± 0.986^{b}
T5	191.20 ± 0.153^{a}	191.63 ± 0.161^{a}	191.42 ± 0.067^{a}	55.02 ± 2.286^{ab}	52.63 ± 0.203^{ab}	53.83 ± 1.075^{ab}
T6	190.93 ± 0.195^{ab}	190.33 ± 0.067^{b}	190.63 ± 0.100^{b}	58.45 ± 0.808a	50.35 ± 0.260^{b}	54.40 ± 0.442^{a}
T7	190.70 ± 0.115^{b}	190.87 ± 0.099^{b}	190.78 ± 0.089^{b}	52.00 ± 0.701^{b}	53.60 ± 1.403^{ab}	52.80 ± 1.052^{ab}
SEM±	0.14	0.69	0.14	1.59	0.69	1.06
CD at 5%	0.43	2.11	0.42	4.90	2.11	3.25
CV%	0.13	2.28	0.12	5.21	2.28	3.48

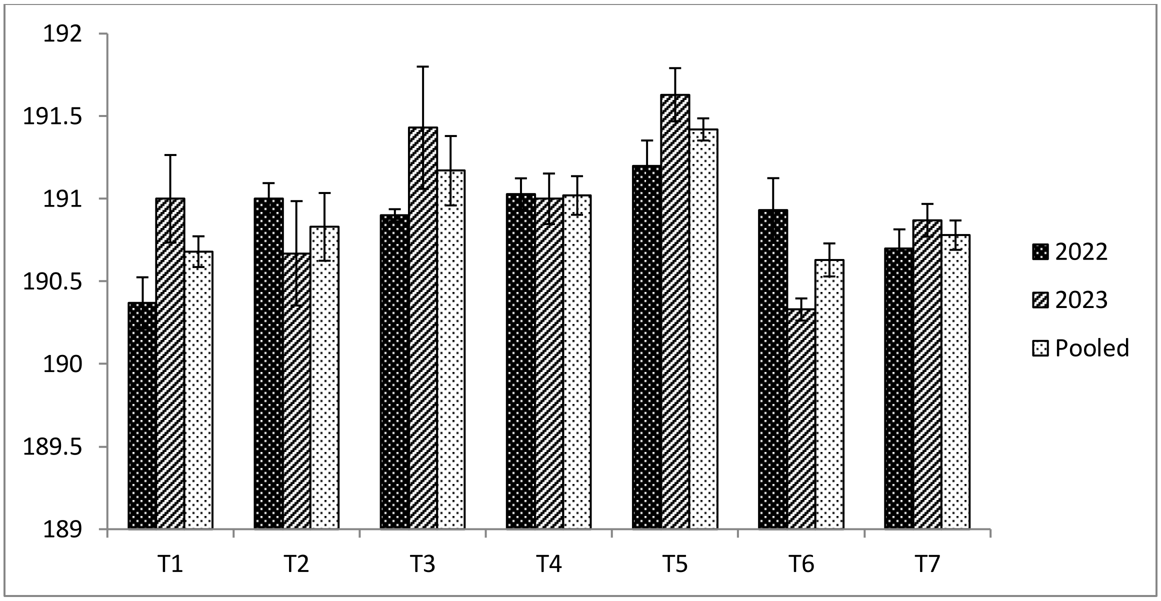

Fig 4.16. Effect of full spectrum light on leaf area under vertical farming system in outdoor conditions

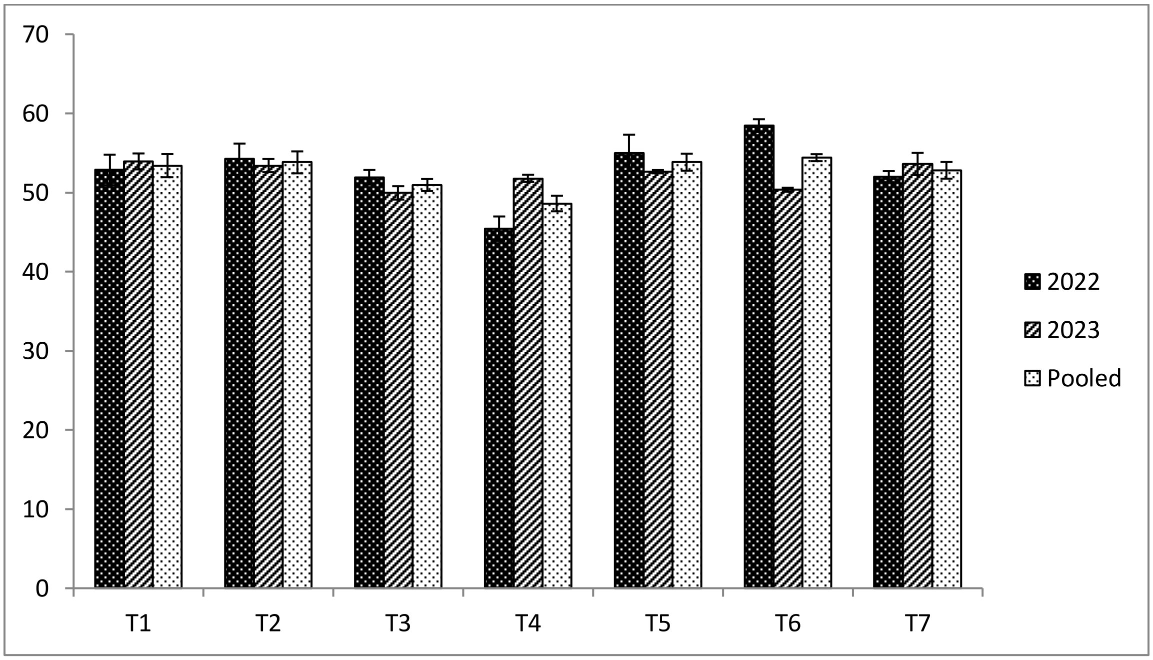

Fig 4.17. Effect of full spectrum light on chlorophyll content index under vertical farming system in outdoor conditions

4.1.8 Days to bud formation

Table 4.7, shows that T3 (natural light + second level) (62.17, 60.83 and 61.50) and T4 (natural light + first level (61.67, 61.33 and 61.50) took maximum days for bud formation after planting followed by T2 (natural light + third level) (61.67, 60.83 and 61.25) and T1 (natural light + fourth level) (60.83, 61.33 and 61.08) under natural light in year 2022, 2023 and in pooled data. When artificial full spectrum light was provided then T6 (natural light + full spectrum (4 hours) + second level) took maximum days for formation of buds (61.33, 61.67 and 61.50) followed by T7 (natural light + full spectrum (6 hours) + first level) (61.33, 60.67 and 61.00) and T5 (natural light + full spectrum (2 hours) + third level) (61.50, 60.17 and 60.83) in year 2022, 2023 and in pooled data. When overall result was discussed, it was found that T3 and T4 took maximum days for bud formation while T5 took minimum days. T4 and T6 were at par in 2022, 2023 and in pooled data.

4.1.9 Days to flowering

As shown in Table 4.7, shows significant variation among the treatment under outdoor condition. Treatment T4 (natural light + first level) took maximum days for flowering (67.00, 66.17 and 66.58) in year 2022, 2023 and in pooled data followed by T3 (natural light + second level) (66.00, 66.00 and 66.00) and T2 (natural light + third level) (65.83, 65.83 and 65.83). With artificial full spectrum light, T7 (natural light + full spectrum (6 hours) + first level) took maximum days to flowering (66.50, 66.17, 66.33) in year 2022, 2023 and in pooled data followed by T6 (natural light + full spectrum (4 hours) + second level) (67.00, 65.50 and 66.25) and T5 (natural light + full spectrum (2 hours) + third level) (66.67, 65.17 and 65.92). In overall performance T4 took maximum days to flowering and T1 took minimum days to flowering. In 2022, 2023 and in pooled data, treatment T4, T6 and T7 were at par.

4.1.10 Days to maturity

Treatment T4 (natural light + first level) took maximum days to maturity (75.50, 73.83 and 74.67) under natural light in year 2022, 2023 and in pooled data followed by T3 (natural light + second level) (72.83, 74.50 and 73.67) and T2 (natural light + third level) (73.50, 73.33 and 73.42). With full spectrum light, T7 (natural light + full spectrum (6 hours) + first level) took maximum number of days to maturity (76.00, 74.83 and 75.42) followed by T6 (natural light + full spectrum (4 hours) + second level) (75.00, 73.83 and 74.42) and T5 (natural light + full spectrum (2 hours) + third level) (74.67, 73.33 and 74.00) in year 2022, 2023 and in pooled data. In overall discussion T7 took maximum days for maturity while T1 took minimum days for maturity. Treatment T4, T6 and T7 were at par in 2022 and 2023 (Table 4.7).

The plants exposed to only natural light grew earlier when plants were at the fourth level (T1) and was superior in comparison to T2, T3 and T4. However, treatment T3 and T4 took similar days for the bud formation, which is 61.5 as well as treatment T6. When given additional full spectrum light, the plants that were grown at the first, second and third levels had improved performance. They also performed well due to early bud formation in T5, which was followed by T7 and T6. Overall, plants grown in artificial light exhibit earlier bud development than those grown in natural light. Similar results found in days to flowering but in overall performance T1 shows early flowering followed by T5 and T6. T3, followed by T2, T1 and T4 show a significant number of buds on a plant grown in natural light. T5 also outperforms in overall treatments.

The control activity of light through AFSL under short days (winter months) solar radiation enhances the crop growth and development efficiency by optimizing the photosynthetic activities which results in changes in internal rhythms to bring morphological and reproductive changes such as flower bud differentiation or improve the biosynthesis and accumulation of plant metabolites necessary for defense against biotic and abiotic stresses (Cavallaro and Muleo, 2022). The optimized light spectrum provided by full spectrum LEDs likely played a role in expediting physiological processes and initiating earlier bud development. In addition, the time required for bud formation to reach maturity was accelerated, resulting in faster fruit ripening and shorter maturation periods (Yoshida *et al.*, 2016 Wai *et al.*, 2023). Longer durations of full spectrum light exposure, particularly during the flowering stage, can promote bud formation and potentially reduce the time it takes for buds to develop as flowers. Providing sufficient light during the appropriate growth stages is crucial for optimal bud development and flower production (Al Murad *et al.,* 2021; Sabzalian *et al.* 2014).

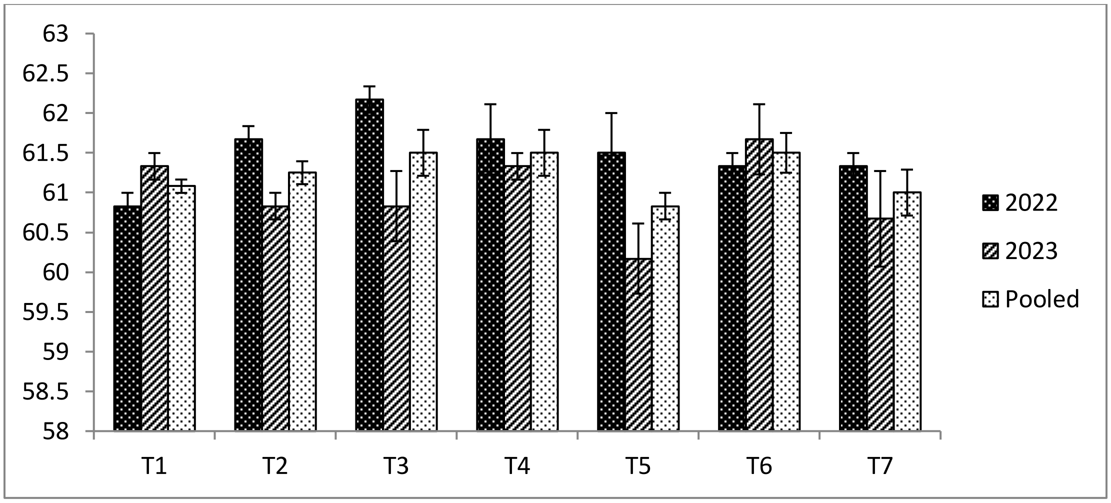

Fig. 4.18. Effect of full spectrum light on days to bud formation under vertical farming system in outdoor conditions.

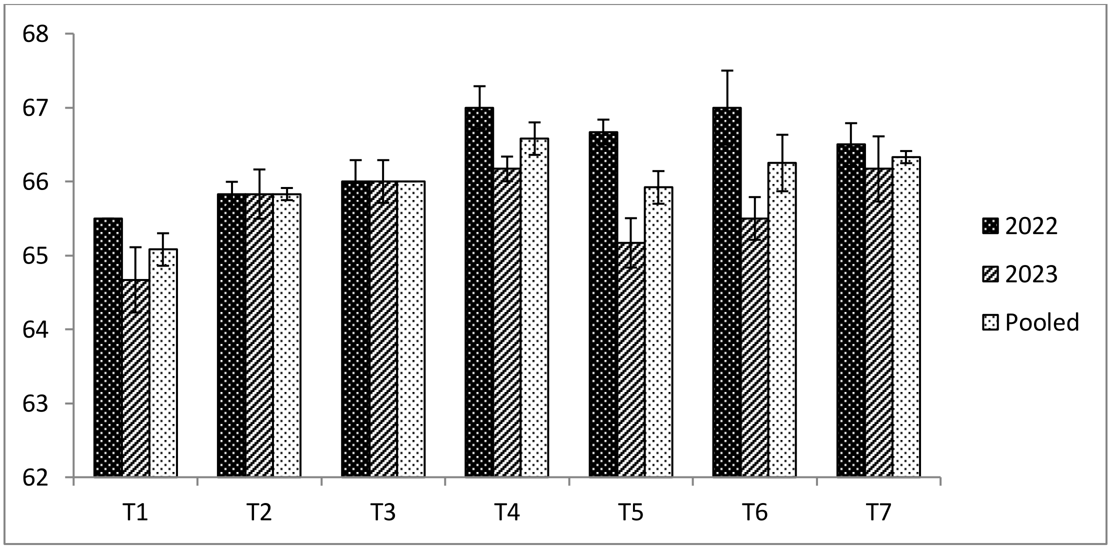

Fig. 4.19. Effect of full spectrum light on days to flowering under vertical farming system in outdoor conditions

Table 4.7: Effect of full spectrum light on flowering parameters under vertical farming system in outdoor conditions.

	Days to bud formation			**Days to flowering**			**Days to maturity**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	60.83 ± 0.167^{b}	61.33 ± 0.167^{ab}	61.08 ± 0.084^{ab}	65.50 ± 0^{b}	64.67 ± 0.441^{b}	65.08 ± 0.220^{b}	72.50 ± 0.289^{c}	72.33 ± 0.333^{b}	72.42 ± 0.301^{e}
T2	61.67 ± 0.166^{ab}	60.83 ± 0.167^{b}	61.25 ± 0.144^{ab}	65.83 ± 0.166^{b}	65.83 ± 0.333^{ab}	65.83 ± 0.082^{b}	73.50 ± 0.500^{c}	73.33 ± 0.441^{b}	73.42 ± 0.363^{d}
T3	62.17 ± 0.166^{a}	60.83 ± 0.441^{b}	61.50 ± 0.289^{a}	66.00 ± 0.289^{b}	66.00 ± 0.289^{ab}	66.00 ± 0^{b}	72.83 ± 0.441^{c}	74.50 ± 0^{a}	73.67 ± 0.221^{cd}
T4	61.67 ± 0.441^{ab}	61.33 ± 0.167^{ab}	61.50 ± 0.289^{a}	67.00 ± 0.289^{a}	66.17 ± 0.167^{a}	66.58 ± 0.220^{a}	75.50 ± 0.500^{ab}	73.83 ± 0.166^{ab}	74.67 ± 0.167^{b}
T5	61.50 ± 0.5^{ab}	60.17 ± 0.441^{b}	60.83 ± 0.167^{b}	66.67 ± 0.167^{ab}	65.17 ± 0.334^{b}	65.92 ± 0.221^{b}	74.67 ± 0.441^{b}	73.33 ± 0.333^{b}	74.00 ± 0.144^{c}
T6	61.33 ± 0.167^{ab}	61.67 ± 0.441^{a}	61.50 ± 0.25^{a}	67.00 ± 0.500^{a}	65.50 ± 0.289^{ab}	66.25 ± 0.382^{ab}	75.00 ± 0.289^{ab}	73.83 ± 0.667^{ab}	74.42 ± 0.221^{bc}
T7	61.33 ± 0.167^{ab}	60.67± 0.601^{b}	61.00 ± 0.289^{ab}	66.50 ± 0.289^{ab}	66.17 ± 0.441^{a}	66.33 ± 0.082^{ab}	76.00 ± 0.289^{a}	74.83 ± 0.166^{a}	75.42 ± 0.221^{a}
SEM±	0.30	0.27	0.17	0.26	0.32	0.16	0.34	0.36	0.17
CD at 5%	0.92	0.83	0.52	0.80	0.99	0.50	1.06	1.10	0.54
CV%	0.84	0.77	0.48	0.67	0.84	0.43	0.80	0.84	0.41

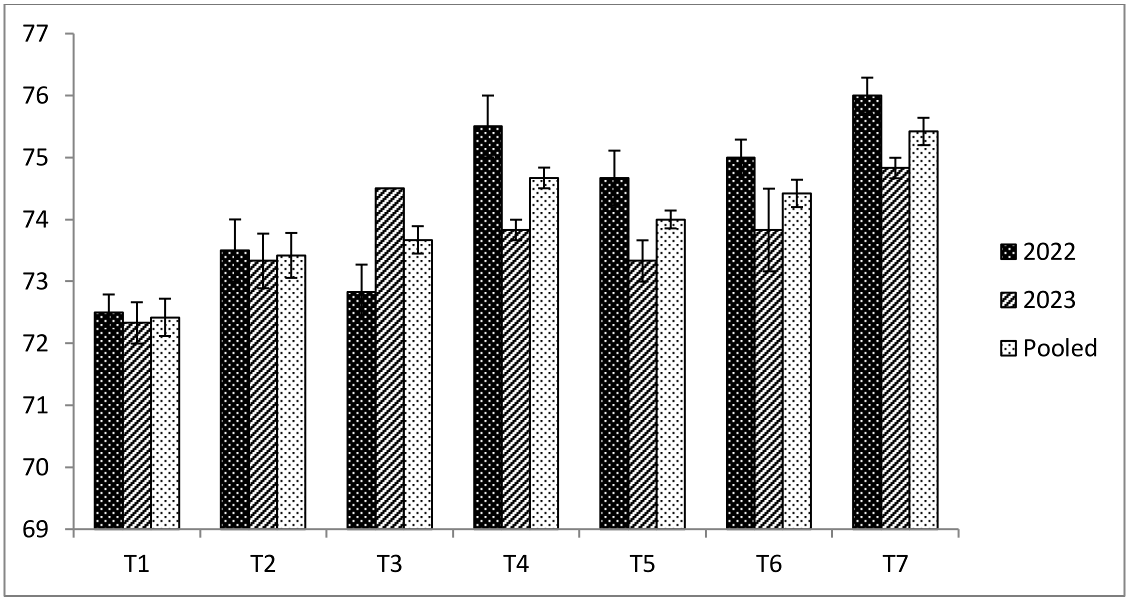

Fig. 4.20. Effect of full spectrum light on days to fruiting under vertical farming system in outdoor conditions

4.1.11 Number of bud formation

Table 4.8, shows significant variation among different treatments grown under outdoor conditions. Treatment T3 (natural light + second level) has maximum number of bud formation (24.83, 24.44 and 24.64) in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (23.17, 25.56 and 24.36) and T1 (natural light + fourth level) (23.00, 25.56 and 24.28). However, with artificial full spectrum light treatment T5 (natural light + full spectrum (2 hours) + third level) has maximum number of bud formation (25.33, 26.78 and 26.06) followed by T7 (natural light + full spectrum (6 hours) + first level) (26.67, 23.89 and 25.28) and T6 (natural light + full spectrum (4 hours) + second level) (25.83, 23.89 and 24.86) in year 2022, 2023 and in pooled data. When we discussed about the overall result than treatment T5 has maximum number of bud formation and T4 has minimum number of bud formation. In year 2022 and pooled data treatment T5, T6 and T7 were at par.

4.1.12 Number of flowers

Maximum number of flowers were found in treatment T1 (natural light + fourth level) (23.11, 24.00 and 23.56) and T2 (natural light + third level) (22.67, 24.44 and 23.56) followed by T3 (natural light + second level) (23.33, 22.44 and 22.89) and T4 (natural light + first level) (21.78, 23.78 and 22.78) in year 2022, 2023 and in pooled data. Under full spectrum light maximum number of flowers counts under treatment T5 (natural light + full spectrum (2 hours) + third level) (22.00, 25.67 and 23.83) in year 2022, 2023 and in pooled data followed by T7 (natural light + full spectrum (6 hours) + first level) (21.89, 22.33 and 22.11) and T6 (natural light + full spectrum (4 hours) + second level) (21.22, 22.56 and 21.89). Treatment T5 (natural light + full spectrum (2 hours) + third level) has utmost number of flowers developed from buds and T7 has minimum number of flowers in overall performance. In 2022, 2023 and in pooled data, T1 and T2 were at par (Table 4.8).

4.1.13 Number of fruits

The data pertaining in table 4.8, shows a significant variation among the treatments in number of fruits. Treatment T1 (natural light + fourth level) performs better (21.78, 22.89 and 22.33) under natural light followed by T2 (natural light + third level) (21.00, 22.89 and 21.94) and T3 (natural light + second level) (21.89, 21.22 and 21.61) in year 2022, 2023 and in pooled data. In case of artificial full spectrum light treatment T5 (natural light + full spectrum (2 hours) + third level) (20.67, 24.78 and 22.72) followed by T7 (natural light + full spectrum (6 hours) + first level) (20.11, 21.22 and 20.67) and T6 (natural light + full spectrum (4 hours) + second level) (19.67, 21.33 and 20.50) in year 2022, 2023 and in pooled data. In overall performance treatment under full spectrum light T5 performs better and have maximum number of fruits but T6 has the minimum number of fruits. In 2022 and in pooled data T1 and T2 were at par (Table 4.8).

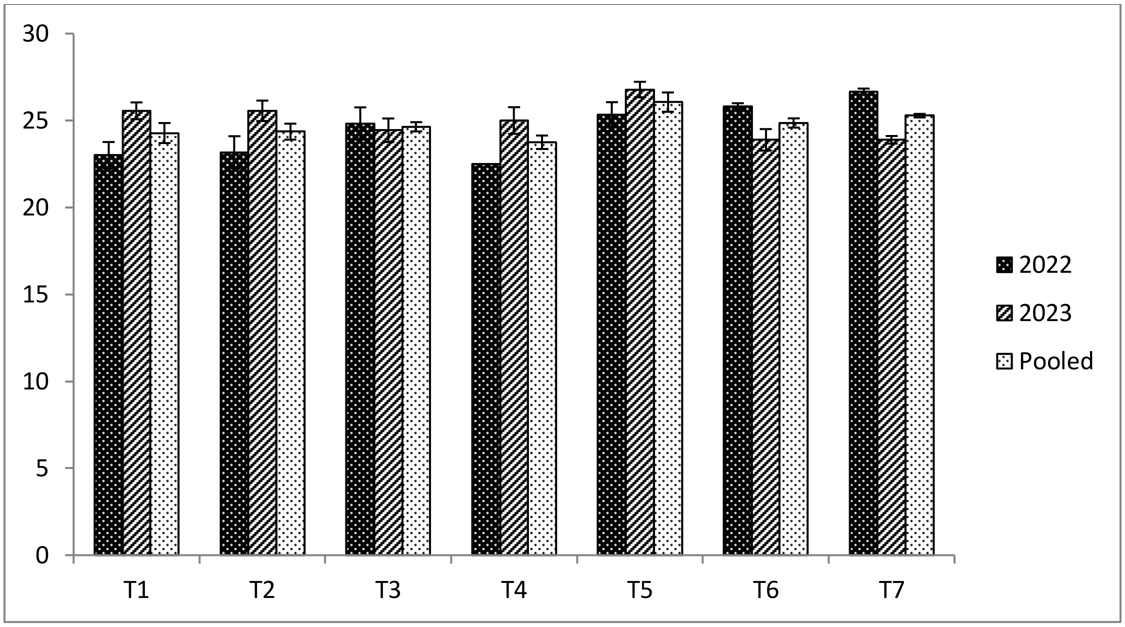

Fig. 4.21. Effect of full spectrum light on number of bud formation under vertical farming system in outdoor conditions

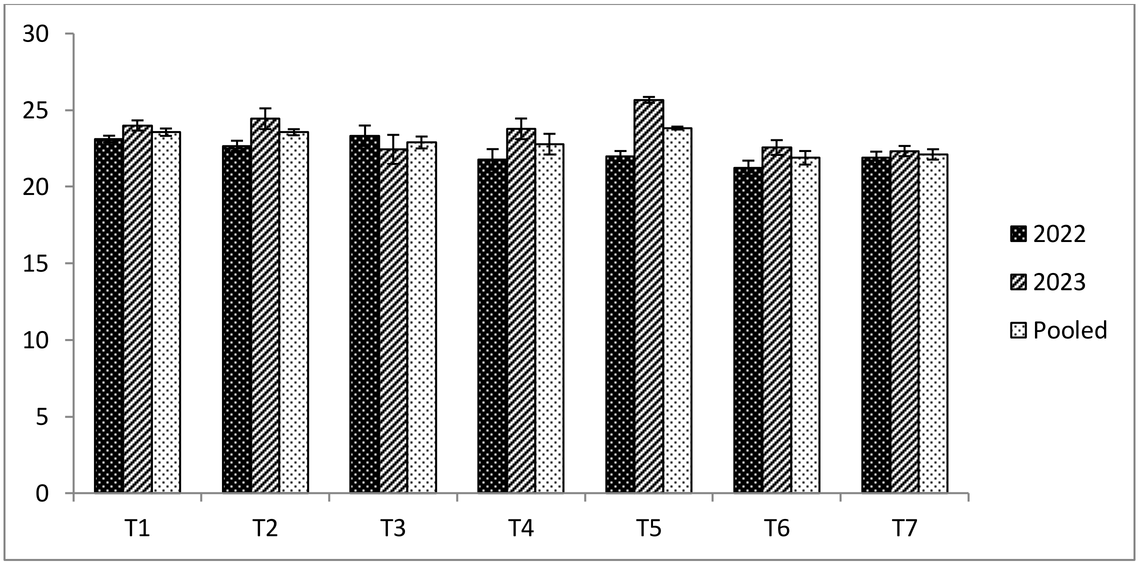

Fig. 4.22. Effect of full spectrum light on number of flowers under vertical farming system in outdoor conditions

Table 4.8: Effect of full spectrum light on number of bud formation, flowering and fruiting under vertical farming system in outdoor conditions.

	Number of bud formation			**Number of flowers**			**Number of fruits**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	23.00 ± 0.764^{b}	25.56 ± 0.483^{ab}	24.28 ± 0.576^{b}	23.11 ± 0.222^{a}	24.00 ± 0.333^{ab}	23.56 ± 0.241^{ab}	21.78 ± 0.400^{a}	22.89 ± 0.402^{b}	22.33 ± 0.384^{ab}
T2	23.17 ± 0.928^{b}	25.56 ± 0.588^{ab}	24.36 ± 0.459^{b}	22.67 ± 0.333^{ab}	24.44 ± 0.678^{ab}	23.56 ± 0.199^{ab}	21.00 ± 0.510^{ab}	22.89 ± 0.776^{b}	21.94 ± 0.474^{ab}
T3	24.83 ± 0.928^{ab}	24.44 ± 0.678^{b}	24.64 ± 0.266^{b}	23.33 ± 0.667^{a}	22.44 ± 0.948^{b}	22.89 ± 0.388^{ab}	21.89 ± 0.890^{a}	21.33 ± 0.839^{bc}	21.61 ± 0.390^{b}
T4	22.50 ± 0^{b}	25.00 ± 0.768^{b}	23.75 ± 0.387^{b}	21.78 ± 0.676^{b}	23.78 ± 0.675^{b}	22.78 ± 0.675^{b}	19.56 ± 0.480^{c}	22.56 ± 0.588^{bc}	21.06 ± 0.529^{bc}
T5	25.33 ± 0.726^{a}	26.78 ± 0.447^{a}	26.06 ± 0.556^{a}	22.00 ± 0.333^{b}	25.67 ± 0.193^{a}	23.83 ± 0.095^{a}	20.67 ± 0.330^{b}	24.78 ± 0.294^{a}	22.72 ± 0.110^{a}
T6	25.83 ± 0.167^{a}	23.89 ± 0.618^{b}	24.86 ± 0.266^{ab}	21.22 ± 0.484^{b}	22.56 ± 0.483^{b}	21.89 ± 0.443^{b}	19.67 ± 0.510^{bc}	21.33 ± 0.384^{bc}	20.50 ± 0.441^{c}
T7	26.67 ± 0.167^{a}	23.89 ± 0.220^{b}	25.28 ± 0.102^{ab}	21.89 ± 0.401^{b}	22.33 ± 0.333^{b}	22.11 ± 0.339^{b}	20.11 ± 0.620^{bc}	21.22 ± 0.294^{c}	20.67 ± 0.419^{bc}
SEM±	0.64	0.57	0.41	0.30	0.58	0.33	0.34	0.53	0.30
CD at 5%	1.97	1.76	1.26	0.93	1.77	1.01	1.05	1.64	0.93
CV%	4.53	3.95	2.87	2.35	4.23	2.46	2.86	4.10	2.42

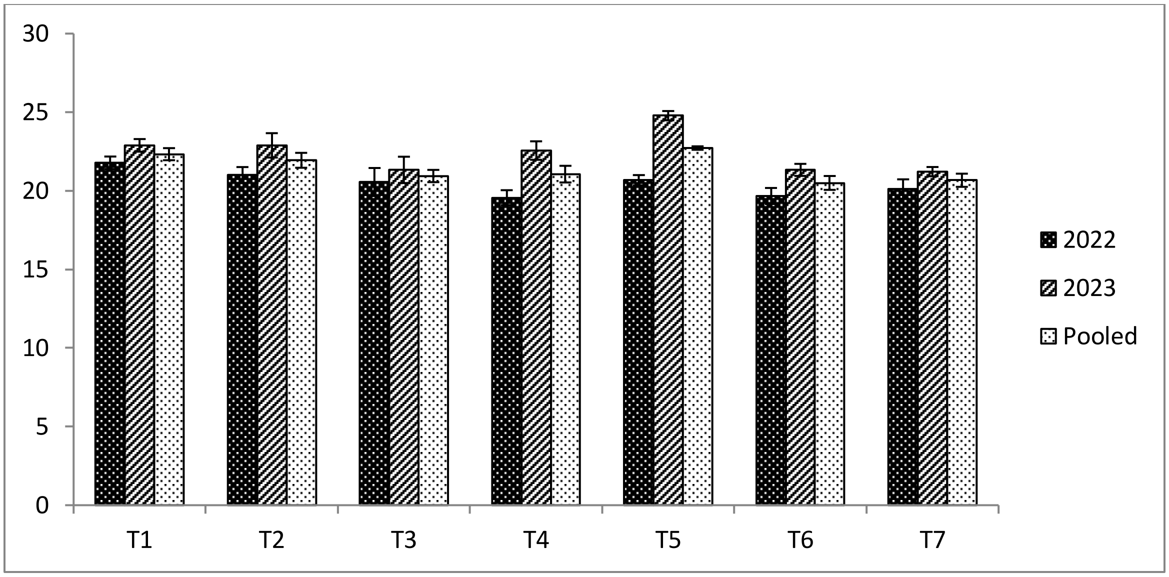

Fig. 4.23. Effect of full spectrum light on number of fruits under vertical farming system in outdoor conditions

Extended exposure to full spectrum light to promote flower induction and increase the number of flowers is a time-dependent process and is influenced by multiple components of the daylight spectrum; however, for harnessing the full advantage of the application of LEDs in crop production it is necessary to know the diurnal impact of light quality on the whole process from floral evocation to anthesis including the involvement of photoreceptors and the flowering regulatory genes (SharathKumar *et al.,* 2021). The results of the study carried out by Murad *et al.,* (2021) showed that flowering in strawberries was increased with the impact of LED light, which is somewhat similar to our study. The improved light spectrum likely stimulated floral initiation and promoted greater flower production (Nadalini *et al.,* 2017), leading to enhanced pollination efficiency and fruit set, ultimately resulting in higher fruit yield (Nguyen *et al.,* 2021).

4.1.14 Fruit set (%)

In table 4.9, T1 (natural light + fourth level) has highest fruit percentage (94.22%, 95.36% and 94.79%) under natural light followed by T2 (natural light + third level) (92.67%, 93.60% and 93.14%) and T4 (natural light + second level) (89.83%, 94.87% and 92.35%)

in year 2022, 2023 and in pooled data. In case of full spectrum light T5 (natural light + full spectrum (2 hours) + third level) has highest fruit set (%) (93.94%, 96.53% and 95.23%) followed by T6 (natural light + full spectrum (4 hours) + second level) (92.67%, 94.60% and 93.64%) and T7 (natural light + full spectrum (6 hours) + first level) (91.85%, 95.03% and 93.44%) in year 2022, 2023 and in pooled data. In overall result T5 was superior and T4 was inferior. Treatment T1 and T5 were at par in year 2022, 2023 and in pooled data.

4.1.15 Fruit volume (cm^3)

Further in fruit volume under natural light T1 (natural light + fourth level) performs better (14.00, 14.24 and 14.12 cm^3) in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (14.07, 13.64 and 13.86 cm^3) and T3 (natural light + second level) (12.74, 13.57 and 13.16 cm^3). Moreover, in addition of full spectrum light T5 (natural light + full spectrum (2 hours) + third level) has higher fruit volume (14.40, 13.89 and 14.14 cm^3) in year 2022, 2023 and in pooled data followed by T6 (natural light + full spectrum (4 hours) + second level) (13.90, 13.74 and 13.82 cm^3) and T7 (natural light + full spectrum (6 hours) + first level) (12.91, 12.94 and 12.93 cm^3). When overall performance was observed it was found that T5 and T1 were superior and T4 was inferior. Treatment T1, T2, T5, T6 were at par in year 2022, 2023 and in pooled data (Table 4.9).

Treatment T_5 has maximum fruit set due to presence of adequate amount of light which was followed by T_1 and T_6. Because full spectrum light, which encompasses the necessary wavelengths for both photosynthesis and reproductive development, is essential for successful fruit set in strawberries. Adequate light intensity and quality during the flowering stage positively impact pollination, fertilization and subsequent fruit formation 21 (Galián *et al.,* 2021). Various factors, such as genetics, environmental conditions and cultivation practices, can influence fruit volume in strawberries. Optimal light quality and intensity are influential factors in determining fruit size and volume. Studies indicate that optimizing the light spectrum and intensity can contribute to increased fruit volume in strawberries cultivated under controlled environments (Samuolienė *et al.,* 2010).

4.1.16 Average berry weight (g)

Table 4.9, shows a significant variation in average berry weight among different treatments grown under outdoor conditions. Treatment T1 (natural light + fourth level) has maximum average berry weight (16.10g, 16.43g and 16.26g) followed by T2 (natural light + third level) (16.01g, 15.12g and 15.57g) and T3 (natural light + second level) (15.02g, 15.35g and 15.19g) in year 2022, 2023 and in pooled data. Moreover, due to addition of full spectrum light T6 has maximum average berry yield (16.80g, 15.88g and 16.34g) in year 2022, 2023 and in pooled data followed by T5 (natural light + full spectrum (6 hours) + first level) (15.37g, 15.37g and 15.37g). In overall performance T6 spectrum (2 hours) + third level) (16.74g, 15.38g and 16.06g) and T7 (natural light + full was superior and T4 was inferior. In 2022, 2023 and pooled data T1, T5 and T6 were at par.

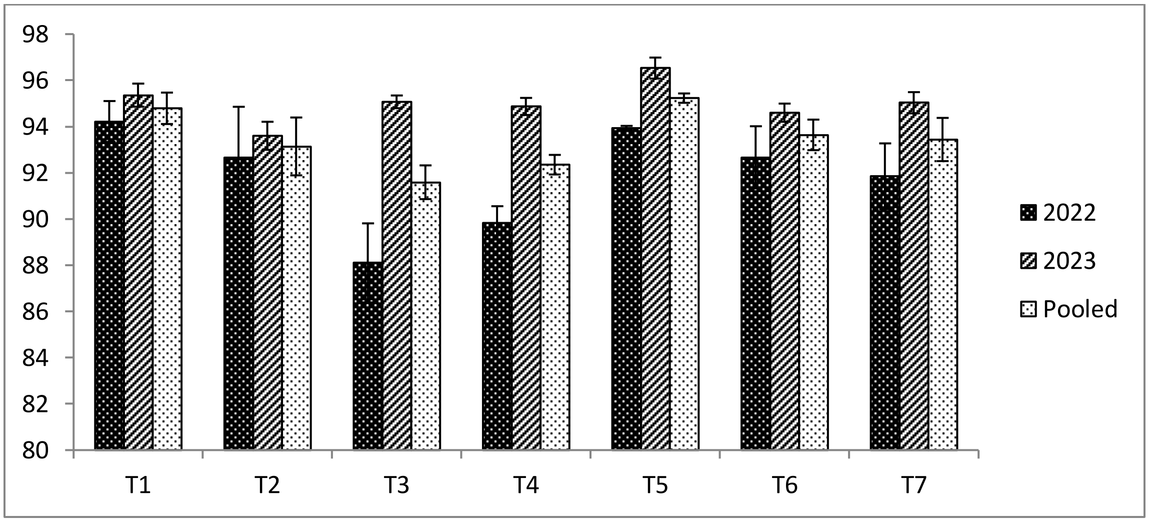

Fig. 4.24. Effect of full spectrum light on fruit Set (%) under vertical farming system in outdoor conditions

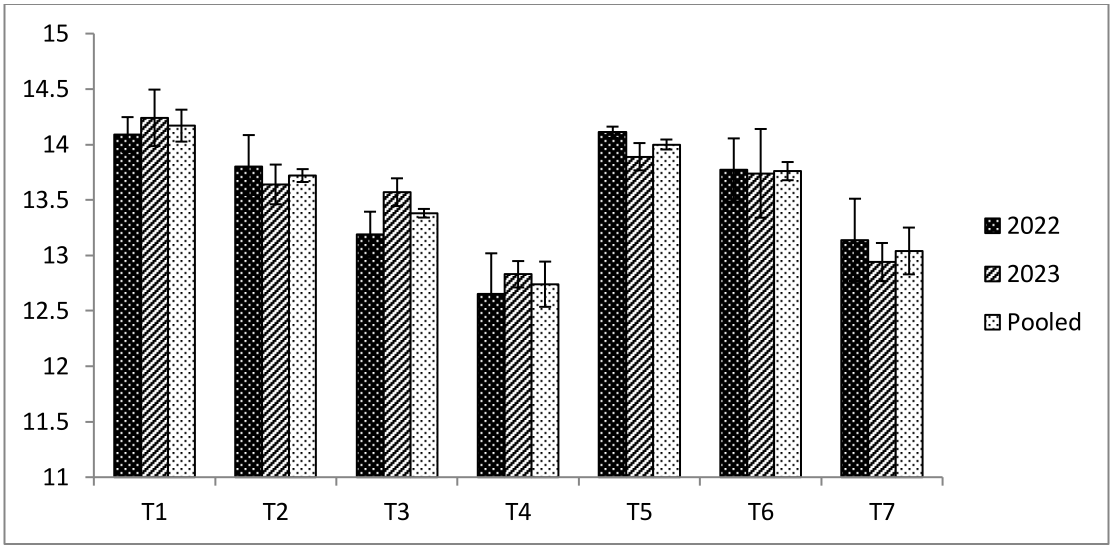

Fig. 4.25. Effect of full spectrum light on fruit volume under vertical farming system in outdoor conditions

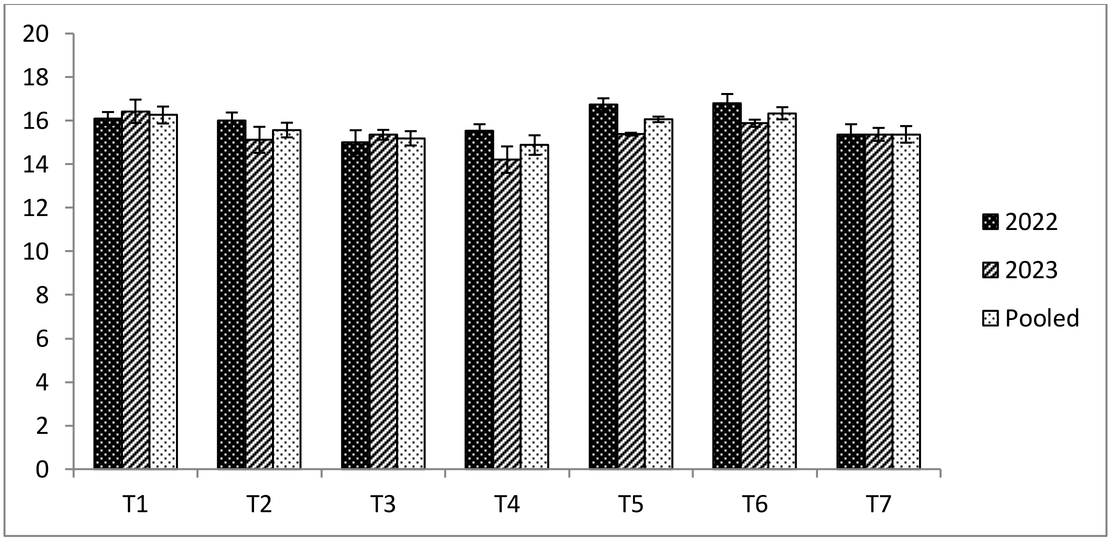

Fig. 4.26. Effect of full spectrum light on average berry weight under vertical farming system in outdoor conditions

Table 4.9: Effect of full spectrum light on yield traits under vertical farming system in outdoor conditions.

	Fruit set %			Fruit volume (cm^3)			Average berry Weight (g)		
Treatment Name	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T1	94.22 ± 0.884^{a}	95.36 ± 0.499^{ab}	94.79 ± 0.680^{ab}	14.00 ± 0.157^{a}	14.24 ± 0.255^{a}	14.12 ± 0.144^{a}	16.10 ± 0.297^{ab}	16.43 ± 0.536^{a}	16.26 ± 0.388^{ab}
T2	92.67 ± 2.185^{ab}	93.60 ± 0.607^{c}	93.14 ± 1.252^{b}	14.07 ± 0.285^{a}	13.64 ± 0.179^{ab}	13.86 ± 0.058^{a}	16.01 ± 0.365^{b}	15.12 ± 0.597^{b}	15.57 ± 0.336^{b}
T3	88.10 ± 1.711^{b}	95.07 ± 0.275^{b}	91.59 ± 0.730^{b}	12.74 ± 0.204^{b}	13.57 ± 0.125^{b}	13.16 ± 0.039^{b}	15.02 ± 0.542^{c}	15.35 ± 0.227^{ab}	15.19 ± 0.329^{b}
T4	89.83 ± 0.723^{b}	94.87 ± 0.37^{bc}	92.35 ± 0.424^{b}	12.88 ± 0.369^{b}	12.83 ± 0.119^{c}	12.86 ± 0.204^{b}	15.54 ± 0.297^{bc}	14.21 ± 0.609^{b}	14.88 ± 0.449^{b}
T5	93.94 ± 0.089^{a}	96.53 ± 0.455^{a}	95.23 ± 0.203^{a}	14.40 ± 0.051^{a}	13.89 ± 0.123^{ab}	14.14 ± 0.045^{a}	16.74 ± 0.287^{ab}	15.38 ± 0.064^{ab}	16.06 ± 0.126^{ab}
T6	92.67 ± 1.343^{ab}	94.60 ± 0.394^{bc}	93.64 ± 0.661^{ab}	13.90 ± 0.285^{a}	13.74 ± 0.400^{ab}	13.82 ± 0.082^{a}	16.80 ± 0.424^{a}	15.88 ± 0.165^{ab}	16.34 ± 0.280^{a}
T7	91.85 ± 1.422^{ab}	95.03 ± 0.459^{b}	93.44 ± 0.935^{ab}	12.91 ± 0.371^{b}	12.94 ± 0.172^{bc}	12.93 ± 0.211^{b}	15.37 ± 0.467^{bc}	15.37 ± 0.298^{ab}	15.37 ± 0.381^{b}
SEM±	1.16	0.42	0.61	0.28	0.21	0.13	0.24	0.39	0.24
CD at 5%=	3.58	1.31	1.88	0.88	0.66	0.41	0.73	1.21	0.73
CV%	2.19	0.77	1.13	3.63	2.72	1.68	2.58	4.40	2.61

4.1.17 Average Yield (g per plant)

Table 4.10, shows significant variation among different treatments grown under outdoor conditions. Maximum average yield was observed in T1 (natural light + fourth level) (350.34, 375.67 and 362.54g per plant) followed by T2 (natural light + third level) (335.89, 345.23 and 340.18g per plant) and T3 (natural light + second level) (327.86, 327.29 and 327.81g per plant) in year 2022, 2023 and in pooled data. When artificial full spectrum light was provided then T5 (natural light + full spectrum (2 hours) + third level) performed superior (345.70, 381.08 and 363.64g per plant) than other treatment. It was followed by T6 (natural light + full spectrum (4 hours) + second level) (330.06, 338.70 and 334.04g per plant) and T7 (natural light + full spectrum (6 hours) + first level) (308.59, 326.11 and 318.53g per plant) in year 2022, 2023 and in pooled data. When overall performance was discussed, it was found that T1 and T5 performed at par and have maximum average yield while T4 (natural light + first level) has the minimum average yield in outdoor conditions.

4.1.18 Estimated Yield (Kg per 1000sqm)

In estimated yield T1 (natural light + fourth level) has maximum yield (7072.72, 7584.17 and 7319.15Kg per 1000sqm) in year 2022, 2023 and in pooled data under natural light which was followed by T2 (natural light + third level) (6781.05, 6969.61 and 6867.60 Kg per 1000sqm) and T3 (natural light + second level) (6618.94, 6607.40 and 6617.98Kg per 1000sqm). Although under full spectrum light T5 (natural light + full spectrum (2 hours) + third level) has highest estimated yield (6979.16, 7693.33 and 7341.25Kg per 1000sqm) followed by T6 (natural light + full spectrum (4 hours) + second level) (6663.32, 6837.83 and 6743.82Kg per 1000sqm) and T7 (natural light + full spectrum (6 hours) + first level) (6230.04, 6583.74 and 6430.61Kg per 1000sqm) in year 2022, 2023 and in pooled data. In overall performance T1 and T6 were performs superior and T4 ((natural light + first level)) was inferior. Treatment T1 and T5 were at par in 2022, 2023 and in pooled data (Table 4.10).

The average berry weight was giving significant results under natural light. Treatment T6 was superior in comparison to T1 and T5 under both natural as well as additional full spectrum light. Moreover, when additional full spectrum light provided to plants than T6 performs better than T5 and T7, respectively. Moreover, average yield in T_5 (363.64g) where 2 hours full spectrum light was provided with natural light was superior in comparison to T_6 and T_7 under full spectrum light. When no additional sunlight was provided then T_1 (362.54g) was superior than other treatments. The average yield of T_1 is also near about the T_5 which was followed by treatment T_2, T_3, T_4, T_5 and T_6. The maximum estimated yield was observed in treatment T_5 (489.40g) while T_1 had the minimum estimated yield (488.88) respectively.

An increase in the yield of strawberry plants was observed in somewhat similar study of Hanenberg et al. (2016) and Hidaka et al. (2013). The weight of strawberries is influenced by multiple factors, such as genetic traits, nutrient availability and environmental conditions. Full spectrum light has the potential to enhance photosynthesis and overall plant vitality, which could result in larger berry sizes (Zheng *et al.,* 2019). Full spectrum light, provided by technologies such as full spectrum LEDs, can optimize plant growth and development, potentially leading to increased yields in vertical farming systems.

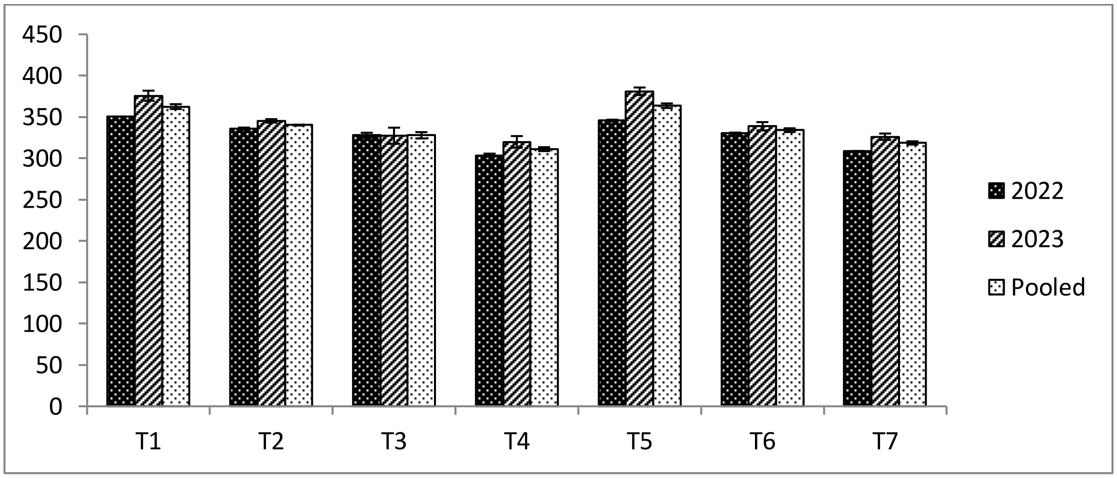

Fig. 4.27. Effect of full spectrum light on average yield per plant under vertical farming system in outdoor conditions

Table 4.10: Effect of full spectrum light on yield under vertical farming system in outdoor conditions.

	Average yield (g per plant)			**Estimated Yield (kg per 1000sqm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	350.34 ± 0.116^{a}	375.67 ± 6.117^{a}	362.54 ± 2.917^{a}	7072.72 ± 0.970^{a}	7584.17 ± 123.530^{a}	7319.15 ± 58.920^{a}
T2	335.89 ± 1.286^{b}	345.23 ± 2.104^{b}	340.18 ± 0.537^{b}	6781.05 ± 25.970^{b}	6969.61 ± 42.490^{b}	6867.60 ± 10.730^{b}
T3	327.86 ± 3.004^{c}	327.29 ± 9.767^{c}	327.81 ± 3.821^{d}	6618.94 ± 60.650^{c}	6607.40 ± 197.160^{c}	6617.98 ± 77.120^{d}
T4	303.67 ± 1.975^{e}	319.87 ± 7.018^{c}	311.06 ± 2.364^{f}	6130.67 ± 39.870^{d}	6457.76 ± 141.720^{c}	6279.73 ± 47.740^{f}
T5	345.70 ± 1.041^{a}	381.08 ± 4.573^{a}	363.64 ± 2.770^{a}	6979.16 ± 20.940^{a}	7693.33 ± 92.290^{a}	7341.25 ± 55.910^{a}
T6	330.06 ± 1.039^{c}	338.70 ± 5.053^{b}	334.04 ± 2.246^{c}	6663.32 ± 21.010^{c}	6837.83 ± 102.030^{bc}	6743.82 ± 45.320^{c}
T7	308.59 ± 0.234^{d}	326.11 ± 3.856^{c}	318.53 ± 2.002^{e}	6230.04 ± 5.070^{d}	6583.74 ± 77.800^{c}	6430.61 ± 40.400^{e}
SEM±	1.58	4.63	1.97	31.91	93.46	39.71
CD at 5%	4.87	14.27	6.06	99.41	291.15	123.73
CV%	0.83	2.33	1.01	0.83	2.33	1.01

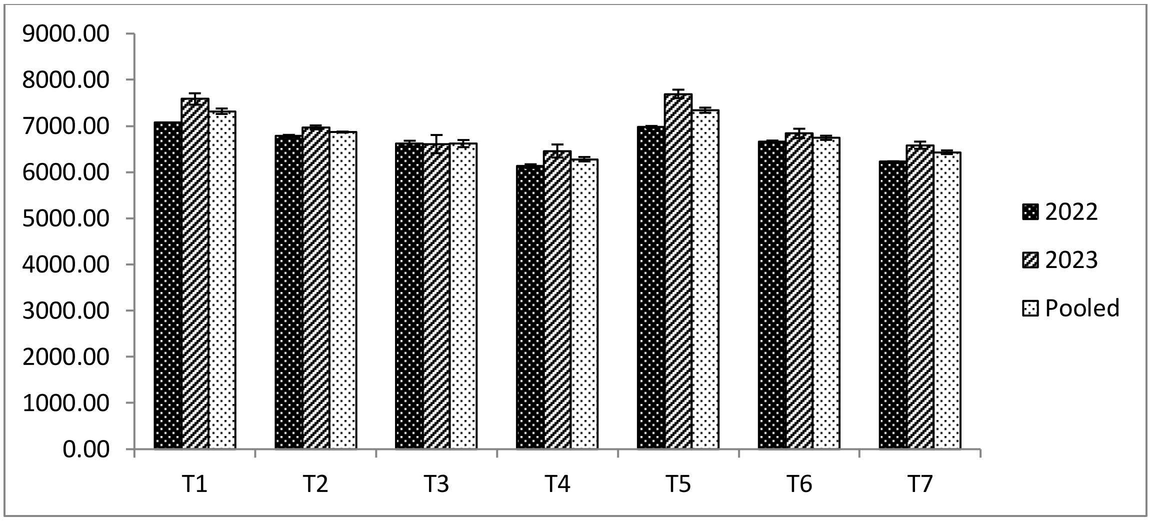

Fig. 4.28. Effect of full spectrum light on estimated yield per 1000 sqm under vertical farming system in outdoor conditions

Yield in strawberry cultivation refers to the quantity of harvested fruits per unit of land. Full spectrum light, provided by technologies like full spectrum LEDs, can optimize plant growth and development, potentially leading to increased yields in vertical farming systems. Research has demonstrated the beneficial impact of full spectrum light on plant yield in various crops, including strawberries (Choi *et al.*, 2015 and Fangfang *et al.,* 2021). Touliatus *et al.,* (2016) also found that vertical farming system increases the yield by incorporating the artificial light.

4.1.19 TSS (˚Brix)

Table 4.11, represent that treatment T3 (natural light + second level) has maximum total soluble solids (11.11, 10.88 and 11.00 ˚Brix) followed by T2 (natural light + third level) (11.11, 10.85 and 10.98 ˚Brix) and T1 (natural light + fourth level) (10.01, 11.45 and 10.73 ˚Brix) in year 2022, 2023 and in pooled data. In case of treatment under additional full spectrum light T6 (natural light + full spectrum (4 hours) + second level) has maximum total soluble solids (11.53, 11.47 and 11.50 ˚Brix) in year 2022, 2023 and in pooled data followed by T5 (natural light + full spectrum (2 hours) + third level) (11.45, 10.80 and 11.12 ˚Brix) and T7 (natural light + full spectrum (6 hours) + first level) (11.47, 10.55 and

11.01 ˚Brix). T6 performs superior in overall performance and T1 performs inferior. In 2022, 2023 and in pooled data, treatment T3 and T6 were at par.

4.1.20 Titrable acidity (%)

In Table 4.11, maximum amount of titrable acidity found in T3 (natural light + second level) (0.68%, 0.69% and 0.69%) and T4 (0.69%, 0.68% and 0.69%) followed by T2 (natural light + third level) (0.67%, 0.66% and 0.67%) and T1 (natural light + fourth level) (0.63%, 0.63% and 0.63%). Although due to additional full spectrum light maximum titrable acidity noticed in T6 (natural light + full spectrum (4 hours) + second level) (0.66%, 0.67% and 0.67%) and T7 (natural light + full spectrum (6 hours) + first level) (0.67%, 0.67% and 0.67%) followed by T5 (natural light + full spectrum (2 hours) + third level) (0.62%, 0.63% and 0.62%). As we observed that T3 and T4 have maximum content of titrable acidity while T5 has minimum in overall performance. Treatment T2, T3, T4 and T7 were at par in year 2022, 2023 and in pooled data.

4.1.21 Vitamin C (mg/100g)

Treatment T1 (natural light + fourth level) performs better (51.11, 51.97 and 51.54 mg/100g) in Vitamin C content in year 2022, 2023 and in pooled data followed by T3 (natural light + second level) (49.99, 50.68 and 50.45 mg/100g) and T2 (natural light + third level) (50.22, 49.18 and 49.70 mg/100g). In case of full spectrum light T5 (natural light + full spectrum (2 hours) + third level) has maximum (51.99, 50.92 and 51.33 mg/100g) Vitamin C content followed by T6 (natural light + full spectrum (4 hours) + second level) (51.32, 49.81 and 50.56 mg/100g) and T7 (natural light + full spectrum (6 hours) + first level) (50.04, 50.65 and 50.35 mg/100g) in year2022, 2023 and in pooled data (Table 4.11).

The TSS, TA and Vitamin C of fruits that have been harvested from plants grown under various duration of supplemental lighting and natural lighting. The TSS values of fruits were generally higher in the supplemental lighting treatments than in the natural light; however, there was no significant difference in TSS among the 2, 4 and 6 hours of full spectrum light and the natural light. In case of titrable acidity T1 (0.63, 51.54) which is top level of vertical farming system and T5 (0.63, 51.33) which is third level of vertical farming system with 2 hours light perform better than the other treatments as well as similar results were found in Vitamin C in outdoor condition (Table 4.11). It was reported that photosynthetic production under LED supplemental lighting was higher which resulted into increased TSS (Maeda and Ito, 2020 and Jiang *et al.,* 2023). Wysocki et al. (2017) had reported increase in contents of extract sugar, anthocyanins, polyphenols, vitamin C. Numerous variables affect TSS, TA and Vit C, including the soils fertility, the strawberry variety, the age of the plantation, the time of harvest, the cultivation method (organic, conventional, integrated, hydroponic, tunnel, or in the open field) and the storage conditions following harvest. Organic strawberries frequently have higher vitamin C content than conventional fruits (Taghavi *et al.,*2019 and Newerli-Guz *et al.,* 2023).

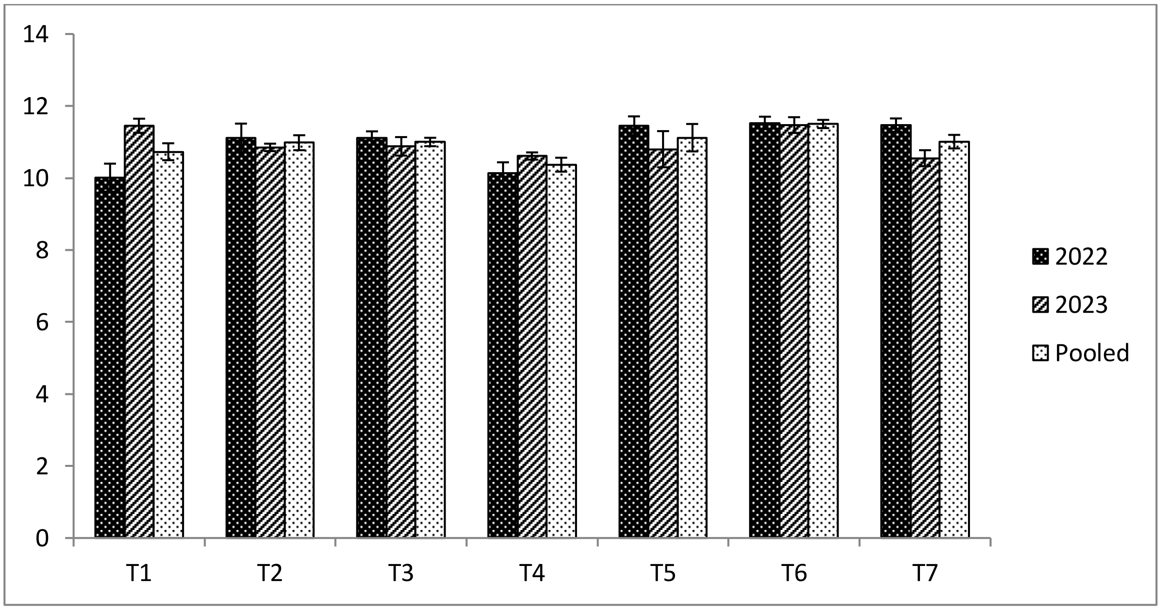

Fig. 4.29. Effect of full spectrum light on TSS under vertical farming system in outdoor conditions

Table 4.11: Effect of full spectrum light on biochemical traits under vertical farming system in outdoor conditions.

	TSS (˚Brix)			**Titrable Acidity (%)**			**Vitamin C (mg per 100g)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	10.01 ± 0.389^{b}	11.45 ± 0.197^{ab}	10.73 ± 0.235^{b}	0.63 ± 0.006^{c}	0.63 ± 0.003^{b}	0.63 ± 0.003^{b}	51.11 ± 0.078^{b}	51.97 ± 0.263^{a}	51.54 ± 0.165^{a}
T2	11.11 ± 0.401^{a}	10.85 ± 0.104^{ab}	10.98 ± 0.208^{ab}	0.67 ± 0.009^{ab}	0.66 ± 0.003^{a}	0.67 ± 0.006^{a}	50.22 ± 0.081^{c}	49.18 ± 0.795^{bc}	49.70 ± 0.366^{c}
T3	11.11 ± 0.186^{a}	10.88 ± 0.257^{ab}	11.00 ± 0.117^{ab}	0.68 ± 0.006^{ab}	0.69 ± 0.006^{a}	0.69 ± 0.003^{a}	49.99 ± 0.078^{c}	50.68 ± 0.730^{ab}	50.45 ± 0.061^{bc}
T4	10.13 ± 0.306^{b}	10.61 ± 0.101^{b}	10.37 ± 0.193^{b}	0.69 ± 0.006^{a}	0.68 ± 0.017^{a}	0.69 ± 0.012^{a}	49.09 ± 0.08^{d}	48.11 ± 0.468^{c}	48.60 ± 0.200^{d}
T5	11.45 ± 0.262^{a}	10.80 ± 0.502^{b}	11.12 ± 0.381^{ab}	0.62 ± 0.012^{c}	0.63 ± 0.025^{b}	0.62 ± 0.009^{b}	51.99 ± 0.08^{a}	50.92 ± 0.145^{ab}	51.33 ± 0.405^{ab}
T6	11.53 ± 0.173^{a}	11.47 ± 0.219^{a}	11.50 ± 0.114^{a}	0.66 ± 0.003^{b}	0.67 ± 0.01^{ab}	0.67 ± 0.006^{a}	51.32 ± 0.129^{b}	49.81 ± 0.202^{b}	50.56 ± 0.165^{b}
T7	11.47 ± 0.185^{a}	10.55 ± 0.222^{b}	11.01 ± 0.188^{ab}	0.67 ± 0.009^{ab}	0.67 ± 0.006^{ab}	0.67 ± 0.007^{a}	50.04 ± 0.080^{c}	50.65 ± 0.602^{ab}	50.35 ± 0.263^{bc}
SEM±	0.31	0.21	0.22	0.01	0.01	0.01	0.08	0.52	0.26
CD at 5%	0.95	0.66	0.67	0.02	0.04	0.02	0.26	1.60	0.81
CV%	4.88	3.39	3.45	1.89	3.41	1.85	0.28	1.79	0.90

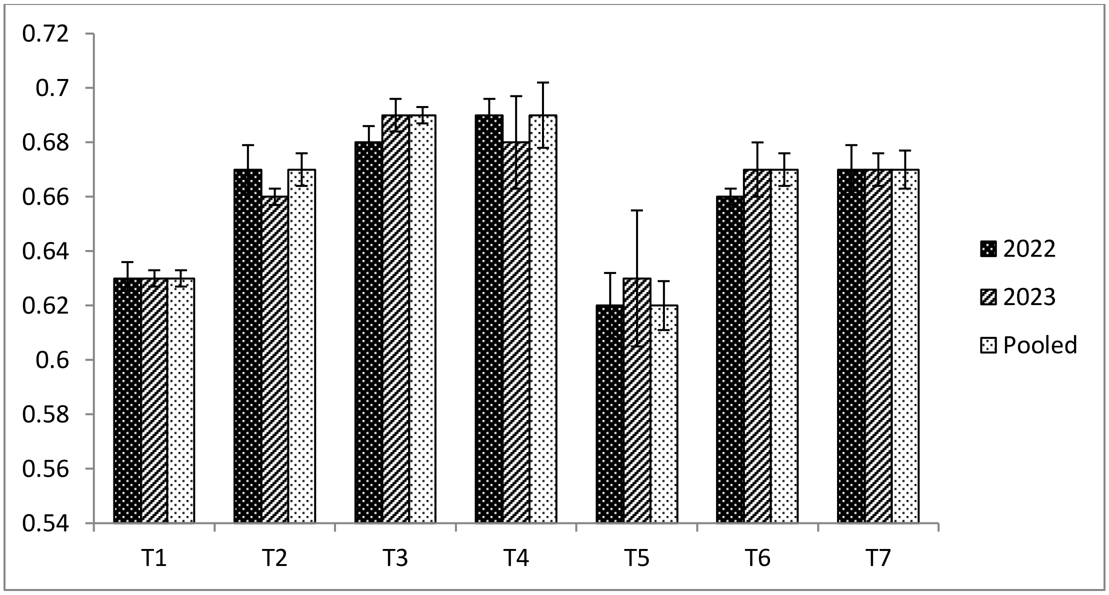

Fig. 4.30 Effect of full spectrum light on titrable acidity under vertical farming system in outdoor conditions

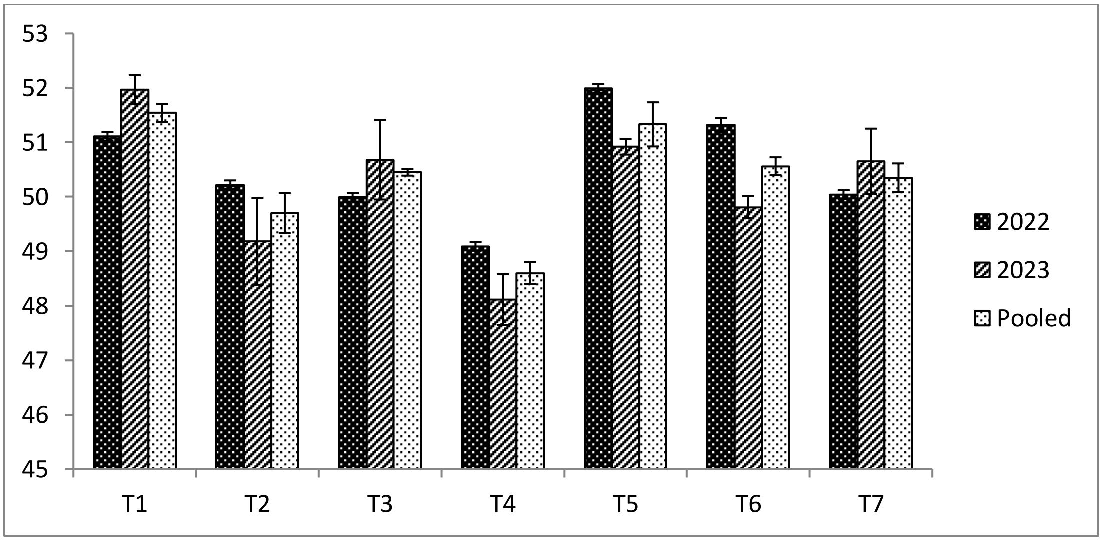

Fig. 4.31 Effect of full spectrum light on vitamin C under vertical farming system in outdoor conditions

4.1.22 Reducing sugar (%)

Table 4.12, shows the recorded data of reducing sugar and confirms significant variation along with different treatments grown under indoor conditions. Under natural light treatment T1 (natural light + fourth level) performs better (2.94%, 2.93% and 2.93%) in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (2.91%, 2.92% and 2.92%) and T3 (natural light + second level) (2.93%, 2.88% and 2.91%). But when additional full spectrum light was used then T5 performs better than natural light in year 2022, 2023 and in pooled data (2.99%, 2.97% and 2.98%) followed by T6 (natural light + full spectrum (4 hours) + second level) (2.96%, 2.94% and 2.95%) and T7 (natural light + full spectrum (6 hours) + first level) (2.96%, 2.93% and 2.95%). When all treatment discussed together it was observed that T5 (natural light + full spectrum (2 hours) + third level) has maximum content of reducing sugar and T4 has minimum content. TreatmentT5 and T6 were at par in 2022, 2023 and pooled data.

4.1.23 Non-reducing sugar (%)

Maximum content observed in T1 (natural light + fourth level) (6.64%, 6.63% and 6.64%) under natural light in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (6.60%, 6.60% and 6.60%) and T3 (natural light + second level) (6.53%, 6.54% and 6.54%). However, with full spectrum light treatment T5 (natural light + full spectrum (2 hours) + third level) performs better (6.65%, 6.63% and 6.64%) followed by T6 (natural light + full spectrum (4 hours) + second level) (6.62%, 6.61% and 6.62%) and T7 (natural light + full spectrum (6 hours) + first level) (6.60%, 6.57% and 6.59%). In overall performance T1 and T5 both treatments were showed superiority but T5 showed inferiority. In 2022, 2023 and in pooled data T1, T5 and T6 were at par (Table 4.12).

4.1.24 Total Sugars (%)

As shown in Table 4.12, under outdoor conditions utmost content of total sugars noticed in treatment T1 (natural light + fourth level) (9.58%, 9.56% and 9.57%) followed by T2 (natural light + third level) (9.51%, 9.52% and 9.51%) and T3 (natural light + second level)

(9.46%, 9.42% and 9.44%) under natural light in year 2022, 2023 and in pooled data. Moreover, T5 (natural light + full spectrum (2 hours) + third level) has maximum (9.64%, 9.60% and 9.62%) total sugars due to use of additional full spectrum light in year 2022, 2023 and in pooled data followed by T6 (natural light + full spectrum (4 hours) + second level) (9.58%, 9.55% and 9.57%) and T7 (natural light + full spectrum (6 hours) + first level) (9.57%, 9.50% and 9.53%). in overall performance T5 has more content of total sugars and T4 has less content of total sugars. T1, T5 and T6 were at par in 2022, 2023 and pooled data.

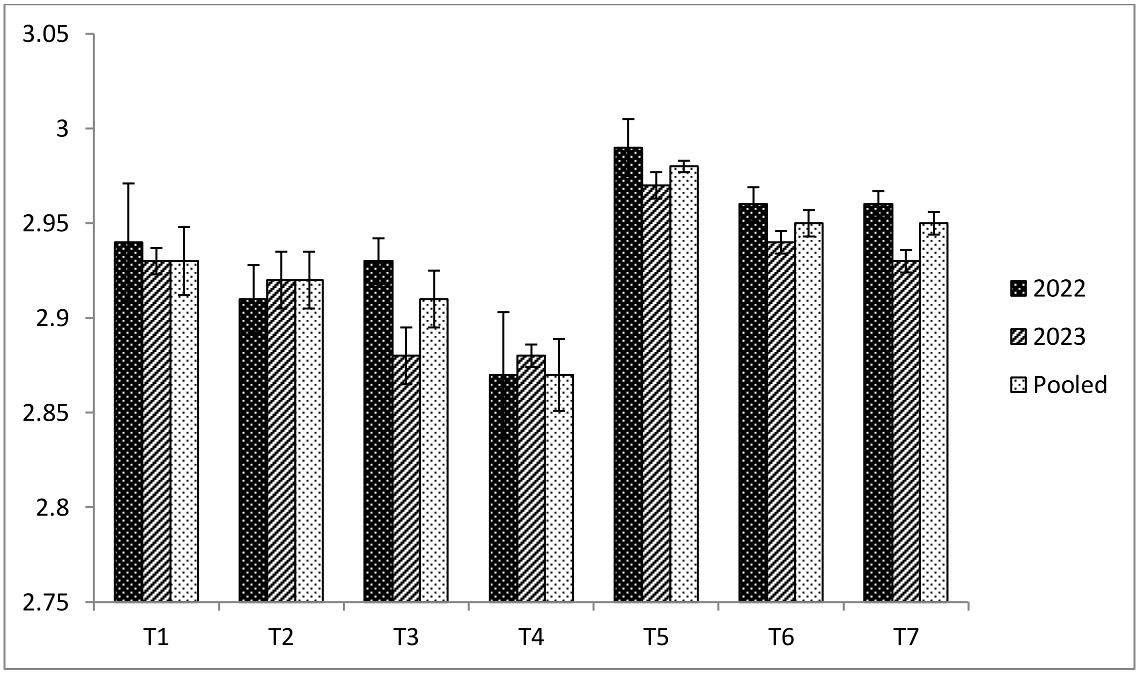

Fig. 4.32 Effect of full spectrum light on reducing sugar under vertical farming system in outdoor conditions

In outdoor conditions a significant result is found between reducing sugar, non-reducing sugar and total sugar. T5 (2.98%, 6.64% and 9.62%) where additional 2 hours full spectrum light is provided with natural light performs superior in all three traits as well as in treatments (T6 and T7) where additional full spectrum light (4 and 6 hours) is used perform better than natural light. In case of natural light treatment on the top level (T1) where maximum natural light is observed by plant in overall the day performs better (2.93%, 6.64% and 9.65%) than the other level of vertical farming system. Particularly during the late harvest season, the supplemental light significantly raised the strawberry fruits concentration of glucose, fructose and total sugar (Xu *et al.*, 2023). As with strawberry fruit weight, supplement light increased accumulation of total sugar, sucrose and reducing sugar. This may be due to the large input of photosynthetic products provided by the large leaves and high photosynthetic abilities under light (Peng *et al.*, 2020).

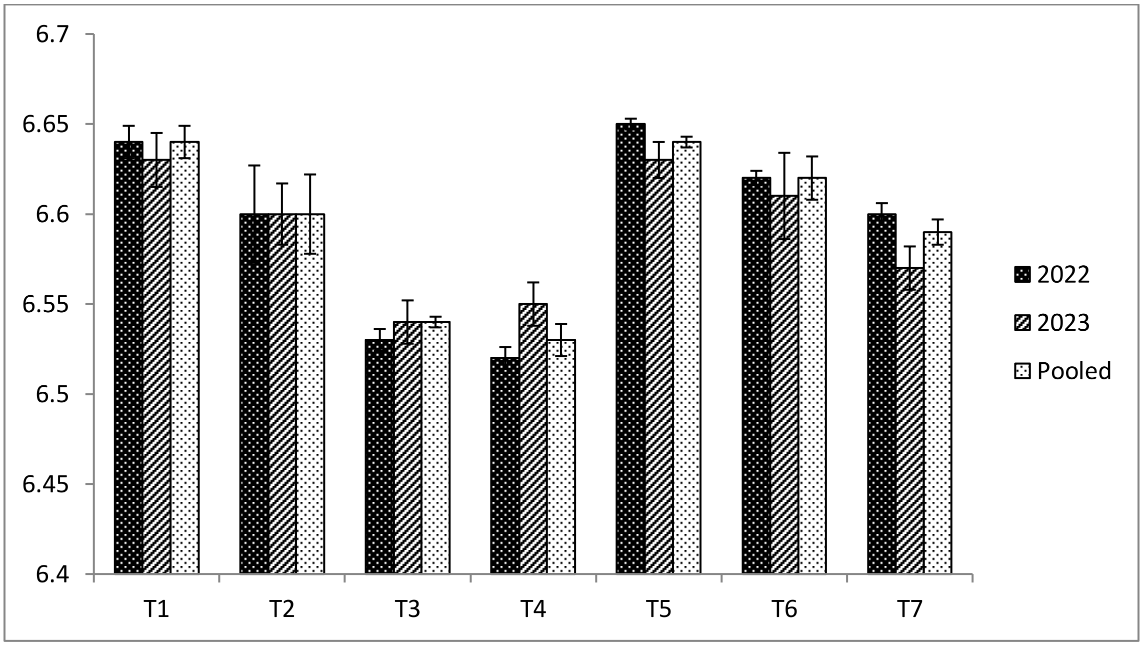

Fig. 4.33: Effect of full spectrum light on non-reducing sugar under vertical farming system in outdoor conditions

Table 4.12: Effect of full spectrum light on sugars under vertical farming system in outdoor conditions.

	Reducing sugar (%)			**Non Reducing Sugar (%)**			**Total Sugars (%)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	2.94 ± 0.031^{ab}	2.93 ± 0.007^{b}	2.93 ± 0.018^{b}	6.64 ± 0.009^{a}	6.63 ± 0.015^{a}	6.64 ± 0.009^{a}	9.58 ± 0.039^{ab}	9.56 ± 0.014^{ab}	9.57 ± 0.025^{ab}
T2	2.91 ± 0.018^{b}	2.92 ± 0.015^{b}	2.92 ± 0.015^{b}	6.60 ± 0.027^{b}	6.60 ± 0.017^{ab}	6.60 ± 0.022^{b}	9.51 ± 0.04^{b}	9.52 ± 0.019^{ab}	9.51 ± 0.029^{b}
T3	2.93 ± 0.012^{ab}	2.88 ± 0.015^{c}	2.91 ± 0.015^{bc}	6.53 ± 0.006^{c}	6.54 ± 0.012^{c}	6.54 ± 0.003^{c}	9.46 ± 0.015^{b}	9.42 ± 0.015^{c}	9.44 ± 0.012^{c}
T4	2.87 ± 0.033^{b}	2.88 ± 0.006^{c}	2.87 ± 0.019^{c}	6.52 ± 0.006^{c}	6.55 ± 0.012^{c}	6.53 ± 0.009^{c}	9.39 ± 0.032^{c}	9.43 ± 0.015^{c}	9.41 ± 0.018^{c}
T5	2.99 ± 0.015^{ab}	2.97 ± 0.007^{a}	2.98 ± 0.003^{a}	6.65 ± 0.003^{a}	6.63 ± 0.01^{a}	6.64 ± 0.003^{a}	9.64 ± 0.012^{a}	9.60 ± 0.003^{a}	9.62 ± 0.009^{a}
T6	2.96 ± 0.009^{a}	2.94 ± 0.006^{ab}	2.95 ± 0.007^{ab}	6.62 ± 0.004^{ab}	6.61 ± 0.024^{ab}	6.62 ± 0.012^{ab}	9.58 ± 0.006^{ab}	9.55 ± 0.026^{ab}	9.57 ± 0.017^{ab}
T7	2.96 ± 0.007^{ab}	2.93 ± 0.006^{b}	2.95 ± 0.006^{ab}	6.60 ± 0.006^{b}	6.57 ± 0.012^{bc}	6.59 ± 0.007^{b}	9.57 ± 0.007^{ab}	9.50 ± 0.015^{bc}	9.53 ± 0.009^{b}
SEM±	0.02	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.02
CD=5%	0.06	0.03	0.04	0.03	0.04	0.03	0.08	0.08	0.05
CV%	1.19	0.59	0.73	0.30	0.35	0.23	0.46	0.54	0.30

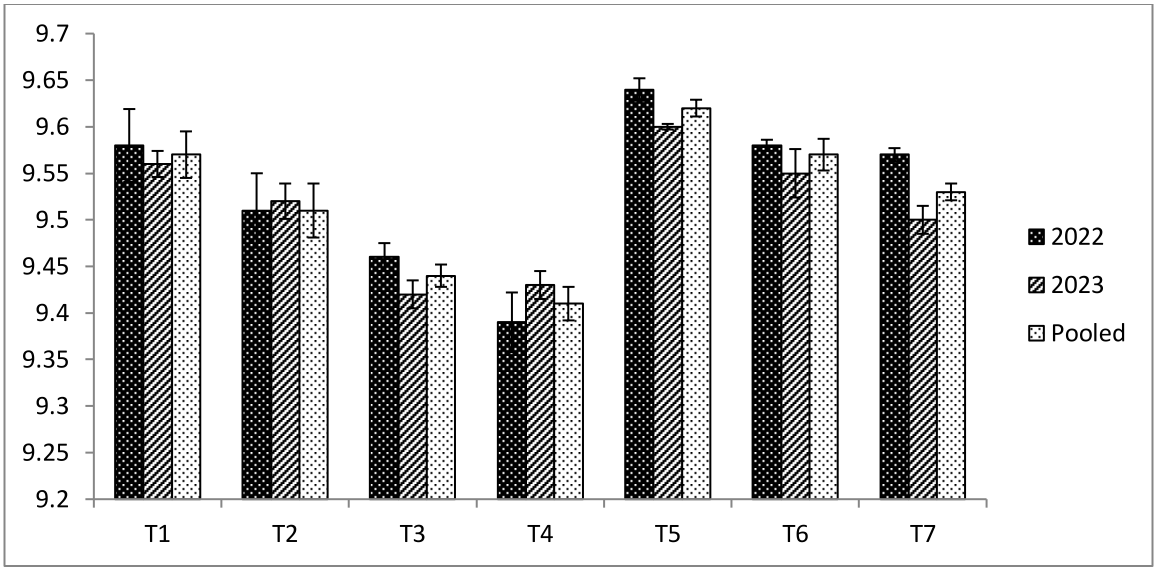

Fig. 4.34: Effect of full spectrum light on total sugars under vertical farming system in outdoor conditions

4.1.25 Antioxidant (%)

Table 4.13, represents higher amount of antioxidant content in year 2022, 2023 and in pooled data observed in T1 (natural light + fourth level) (80.84%, 81.08% and 80.96%) under natural light followed by T2 (natural light + third level) (78.04%, 77.73% and 77.88%) and T3 (natural light + second level) (76.97%, 78.45% and 77.71%). Although with additional use of full spectrum light treatment T5 (natural light + full spectrum (2 hours) + third level) performs superior (81.08%, 81.11% and 81.09%) from all other treatment followed by T6 (natural light + full spectrum (4 hours) + second level) (79.17%, 79.40% and 79.29%) and T7 (natural light + full spectrum (6 hours) + first level) (77.31%, 77.74% and 77.53%). in year 2022, 2023 and in pooled data. If overall result, it was found that T5 perform superior and T4 performs inferior. Treatment T1 and T5 were at par in 2022, 2023 and in pooled data.

4.1.26 Total Flavonoids (mg QE per 100g)

In year 2022, 2023 and pooled data higher flavonoids content noticed under natural light is T1 (natural light + fourth level) (49.44, 50.35 and 49.89 mg QE per 100g) followed by T4 (natural light + first level) (49.63, 48.91 and 49.27 mg QE per 100g) and T2 (natural light + third level) (48.39, 49.75 and 49.07 mg QE per 100g). But when artificial full spectrum light was provided than T5 (natural light + full spectrum (2 hours) + third level) performs superior (50.34, 50.72 and 50.53 mg QE per 100g) in overall treatment in year 2022, 2023 and in pooled data. Under full spectrum light T5 (natural light + full spectrum (2 hours) + third level) showed highest (50.34, 50.72 and 50.53 mg QE per 100g) flavonoid content followed by T7 (natural light + full spectrum (6 hours) + first level) (49.40, 49.57 and 49.48 mg QE per 100g) and T6 (natural light + full spectrum (4 hours) + second level) (49.33, 49.23 and 49.28 mg QE per 100g). It was noticed that T5 was maximum in flavonoids content and T3 has minimum content in overall performance. In 2022 and 2023, T1 and T5 were also at par (Table 4.13).

4.1.27 Total Phenols (mg GAE per 100 g)

As shown in Table 4.13, higher phenol content found in T1 (natural light + fourth level) (148.31, 146.77 and 147.54 mg GAE per 100g) in year 2022, 2023 and in pooled data followed by T2 (natural light + third level) (143.65, 143.37 and 143.51 mg GAE per 100g) and T3 (natural light + second level) (140.50, 141.32 and 140.91 mg GAE per 100g). On the other hand with use of artificial full spectrum light T5 (natural light + full spectrum (2 hours) + third level) have higher (147.67, 147.84 and 147.75 mg GAE per 100g) content in year 2022, 2023 and in pooled data followed by T6 (natural light + full spectrum (4 hours) + second level) (143.12, 143.63 and 143.38 mg GAE per 100g) and T7 (natural light + full spectrum (6 hours) + first level) (141.38, 141.80 and 141.59 mg GAE per 100g). In overall result T5 has maximum phenol content in fruit and T4 has the lowest content. Treatment T1 and T5 were also at par in 2022, 2023 and in pooled data.

The antioxidant content and phenols in T_1 (under natural light conditions) and T_5 (with 2hours full spectrum light) was superior in comparison to T_2, T_3, T_4, T_6 and T_7. The antioxidant content and phenols contents in T_3 and T_5 were near about which was followed by treatment T_3, T_6 and T_7. The maximum flavonoids were observed in treatment T_5 while T_3 had the minimum flavonoids content respectively. The antioxidant, flavonoids and phenols content in strawberries grown outdoors can be affected by the length of full spectrum light as well as natural light in a vertical farming system.

It was found that to control fruit maturation time as well as to increase the sugar, flavonoids content and antioxidant contents of fruits, a voluntary adoption of LED light wavelength could be necessary (Choi Hyogil *et al.,* 2013 and Sharma *et al.,* 2019). Additionally, it was studied that contents of total flavonoids, phenolics, anthocyanins, proanthocyanidins and total antioxidant capacities treated with supplement light helps to kept the fruit at stable levels throughout the entire storage (Zhang *et al.,*2022 and Jiang *et al.*, 2023).

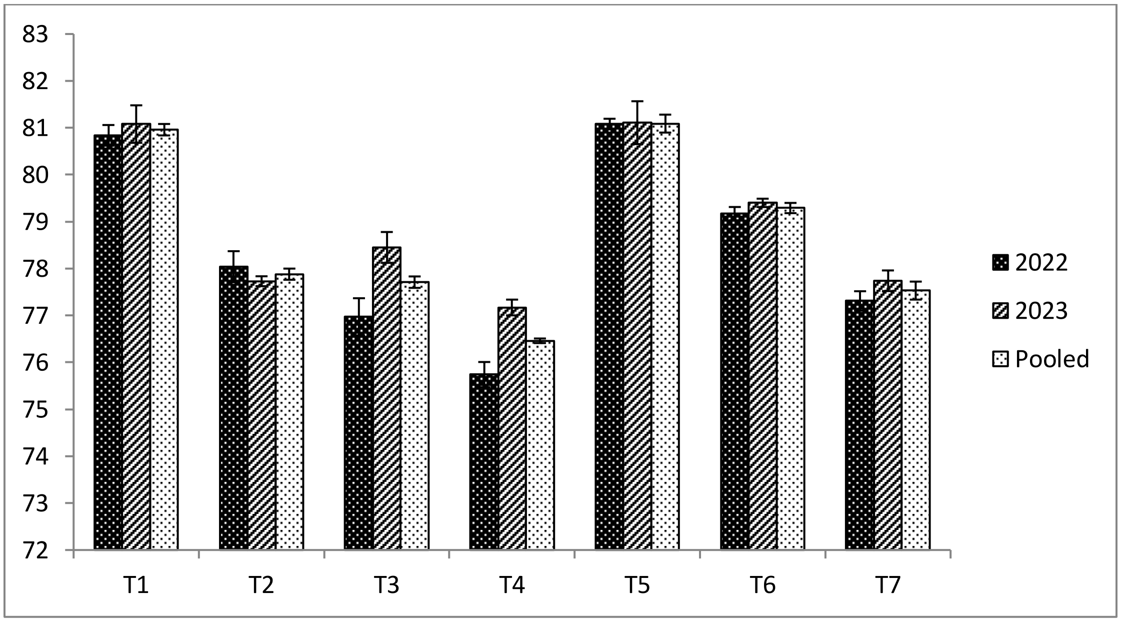

Fig. 4.35: Effect of full spectrum light on antioxidants under vertical farming system in outdoor conditions

Table 4.13: Effect of full spectrum light on biochemical traits under vertical farming system in outdoor conditions

	Antioxidant (%)			**Flavonoids (mg QE per 100 g FW)**			**Total phenols (mg GAE per 100 g FW)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	80.84 ± 0.220^{a}	81.08 ± 0.400^{a}	80.96 ± 0.122^{a}	49.44 ± 0.632^{ab}	50.35 ± 0.797^{ab}	49.89 ± 0.083^{b}	148.31 ± 0.984^{a}	146.77 ± 0.162^{a}	147.54 ± 0.413^{a}
T2	78.04 ± 0.330^{c}	77.73 ± 0.105^{cd}	77.88 ± 0.119^{c}	48.39 ± 0.598^{bc}	49.75 ± 0.328^{bc}	49.07 ± 0.443^{c}	143.65 ± 0.285^{b}	143.37 ± 0.160^{bc}	143.51 ± 0.108^{b}
T3	76.97 ± 0.397^{d}	78.45 ± 0.329^{c}	77.71 ± 0.122^{c}	47.83 ± 0.736^{c}	48.39 ± 0.401^{c}	48.11 ± 0.279^{d}	140.50 ± 0.441^{c}	141.32 ± 1.019^{c}	140.91 ± 0.712^{cd}
T4	75.74 ± 0.268^{e}	77.17 ± 0.168^{d}	76.46 ± 0.049^{d}	49.63 ± 0.409^{ab}	48.91 ± 0.226^{bc}	49.27 ± 0.096^{c}	140.69 ± 0.35^{c}	140.33 ± 0.309^{c}	140.51 ± 0.311^{d}
T5	81.08 ± 0.113^{a}	81.11 ± 0.457^{a}	81.09 ± 0.191^{a}	50.34 ± 0.518^{a}	50.72 ± 0.318^{a}	50.53 ± 0.376^{a}	147.67 ± 0.589^{a}	147.84 ± 0.537^{a}	147.75 ± 0.532^{a}
T6	79.17 ± 0.142^{b}	79.40 ± 0.089^{b}	79.29 ± 0.109^{b}	49.33 ± 0.445^{b}	49.23 ± 0.259^{bc}	49.28 ± 0.261^{c}	143.12 ± 0.721^{b}	143.63 ± 0.668^{b}	143.38 ± 0.075^{b}
T7	77.31 ± 0.206^{cd}	77.74 ± 0.220^{cd}	77.53 ± 0.192^{c}	49.40 ± 0.389^{ab}	49.57 ± 0.283^{b}	49.48 ± 0.191^{bc}	141.38 ± 0.147^{c}	141.80 ± 0.189^{c}	141.59 ± 0.148^{c}
SEM±	0.24	0.30	0.14	0.32	0.30	0.16	0.54	0.52	0.33
CD at 5%	0.75	0.93	0.44	0.98	0.93	0.48	1.66	1.60	1.03
CV%	0.53	0.66	0.32	1.40	1.06	0.54	0.65	0.63	0.40

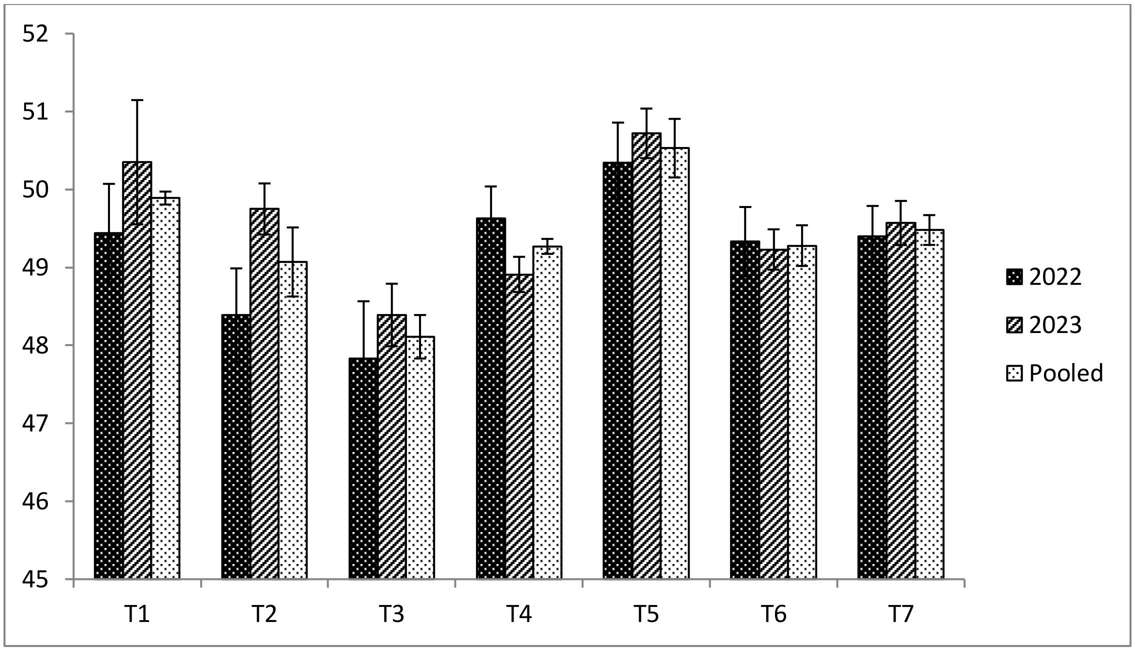

Fig. 4.36: Effect of full spectrum light on flavonoids under vertical farming system in outdoor conditions

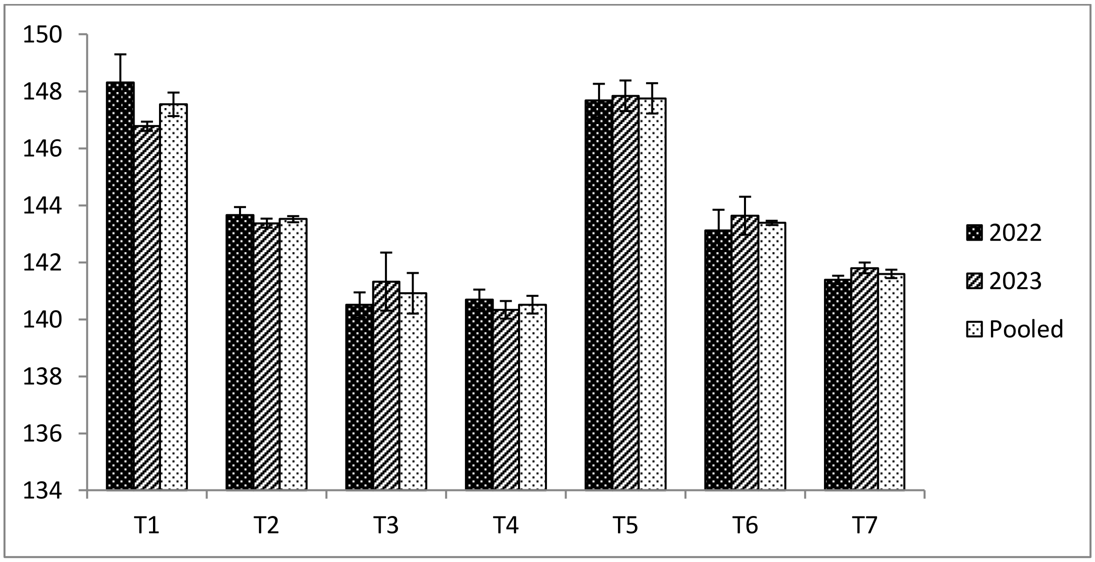

Fig. 4.37: Effect of full spectrum light on total phenols under vertical farming system in outdoor conditions

4.1.28 Chlorophyll a (mg/g)

Highest amount chlorophyll a was observed in T1 (natural light + fourth level under natural light that is 1.20 mg/g, 1.19 mg/g and 1.19 mg/g followed by T2 (natural light + third level) (1.16, 1.17 and 1.17 mg/g) and T3 (natural light + second level) (1.16, 1.14 and 1.15 mg/g) in year 2022, 2023 and in pooled data (Table 4.14). But with artificial full spectrum light, T5 (natural light + full spectrum (2 hours) + third level) have highest chlorophyll a content (1.24, 1.25 and 1.25 mg/g) in year 2022, 2023 and in pooled data followed by T6 (natural light + full spectrum (4 hours) + second level) (1.23 mg/g) and T7 (natural light + full spectrum (6 hours) + first level) (1.19, 1.21 and 1.20 mg/g). In overall performance treatment with additional full spectrum light performs better than natural light. T5 has maximum content of Chl a and T4 has the lowest content. Treatment T5 and T6 were at par in 2022, 2023 and in pooled data.

4.1.29 Chlorophyll b (mg/g)

As shown in Table 4.14, higher Chlorophyll b content in year 2022, 2023 and in pooled data under natural light found in T1 (natural light + fourth level) (1.95, 1.99 and 1.97 mg/g) and T3 (natural light + second level) (1.97, 1.96 and 1.97 mg/g) followed by T2 (natural light + third level) (1.91, 1.96 and 1.93 mg/g) and T4 (natural light + first level) (1.89, 1.91 and 1.90 mg/g). Although with full spectrum light T5 (natural light + full spectrum (2 hours) + third level) performs superior (2.31, 2.30 and 2.31 mg/g) in year 2022, 2023 and in pooled data followed by T7 (natural light + full spectrum (8 hours) + first level) (2.29, 2.27 and 2.28 mg/g) and T6 (natural light + full spectrum (4 hours) + second level) (2.23, 2.26 and 2.25 mg/g). In overall performance treatment with additional full spectrum light perform supercilious than the treatment under natural light only. It was observed that treatment T5 was superior in Chl b content and T4 was inferior. In year 2022. Treatment T5, T6 and T7 were at par in 2022, 2023 and in pooled data.

4.1.30 Total chlorophyll (mg/g)

Data revealed that in total chlorophyll content in year 2022, 2023 and pooled data was highest in T1 (natural light and fourth level) (3.99, 4.00 and 3.99 mg/g) followed by T2 (natural light + third level) (3.98, 3.96 and 3.97 mg/g), T3 (natural light + second level) (3.94, 3.96 and 3.95 mg/g) and T4 (natural light + first level) (3.95, 3.94 and 3.95 mg/g) but with additional use of full spectrum light T5 (natural light + full spectrum (2 hours) + third level) performed superior (4.21, 4.22 and 4.22 mg/g) than others and followed by T6 (natural light + full spectrum (4 hours) + second level) (4.19, 4.22 and 4.20 mg/g) and T7 (natural light + full spectrum (6 hours) + first level) (4.18, 4.20 and 4.19 mg/g) (Table 4.14). In overall performance T5 was superior and T3 and T4 were inferior. In year 2022, 2023 and in pooled data, T5, T6 and T7 were at par.

Strawberry plants chlorophyll concentration was also influenced by additional supply of light (T_5 to T_7). Chlorophyll synthesis and accumulation can be affected by the various light spectra that LEDs can provide. It has been shown that strawberry plants produce more chlorophyll when exposed to red and blue light spectrum (Samuolienė *et al.,* 2010). By effectively absorbing this spectrum, chlorophyll pigments their synthesis is stimulated which could be responsible for increasing the chlorophyll content of leaves. Plants grown under indoor condition, were significantly influenced by additional light hours which could be due to lower availability of natural light so light might have become the limiting factor for activation of chlorophyll synthesis and stimulation of photosynthetic process. Chlorophyll a and chlorophyll b are both essential pigments involved in the process of photosynthesis, where plants convert light energy into chemical energy to fuel their growth and development (Jou *et al.,* 2015). Full spectrum light refers to a lighting system that provides a balanced combination of light wavelengths across the entire visible spectrum, including red, blue and green light (Costa *et al.,* 2012 and Choi *et al.,* 2015).

Table 4.14: Effect of full spectrum light on photosynthetic activities under vertical farming system in outdoor conditions.

	Chlorophyll a (mg/g)			**Chlorophyll b (mg/g)**			**Total Chlorophyll (mg/g)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	1.20 ± 0.018^{a}	1.19 ± 0.006^{bc}	1.19 ± 0.012^{bc}	1.95 ± 0.017^{b}	1.99 ± 0.022^{b}	1.97 ± 0.007^{b}	3.99 ± 0.038^{b}	4.00 ± 0.019^{b}	3.99 ± 0.022^{b}
T2	1.16 ± 0.003^{a}	1.17 ± 0.007^{c}	1.17 ± 0.003^{c}	1.91 ± 0.037^{b}	1.96 ± 0.061^{b}	1.93 ± 0.044^{b}	3.98 ± 0.023^{b}	3.96 ± 0.015^{bc}	3.97 ± 0.015^{b}
T3	1.16 ± 0.007^{a}	1.14 ± 0.009^{d}	1.15 ± 0.007^{c}	1.97 ± 0.049^{b}	1.96 ± 0.04^{b}	1.97 ± 0.043^{b}	3.94 ± 0.009^{b}	3.96 ± 0.025^{bc}	3.95 ± 0.019^{b}
T4	1.09 ± 0.009^{b}	1.10 ± 0.007^{e}	1.09 ± 0.003^{e}	1.89 ± 0.015^{b}	1.91 ± 0.019^{b}	1.90 ± 0.006^{b}	3.95 ± 0.022^{b}	3.94 ± 0.019^{c}	3.95 ± 0.020^{b}
T5	1.24 ± 0.021^{a}	1.25 ± 0.003^{a}	1.25 ± 0.009^{a}	2.31 ± 0.015^{a}	2.30 ± 0.018^{a}	2.31 ± 0.006^{a}	4.21 ± 0.011^{a}	4.22 ± 0.015^{a}	4.22 ± 0.012^{a}
T6	1.23 ± 0.012^{a}	1.23 ± 0.007^{ab}	1.23 ± 0.009^{a}	2.23 ± 0.015^{a}	2.26 ± 0.015^{a}	2.25 ± 0.015^{a}	4.19 ± 0.009^{a}	4.22 ± 0.019^{a}	4.20 ± 0.009^{a}
T7	1.19 ± 0.009^{b}	1.21 ± 0.009^{b}	1.20 ± 0.006^{b}	2.29 ± 0.015^{a}	2.27 ± 0.023^{a}	2.28 ± 0.003^{a}	4.18 ± 0.015^{a}	4.20 ± 0.009^{a}	4.19 ± 0.009^{a}
SEM±	0.01	0.01	0.01	0.03	0.03	0.03	0.02	0.01	0.02
CD at 5%	0.04	0.02	0.02	0.08	0.09	0.08	0.07	0.04	0.05
CV%	1.94	0.96	1.01	2.24	2.43	2.11	0.93	0.58	0.67

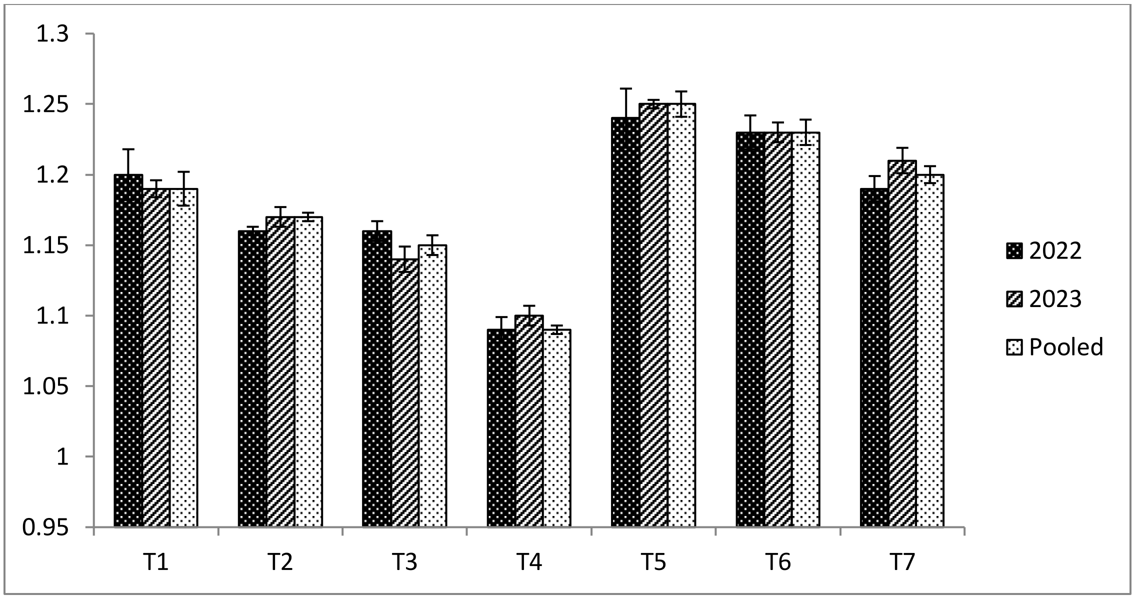

Fig. 4.38: Effect of full spectrum light on chlorophyll a under vertical farming system in outdoor conditions

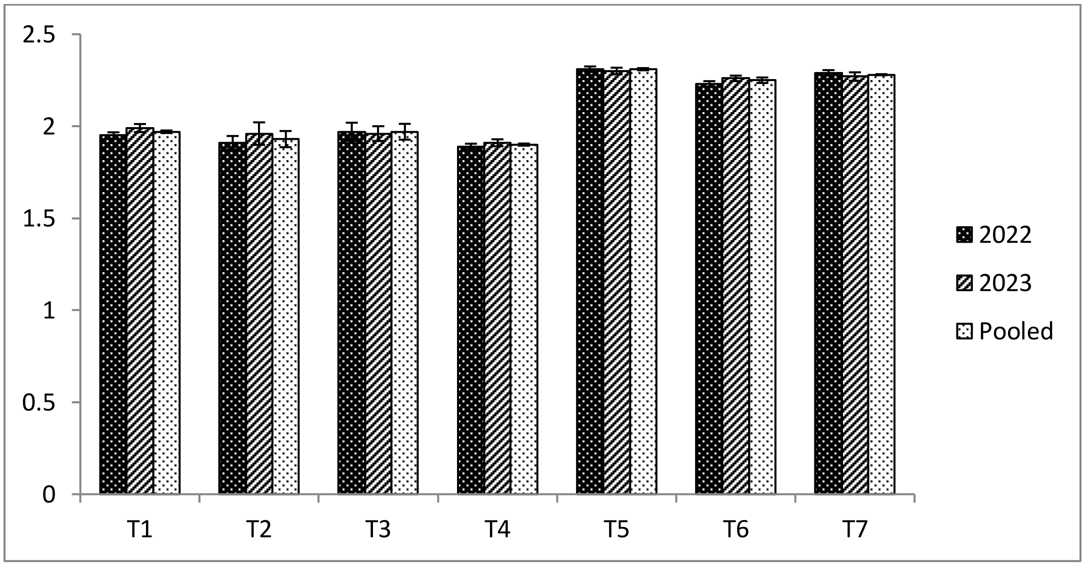

Fig. 4.39: Effect of full spectrum light on chlorophyll b under vertical farming system in outdoor conditions

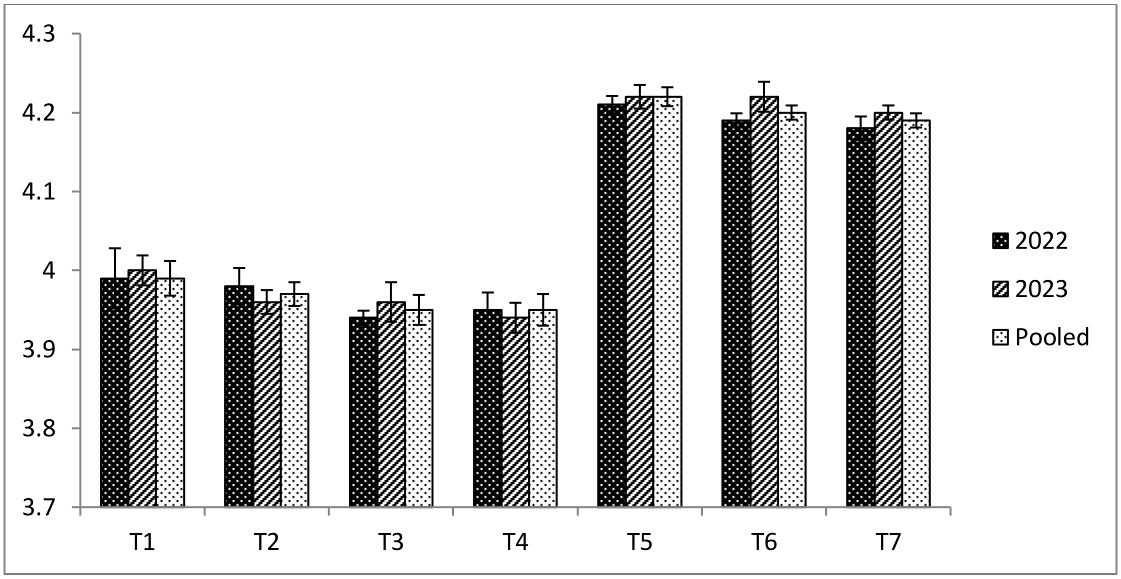

Fig. 4.40: Effect of full spectrum light on total chlorophyll under vertical farming system in outdoor conditions

4.1.31 Total Anthocyanin Content (mg per 100g)

Table 4.15, signifies treatment T1 (natural light + fourth level) performs better (56.98, 56.34 and 56.66 mg/100g) than other treatments followed by T2 (natural light + third level) (54.92, 55.03 and 54.98 mg/100g) and T3 (natural light + second level) (55.30, 64.64 and 54.97 mg/100g). While with full spectrum light T5 (natural light + full spectrum (2 hours) + third level) performs superior (57.67, 57.94 and 57.80 mg/100g) than T6 (natural light + full spectrum (4 hours) + second level) (56.29, 56.73 and 56.51 mg/100g) and T7 (natural light + full spectrum (6 hours) + third level) (55.05, 54.68 and 54.86 mg/100g). In overall performance T5 was superior and T4 performs inferior. In 2022, T1 and T5 were at par.

It was found that the treatment at fourth level (T1) with natural light performs superior than the treatments on other level (T2, T3 and T4). But in case of additional full spectrum light is provided than treatment (T5) with additional 2 hours light performs better than T6 and T7 and as well as treatment under natural light that is (57.8 mg/100g) followed by T1 (56.66 mg/100g) and T6 (56.51 mg/100g). Understanding how full spectrum light affects the anthocyanin content of strawberries will help growers make the most of the fruits aesthetic appeal and potential health benefits (Zhang *et al.,* 2018). Anthocyanin also helps in ripening of strawberry (Song *et al.,* 2015). Wysocki et al. (2017) had also reported increase in contents of extract sugar, anthocyanins, polyphenols, vitamin C.

4.1.32 Total Caretenoids Content (mg per g)

As shown in Table 4.15, total caretonoids content confirms significant variation among different treatments in grown under outdoor conditions. Treatment T1 (natural light + fourth level) performs superior under natural light (0.94, 0.95 and 0.94 mg/g) followed by T2 (natural light + third level) (0.92, 0.93 and 0.93 mg/g), T3 (natural light + second level) (0.91, 0.92 and 0.92 mg/g) and T4 (natural light + first level) (0.92, 0.91 and 0.92 mg/g). Artificial full spectrum light performs superior and more content of caretonoids observed in T5 (natural light + full spectrum (2 hours) + third level) (0.95, 0.96 and 0.96 mg/g) in year 2022, 2023 and in pooled data followed by T6 (natural light + full spectrum (4 hours) + second level) (0.94, 0.95 and 0.95 mg/g) and T7 (natural light + full spectrum (6 hours) + first level) (0.91, 0.91 and 0.91 mg/g). In overall performance highest carotenoids content found in T5 and lowest carotenoids content observed in T7. T1, T2, T3, T4 , T5 and T6 were at par in 2022, 2023 and in pooled data.

In case of carotenoids, a significant variation in levels of growing strawberry plants in the verticals was reported under outdoor and indoor conditions. It was also observed that the effect of growing levels was effectively supplemented by additional full spectrum light provided in T_5 and T_6 for the plants grown under outdoor condition; however, this full spectrum light was not sufficient for the plants grown at first (lower) level (T_7) even the duration was high (6 hours). Treatments which were supplemented with additional full spectrum light were superior in carotenoids content than treatment under natural light only.

In addition to being important for their vivid colors, anthocyanins also help plants defend themselves. Insects are drawn to them due to the color of the flowers and fruits, but they also have antibacterial qualities and protect cells from overexposure to light by absorbing damaging blue and ultraviolet radiation. The orange and yellow pigments called carotenoids, which are found in chromoplasts and chloroplasts, work to shield plants from light damage by eliminating excess energy, eliminating free radicals and preserving membrane integrity (Ouzounis *et al.*, 2015). When compared to cool-white fluorescent lamps, research showed that baby leaf lettuce (Lactuca sativa 'Red Cross') grown under LED lighting had higher levels of anthocyanins, xanthophylls and β-carotene.

Blue, UV-A and UV-B light have the greatest effect on the anthocyanin concentration in Lactuca sativa, or green leaf lettuce. Studies show that the highest levels of anthocyanin content are achieved when UV Fluorescent Tubes (FL-Tubes) are used to supplement sunlight (Thoma *et al.*, 2020). Full spectrum light has been found to positively influence carotenoid accumulation in plants. Carotenoids, such as beta-carotene and lutein, play crucial roles in light absorption and photo-protection (Xu *et al.*, 2023). Full spectrum light provides a range of wavelengths that promote carotenoid synthesis, leading to higher levels of carotenoid pigments in strawberry plants.

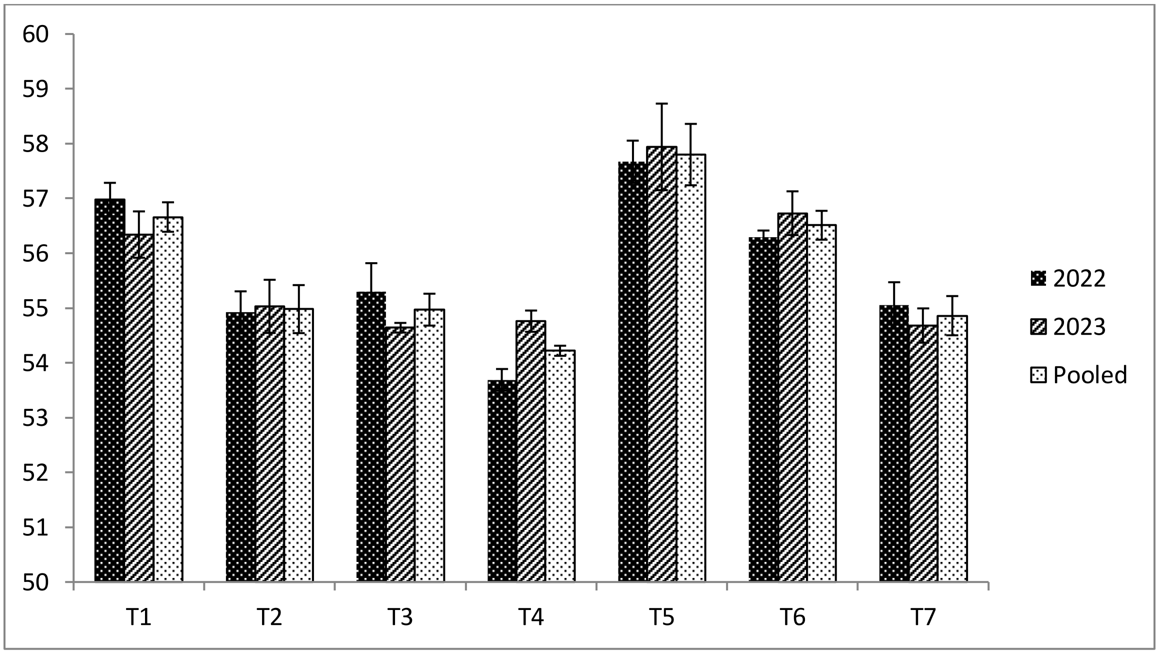

Fig. 4.41: Effect of full spectrum light on total anthocyanin under vertical farming system in outdoor conditions

Table 4.15: Effect of full spectrum light on biochemical traits under vertical farming system in outdoor conditions.

	Total anthocyanin (mg per 100g)			**Total caretonoids (mg per g)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	56.98 ± 0.304^{ab}	56.34 ± 0.423^{b}	56.66 ± 0.269^{b}	0.94 ± 0.006^{ab}	0.95 ± 0.003^{ab}	0.94 ± 0.003^{ab}
T2	54.92 ± 0.384^{c}	55.03 ± 0.485^{c}	54.98 ± 0.438^{c}	0.92 ± 0.003^{ab}	0.93 ± 0.003^{ab}	0.93 ± 0.003^{ab}
T3	55.30 ± 0.518^{bc}	54.64 ± 0.088^{c}	54.97 ± 0.291^{c}	0.91 ± 0.018^{b}	0.92 ± 0.006^{ab}	0.92 ± 0.006^{b}
T4	53.69 ± 0.197^{d}	54.76 ± 0.194^{c}	54.22 ± 0.092^{c}	0.92 ± 0.006^{ab}	0.91 ± 0.012^{b}	0.92 ± 0.009^{b}
T5	57.67 ± 0.384^{a}	57.94 ± 0.790^{a}	57.80 ± 0.560^{a}	0.95 ± 0.006^{a}	0.96 ± 0.006^{a}	0.96 ± 0.003^{a}
T6	56.29 ± 0.124^{b}	56.73 ± 0.399^{ab}	56.51 ± 0.263^{b}	0.94 ± 0.003^{ab}	0.95 ± 0.006^{ab}	0.95 ± 0.006^{a}
T7	55.05 ± 0.420^{c}	54.68 ± 0.313^{c}	54.86 ± 0.358^{c}	0.91 ± 0.003^{b}	0.91 ± 0.024^{b}	0.91 ± 0.012^{b}
SEM±	0.3	0.42	0.31	0.01	0.01	0.01
CD at 5%	0.91	1.3	0.97	0.03	0.04	0.02
CV%	0.92	1.31	0.98	1.52	2.14	1.28

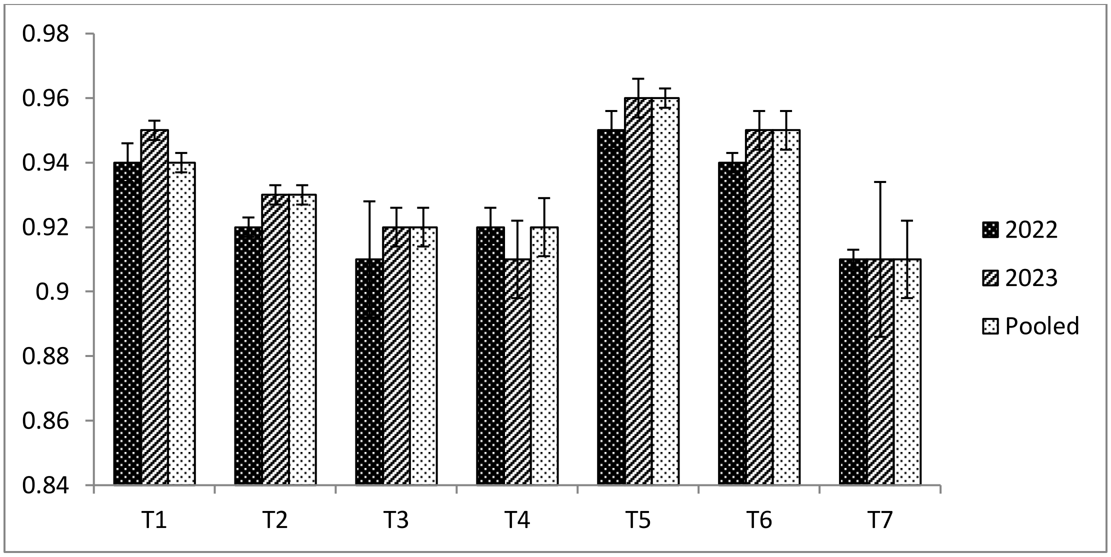

Fig. 4.42: Effect of full spectrum light on total carotenoids under vertical farming system in outdoor conditions.

4.2 EXPERIMENT 1: INDOOR CONDITIONS

In this experiment two structured with four levels were placed in indoor conditions. In one structure full spectrum light was provided for 0,4,6 and 8 hours on the other hand in structure for comparison of different duration on different level full spectrum light was provided for 0, 6 and 8hours with natural light.

4.2.1 Plant height (cm) (30, 60 and 90 DAP)

The data pertaining to plant height (cm) of strawberry plants, presented in Table 4.16, confirms significant variation among different treatments grown under indoor conditions. At 30 DAP, highest plant height in strawberry plant in year 2022, 2023 and pooled data was highest in T6 (full spectrum light (8 hours) + natural light + second level) (15.87, 16.93 and 16.40 cm) followed by T4 (full spectrum light (8 hours) + natural light + first level) (14.42, 15.61 and 15.02 cm) and T2 (full spectrum light (4 hours) + natural light + third level) (15.07, 15.23 and 15.15 cm). However, the lowest plant height was reported in T1 combination of natural light + fourth level or where full spectrum light was not provided (10.23, 10.12 and 10.17 cm) followed by T5 combination of full spectrum light (6 hours) + natural light + third level) (13.47, 14.58 and 14.03 cm) and T3 (full spectrum light (6 hours) + natural light + second level) (14.01, 14.87 and 14.44 cm).

After 60 DAP, highest plant height (19.44, 18.48 and 18.96) was estimated in T6 (full spectrum light (8 hours) + natural light + second level) in year 2022, 2023 and pooled data followed by T5 combination of full spectrum light (6 hours) + natural light +third level) (17.33, 17.83 and 17.58) and T4 (full spectrum light (8 hours) + natural light + first level) (17.30, 15.61 and 16.46). Treatments T4 and T5 were at par in 2022 and in 2023. Though, lowest plant height (14.67, 14.57 and 14.62 cm) was observed in T2 (full spectrum light (4 hours) + natural light + third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (14.42, 15.80 and 15.11 cm). In T1 treatment plants dies after 40 days of planting (Table 4.16).

Further after 90 DAP, the maximum plant height (15.79, 16.40 and 16.09 cm) in year 2022, 2023 and pooled data was observed in T6 (full spectrum light (8 hours) + natural light + second level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (12.50, 14.21 and 13.36 cm) and T5 combination of full spectrum light (6 hours) + natural light + third level) (17.58, 13.04 and 13.07 cm). Treatment T2, T4 and T5 were at par in 2022, 2023 and in pooled data. However, minimum (12.24, 13.18 and 12.71 cm) plant height was noticed in treatment T4 (full spectrum light (8 hours) + natural light + first level) followed by T2 (full spectrum light (4 hours) + natural light + third level) (12.20, 13.25 and 12.72 cm).

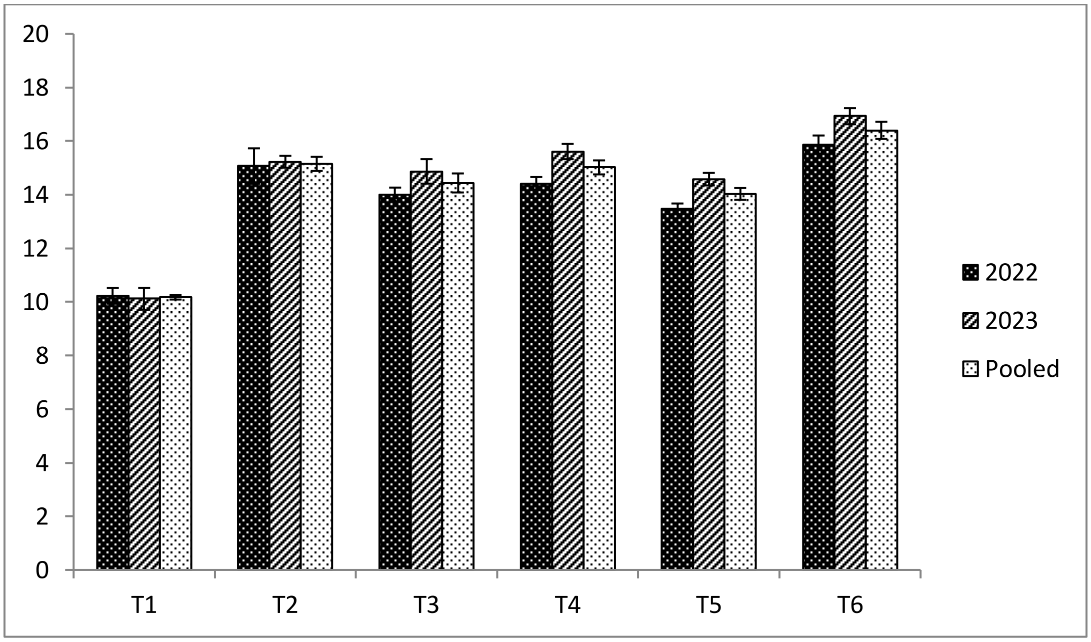

Fig. 4.43: Effect of full spectrum light on plant height at 30 DAP under vertical farming system in indoor conditions

Table 4.16: Effect of full spectrum light on plant height (cm) under vertical farming system in indoor conditions.

	Plant Height 30 days (cm)			**Plant Height 60 days (cm)**			**Plant Height 90 days (cm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	10.23 ± 0.294^{c}	10.12 ± 0.41^{d}	10.17 ± 0.081^{d}	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	15.07 ± 0.662^{ab}	15.23 ± 0.221^{bc}	15.15 ± 0.264^{b}	14.67 ± 0.533^{c}	14.57 ± 0.544^{b}	14.62 ± 0.236^{d}	12.20 ± 0.515^{b}	13.25 ± 4.309^{bc}	12.72 ± 0.517^{b}
T3	14.01 ± 0.257^{b}	14.87 ± 0.456^{bc}	14.44 ± 0.355^{bc}	14.42 ± 0.394^{c}	15.80 ± 0.469^{b}	15.11 ± 0.393^{d}	12.50 ± 0.179^{b}	14.21 ± 0.211^{b}	13.36 ± 0.273^{b}
T4	14.42 ± 0.239^{b}	15.61 ± 0.285^{b}	15.02 ± 0.261^{b}	17.30 ± 0.103^{b}	15.61 ± 0.285^{b}	16.46 ± 0.184^{c}	12.24 ± 0.295^{b}	13.18 ± 0.620^{c}	12.71 ± 0.286^{b}
T5	13.47 ± 0.203^{b}	14.58 ± 0.234^{c}	14.03 ± 0.219^{c}	17.33 ± 0.303^{b}	17.83 ± 1.017^{a}	17.58 ± 0.645^{b}	13.04 ± 0.363^{b}	13.07 ± 0.291^{c}	13.05 ± 0.388^{b}
T6	15.87 ± 0.341^{a}	16.93 ± 0.300^{a}	16.40 ± 0.320^{a}	19.44 ± 0.242^{a}	18.48 ± 0.308^{a}	18.96 ± 0.260^{a}	15.79 ± 0.351^{a}	16.40 ± 0.251^{a}	16.09 ± 0.506^{a}
SEM±	0.31	0.29	0.23	0.30	0.43	0.26	0.28	0.31	0.25
CD at 5%	0.99	0.92	0.74	0.95	1.37	0.81	0.90	0.96	0.78
CV%	3.91	3.48	2.86	3.76	5.47	3.24	4.49	4.53	3.78

*Plant dies after 40 days of planting

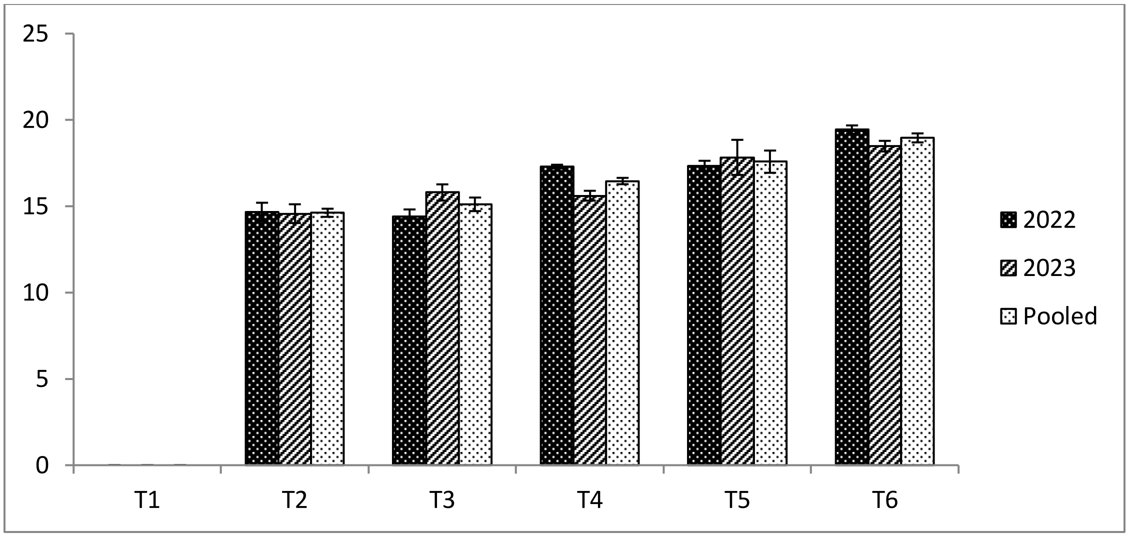

Fig. 4.44: Effect of full spectrum light on plant height at 60 DAP under vertical farming system in indoor conditions

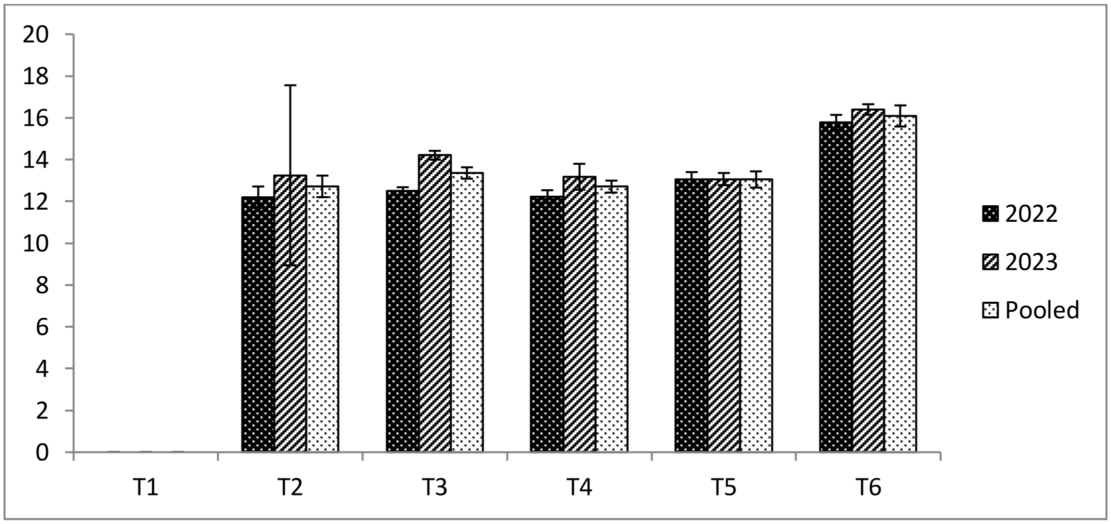

Fig. 4.45: Effect of full spectrum light on plant height at 90 DAP under vertical farming system in indoor conditions

4.2.2 Petiole length (cm) (30, 60 and 90 DAP)

As shown in Table 4.17, shows the recorded data of petiole length (cm) and confirms significant variation along with different treatments grown. At 30 DAP treatment T6 (full spectrum light (8 hours) + natural light + second level) showed highest (14.81, 15.98 and 15.40 cm) petiole length followed by T4 (full spectrum light (8 hours) + natural light + first level) (13.95, 14.83 and 14.39 cm) and T2 (full spectrum light (4 hours) + natural light + third level) (14.07, 14.31 and 14.91 cm). Treatment T2 and T4 were at par in year 2022, 2023 and in pooled data. Although lowest (9.24, 9.32 and 9.28 cm) petiole length was observed in T1 (natural light + fourth level) or where full spectrum light was not provided in year 2022, 2023 and pooled data followed by T3 (full spectrum light (6 hours) + natural light + second level) (13.65, 13.68 and 13.66 cm).

The data showed a significant change among different treatments at 60 DAP under indoor conditions. Maximum (18.66, 17.59 and 18.13 cm) petiole length revealed in treatment T6 (full spectrum light (8 hours) + natural light + second level) followed by T5 (16.43, 16.52 and 16.48 cm) and T4 (full spectrum light (8 hours) + natural light + first level) (16.48, 15.09 and 15.79 cm). However, the lowest (13.62, 13.64 and 13.63 cm) petiole length was found in T2 (full spectrum light (4 hours) + natural light + third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (13.49, 14.85 and 14.17 cm). While plants of T1 (natural light + fourth level) where full spectrum light was not provided) dies after 40 DAP (Table 4.17). Treatment T4 and T5 were at in year 2022 and in pooled data.

At 90 DAP, highest (15.21, 15.77 and 15.49 cm) petiole length noticed in T6 (full spectrum light (8 hours) + natural light + second level) in year 2022, 2023 and pooled data followed by T3 (full spectrum light (6 hours) + natural light + second level) (11.94, 13.72 and 12.20 cm) and T5 combination of full spectrum light (6 hours) + natural light +third level) (12.44, 12.61 and 12.52 cm). Treatment T2 and T3 were at par in year 2022, 2023 and in pooled data. Thought lowest (11.60, 11.87 and 11.73 cm) petiole length observed in T4 (full spectrum light (8 hours) + natural light + first level) followed by T2 (full spectrum light (4 hours) + natural light + third level) (11.62, 12.77 and 12.20 cm) in year 2022, 2023 and in pooled data (Table 4.17).

The average plant height of strawberry grown under indoor condition with additional supply of light was significantly affected by the levels of verticals and the duration of full spectrum light provided at all days of observations (30, 60 and 90 days after planting). The plants subjected with full spectrum light with 8 hours have grown better when plants were at second level (T_6) and was superior in comparison to T_3, T_4 and T_5. Similarly, the petiole length (Table 2) of the plants that have been exposed to full spectrum light for 8 hours have maximum petiole length when plants were at second level (T_6) and were superior in comparison to other treatments. Thus, the plant height and petiole length of strawberries were significantly influenced by the length of the full spectrum light in an indoor vertical farming system where longer exposure times to full spectrum light encouraged taller plants and longer petioles. This could be associated with the efficient utilization of nutrients provided to the plants and balanced metabolic processes under higher lux value.

The light induced nutrient uptake depends on fluctuating light quality which is sensed by the photoreceptors of the plants across the wider range of wavelengths to induce wavelength specific responses (van Gelderen *et al.,* 2018). Further, photosynthetic activity is function of light energy which can create sink for nutrients in leaves by accelerating the photosynthetic process resulting enhanced nutrient uptake (Wang *et al.,* 2019). The cultivation under indoor condition and verticals has its own challenge as availability of sufficient light so to maximize plant height and petiole length in strawberries under controlled lighting conditions the precise optimal duration needs to be determined (Nadalini *et al.,* 2017). In initial 30 days after planting, the impact of light intensity and duration was not clear; however, it has become more defined at later stage of growth which could be due to development of sufficient leaves to respond the available light for improvement in nutrient uptake. Plant nutrient acquisition depends on the light period and stimulates photosynthetic phenomenon (Sakuraba and Yanagisawa, 2018). However, the nutrient supply from roots should coordinate with photosynthetic activities in shoots through signalling molecules like phytohormones, proteins and sucrose and is probably linked to ion uptake and light, respectively (Xu *et al.,* 2021).

Table 4.17: Effect of full spectrum light on petiole length (cm) under vertical farming system in indoor conditions.

	Petiole Length 30 days (cm)			Petiole Length 60 days (cm)			Petiole Length 90 days (cm)		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	9.24 ± 0.507^{c}	9.32 ± 0.547^{d}	9.28 ± 0.159^{d}	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	14.07 ± 0.520^{ab}	14.31 ± 0.266^{bc}	14.19 ± 0.128^{bc}	13.62 ± 0.401^{c}	13.64 ± 0.374^{c}	13.63 ± 0.166^{c}	11.62 ± 0.544^{b}	12.77 ± 0.542^{bc}	12.20 ± 0.542^{bc}
T3	13.65 ± 0.278^{b}	13.68 ± 0.264^{c}	13.66 ± 0.240^{c}	13.49 ± 0.358^{c}	14.85 ± 0.248^{b}	14.17 ± 0.226^{c}	11.94 ± 0.209^{b}	13.72 ± 0.708^{b}	12.83 ± 0.299^{b}
T4	13.95 ± 0.123^{ab}	14.83 ± 0.325^{b}	14.39 ± 0.224^{b}	16.48 ± 0.301^{b}	15.09 ± 0.199^{b}	15.79 ± 0.231^{b}	11.60 ± 0.234^{b}	11.87 ± 0.297^{c}	11.73 ± 0.247^{c}
T5	12.99 ± 0.146^{b}	13.80 ± 0.184^{c}	13.40 ± 0.165^{c}	16.43 ± 0.391^{b}	16.52 ± 0.821^{a}	16.48 ± 0.606^{b}	12.44 ± 0.370^{b}	12.61 ± 0.402^{c}	12.52 ± 0.385^{bc}
T6	14.81 ± 0.195^{a}	15.98 ± 0.290^{a}	15.40 ± 0.224^{a}	18.66 ± 0.236^{a}	17.59 ± 0.347^{a}	18.13 ± 0.257^{a}	15.21 ± 0.437^{a}	15.77 ± 0.673^{a}	15.49 ± 0.546^{a}
SEM±	0.32	0.31	0.19	0.29	0.36	0.24	0.31	0.32	0.26
CD at 5%	1.00	0.98	0.61	0.90	1.13	0.76	0.99	1.00	0.83
CV%	4.19	3.96	2.51	3.78	4.81	3.22	5.19	4.95	4.25

*Plant dies after 40 days of planting

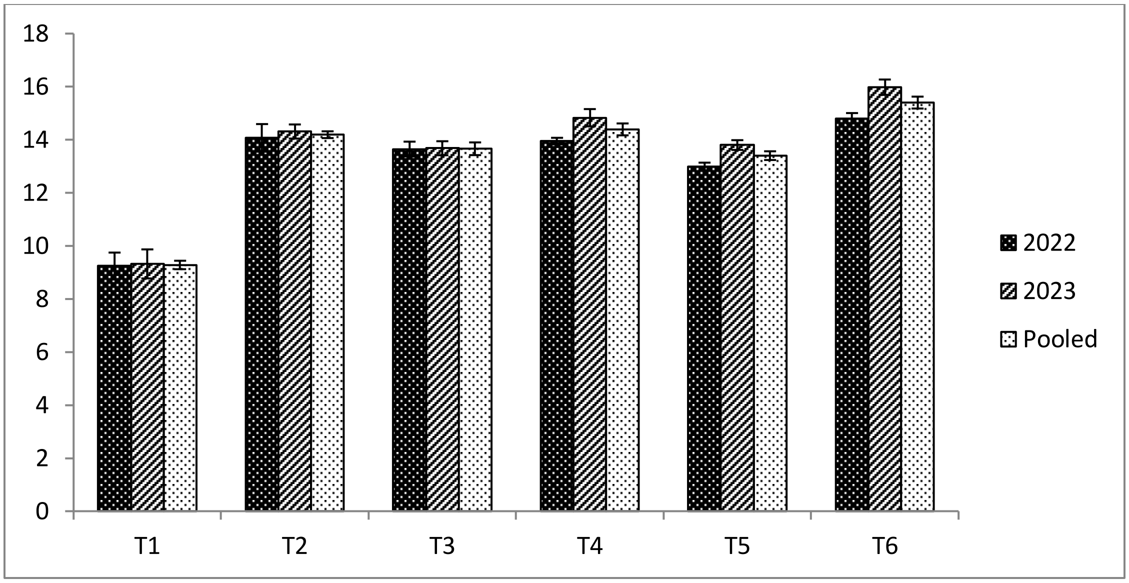

Fig. 4.46: Effect of full spectrum light on petiole length at 30 DAP under vertical farming system in indoor conditions

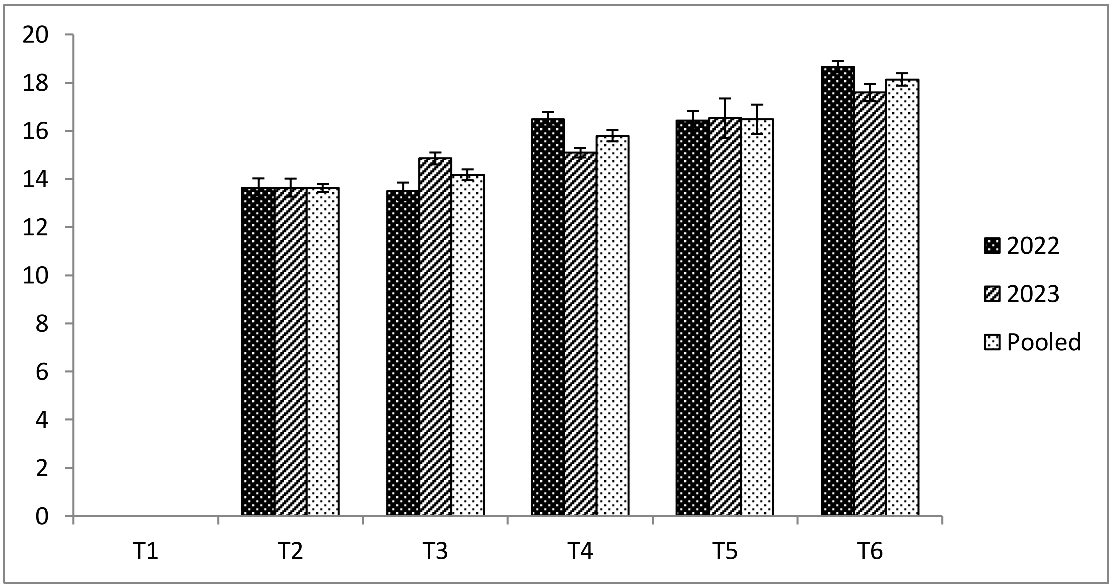

Fig. 4.47: Effect of full spectrum light on petiole length at 60 DAP under vertical farming system in indoor conditions

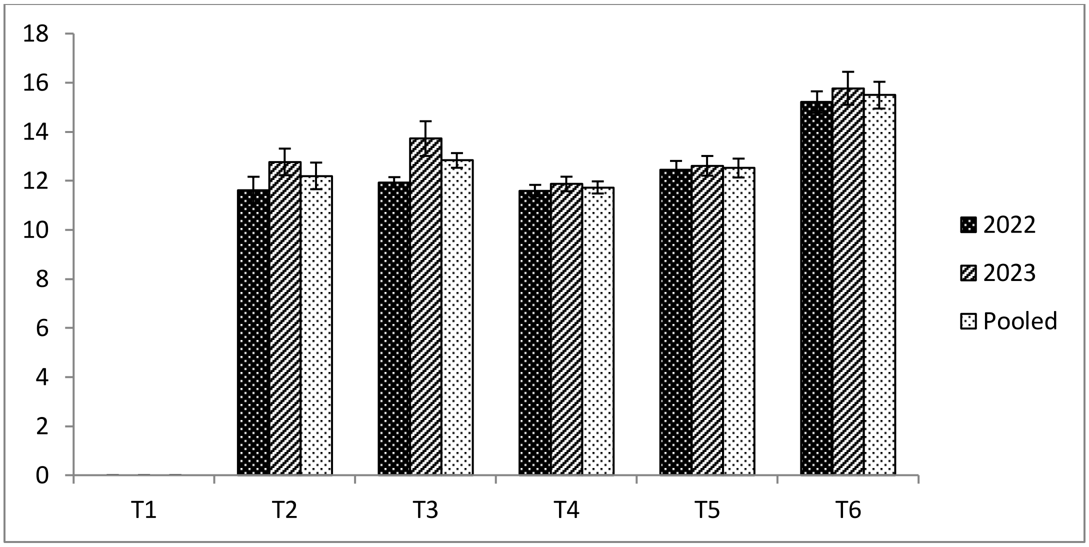

Fig. 4.48: Effect of full spectrum light on petiole length at 90 DAP under vertical farming system in indoor conditions

4.2.3 Plant spread (E-W) cm (30, 60 and 90 DAP)

In Table 4.18, represents that at 30 DAP, highest (4.27, 6.05 and 5.16 cm) plant spread (E-W) in year 2022, 2023 and pooled data was estimated in T2 (full spectrum light (4 hours) + natural light + third level) followed by T5 combination of full spectrum light (6 hours) + natural light + third level) (4.97, 3.20 and 4.09 cm) and T6 (full spectrum light (8 hours) + natural light + second level) (3.42, 4.42 and 3.92 cm). However lowest (1.27, 6.15 and 3.71 cm) plant spread (E-W) was observed in T4 (full spectrum light (8 hours) + natural light + first level) followed by T1 (natural light + fourth level) (3.21, 4.23 and 3.72 cm) in 2022, 2023 and pooled data.

After 60 DAP, highest (9.62, 11.52 and 10.57 cm) plant spread (E-W) was estimated in T5 (full spectrum light (6 hours) + natural light +third level) in year 2022, 2023 and pooled data followed by T3 (full spectrum light (6 hours) + natural light + second level) (7.45, 11.86 and 9.66 cm) and T6 (full spectrum light (8 hours) + natural light + second level) (7.81, 10.56 and 9.18 cm). Treatment T3, T4 and T6 were at par in year 2022 and in pooled data. Though lowest spread obtained in year 2022, 2023 and pooled data was 6.87cm, 9.69cm and 8.28cm in T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (7.65, 10.61 and 9.13 cm). In T1 treatment plants dies after 40 days of planting (Table 4.18).

Further after 90 DAP, the maximum (11.75, 12.41 and 12.8 cm) plant spread (E-W) was observed in T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (11.02, 10.95 and 10.98 cm) and T4 is combination of full spectrum light (8 hours) + natural light + first level) (11.07, 10.40 and 10.74 cm) in year 2022, 2023 and pooled data. Treatment T3 and T4 were at par in 2022, 2023 as well as in pooled data. However, minimum (7.98, 7.77 and 7.88 cm) petiole length was noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T6 (full spectrum light (8 hours) + natural light + second level) (10.86, 10.55 and 10.70 cm) after 90 days of planting. In T1 treatment plants dies after 40 days of planting (Table 4.18).

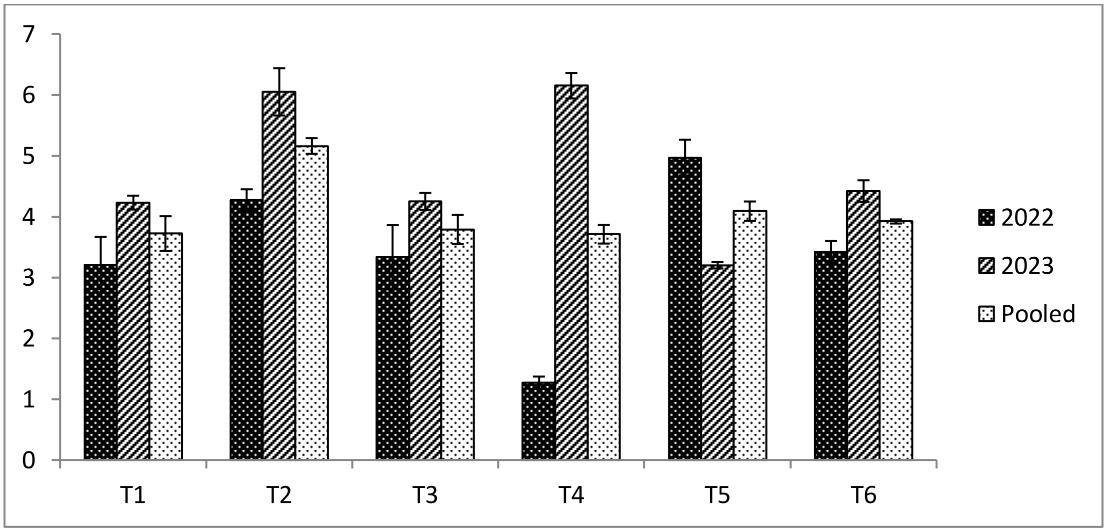

Fig. 4.49: Effect of full spectrum light on Plant spread (E-W) at 30 DAP under vertical farming system in indoor conditions

Table 4.18: Effect of full spectrum light on plant spread (E-W) (cm) under vertical farming system in indoor conditions.

	Plant spread (E-W) 30 days (cm)			**Plant spread (E-W) 60 days (cm)**			**Plant spread (E-W) 90 days (cm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	3.21 ± 0.459^{b}	4.23 ± 0.114^{b}	3.72 ± 0.285^{b}	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	4.27 ± 0.178^{ab}	6.05 ± 0.388^{a}	5.16 ± 0.128^{a}	6.87 ± 0.657^{b}	9.69 ± 0.458^{b}	8.28 ± 0.450^{c}	7.98 ± 0.223^{b}	7.77 ± 0.273^{c}	7.88 ± 0.237^{c}
T3	3.33 ± 0.528^{b}	4.25 ± 0.138^{b}	3.79 ± 0.240^{b}	7.45 ± 0.214^{b}	11.86 ± 0.144^{a}	9.66 ± 0.042^{b}	11.02 ± 0.117^{ab}	10.95 ± 0.380^{b}	10.98 ± 0.184^{b}
T4	1.27 ± 0.101^{c}	6.15 ± 0.208^{a}	3.71 ± 0.153^{b}	7.65 ± 0.105^{b}	10.61 ± 0.484^{b}	9.13 ± 0.290^{bc}	11.07 ± 0.345^{ab}	10.40 ± 0.233^{b}	10.74 ± 0.241^{b}
T5	4.97 ± 0.294^{a}	3.20 ± 0.053^{c}	4.09 ± 0.158^{b}	9.62 ± 0.397^{a}	11.52 ± 0.178^{ab}	10.57 ± 0.197^{a}	11.75 ± 0.229^{a}	12.41 ± 0.407^{a}	12.08 ± 0.318^{a}
T6	3.42 ± 0.181^{b}	4.42 ± 0.176^{b}	3.92 ± 0.034^{b}	7.81 ± 0.360^{b}	10.56 ± 0.346^{b}	9.18 ± 0.349^{b}	10.86 ± 0.406^{b}	10.55 ± 0.156^{b}	10.70 ± 0.257^{b}
SEM±	0.30	0.21	0.19	0.32	0.35	0.27	0.26	0.29	0.23
CD=5%	0.93	0.65	0.61	1.02	1.10	0.86	0.81	0.90	0.71
CV%	15.04	7.56	8.26	8.57	6.67	6.08	5.09	5.71	4.49

*Plant dies after 40 days of planting

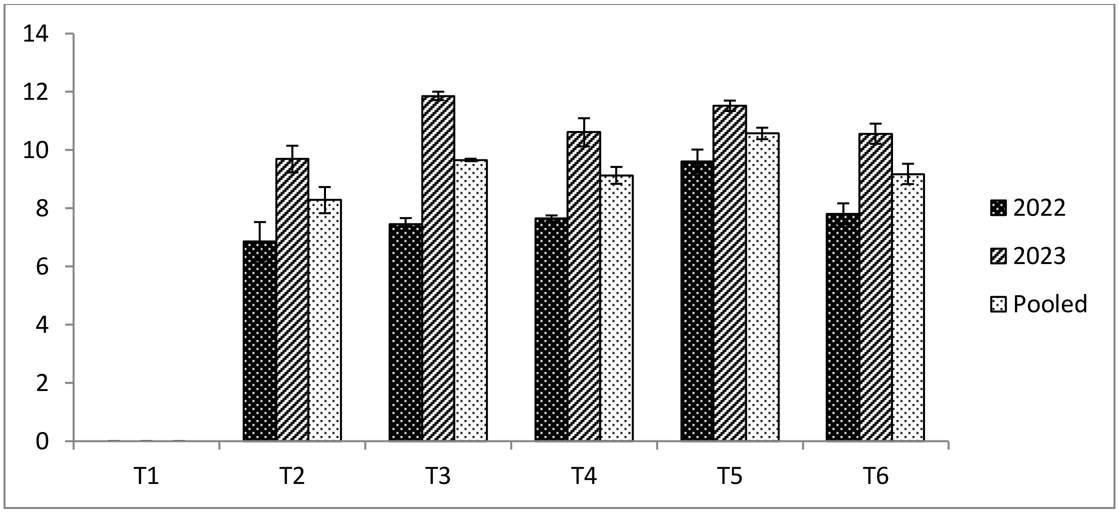

Fig. 4.50: Effect of full spectrum light on Plant spread (E-W) at 60 DAP under vertical farming system in indoor conditions

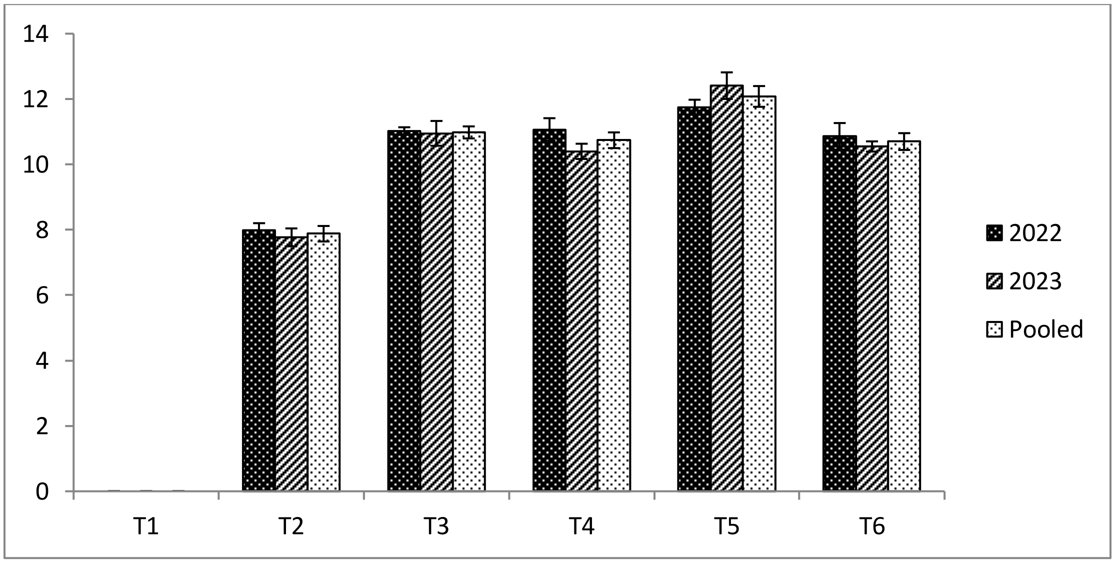

Fig. 4.51: Effect of full spectrum light on Plant spread (E-W) at 90 DAP under vertical farming system in indoor conditions

4.2.4 Plant spread (N-S) cm (30, 60 and 90 DAP)

Table 4.19 shows the recorded data of plant spread (N-S) (cm) at 30 DAP and confirms significant variation along with different treatments. At 30 DAP, treatment T3 (full spectrum light (6 hours) + natural light + second level) showed highest plant spread (N-S) (3.50, 4.17 and 3.18 cm) followed by T6 (full spectrum light (8 hours) + natural light + second level) (3.34, 4.21 and 3.78 cm) and T5 combination of full spectrum light (6 hours) + natural light +third level) (3.88, 3.31 and 3.59 cm). However lowest (2.94, 2.85 and 2.89 cm) plant spread (N-S) in 2022, 2023 and in pooled data was noticed in T1 (natural light + fourth level) or where full spectrum light was not provided followed by T2 (full spectrum light (4 hours) + natural light + third level) (4.12, 2.42 and 3.27 cm). Treatment T3 and T6 were at par in 2022, 2023 and in pooled data.

At 60 DAP, maximum (10.86, 11.43 and 11.15 cm) plant spread (N-S) observed in T5 (full spectrum light (6 hours) + natural light +third level) followed by T6 (full spectrum light (8 hours) + natural light + second level) (8.95, 11.16 and 10.06 cm) and T3 (full spectrum light (6 hours) + natural light + second level) (9.59, 10.34 and 9.96 cm) in year 2022, 2023 and in pooled data. Treatment T3 and T6 were at par in 2022 and in pooled data. Although, lowest (7.08, 8.50 and 7.79 cm) plant spread (N-S) were noticed in T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + fourth level) (8.63, 9.21 and 8.92 cm). In T1 treatment plants dies after 40 days of planting.

After 90 DAP, highest (13.77, 11.76 and 12.76 cm) plant spread (N-S) was found in treatment T5 is combination of full spectrum light (6 hours) + natural light +third level) followed by T6 (full spectrum light (8 hours) + natural light + second level) (11.93, 10.68 and 11.31 cm) and T3 (full spectrum light (6 hours) + natural light + second level) (10.81, 10.65 and 10.73 cm) in year 2022, 2023 and pooled data. However, the lowest (8.73, 9.71 and 9.22 cm) plant spread was observed in T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + fourth level) (10.15, 10.44 and 10.29 cm). Treatment T3 and T6 were at par in year 2023 and in pooled data (Table 4.19).

Table 4.19: Effect of full spectrum light on plant spread (N-S) (cm) under vertical farming system in indoor conditions.

	Plant spread (N-S) 30 days (cm)			**Plant spread (N-S) 60 days (cm)**			**Plant spread (N-S) 90 days (cm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	2.94 ± 0.046^{b}	2.85 ± 0.070^{bc}	2.89 ± 0.052^{b}	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	4.12 ± 0.401^{a}	2.42 ± 0.191^{c}	3.27 ± 0.210^{b}	7.08 ± 0.378^{c}	8.50 ± 0.582^{c}	7.79 ± 0.26^{d}	8.73 ± 0.518^{d}	9.71 ± 0.277^{c}	9.22 ± 0.189^{d}
T3	3.50 ± 0.114^{ab}	4.17 ± 0.193^{a}	3.84 ± 0.124^{a}	9.59 ± 0.216^{b}	10.34 ± 0.114^{b}	9.96 ± 0.158^{b}	10.81 ± 0.46^{c}	10.65 ± 0.348^{b}	10.73 ± 0.399^{bc}
T4	2.36 ± 0.115^{b}	4.58 ± 0.266^{a}	3.47 ± 0.189^{ab}	8.63 ± 0.428^{b}	9.21 ± 0.304^{c}	8.92 ± 0.253^{c}	10.15 ± 0.292^{c}	10.44 ± 0.155^{bc}	10.29 ± 0.172^{c}
T5	3.88 ± 0.546^{ab}	3.31 ± 0.116^{b}	3.59 ± 0.219^{ab}	10.86 ± 0.214^{a}	11.43 ± 0.277^{a}	11.15 ± 0.245^{a}	13.77 ± 0.468^{a}	11.76 ± 0.280^{a}	12.76 ± 0.374^{a}
T6	3.34 ± 0.147^{ab}	4.21 ± 0.164^{a}	3.78 ± 0.092^{ab}	8.95 ± 0.375^{b}	11.16 ± 0.39^{ab}	10.06 ± 0.075^{b}	11.93 ± 0.319^{b}	10.68 ± 0.321^{b}	11.31 ± 0.168^{b}
SEM±	0.30	0.18	0.18	0.31	0.30	0.20	0.31	0.28	0.22
CD at 5%	0.94	0.55	0.55	0.99	0.93	0.62	0.98	0.87	0.70
CV%	15.42	8.48	8.73	7.22	6.08	4.24	5.82	5.42	4.23

*Plant dies after 40 days of planting

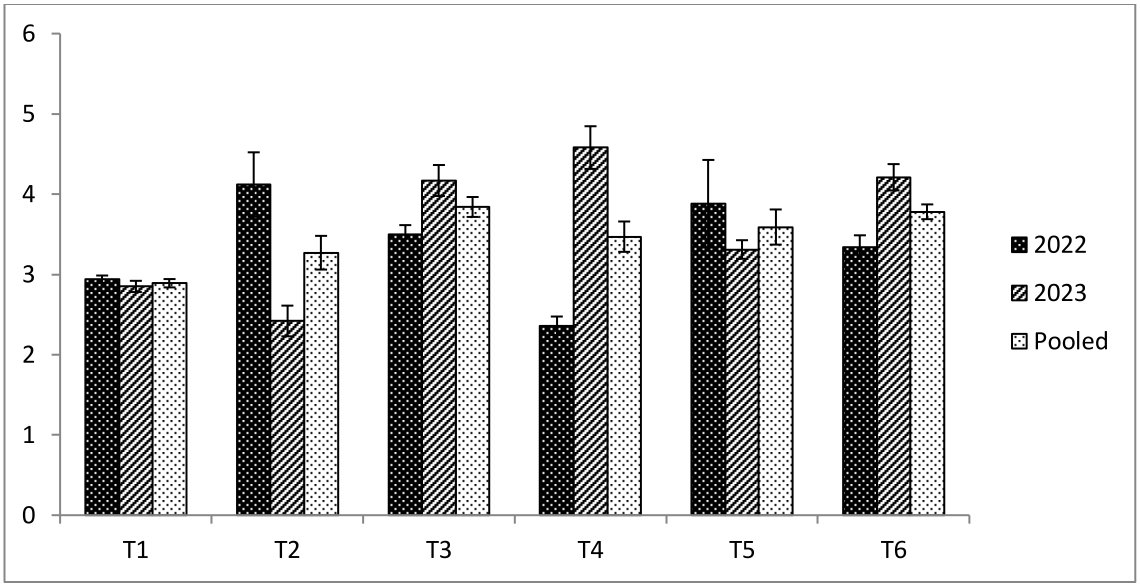

Fig. 4.52: Effect of full spectrum light on Plant spread (N-S) at 30 DAP under vertical farming system in indoor conditions

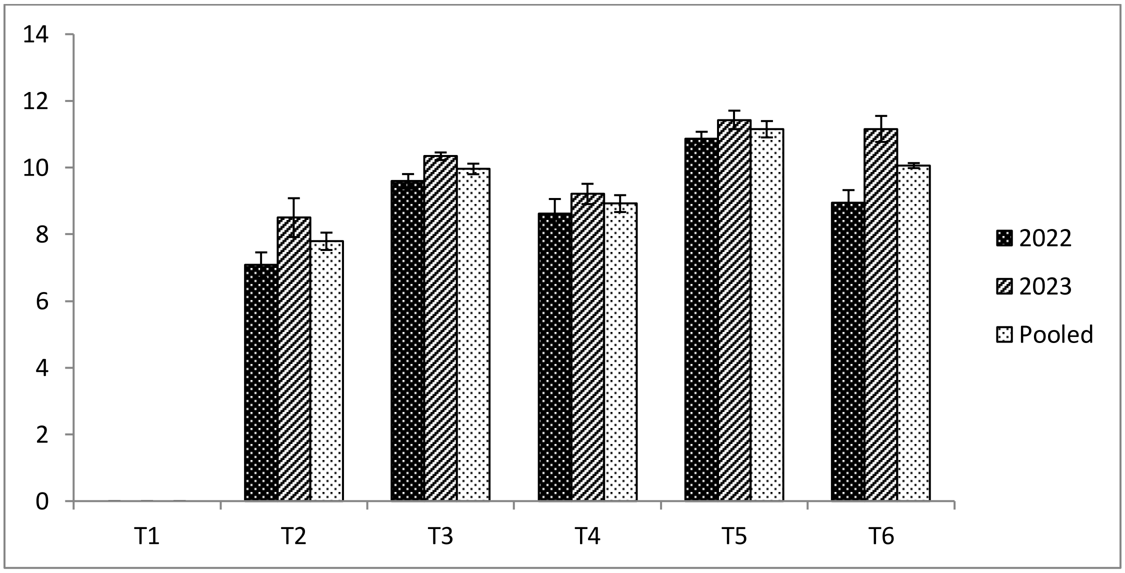

Fig. 4.53: Effect of full spectrum light on Plant spread (N-S) at 60 DAP under vertical farming system in indoor conditions

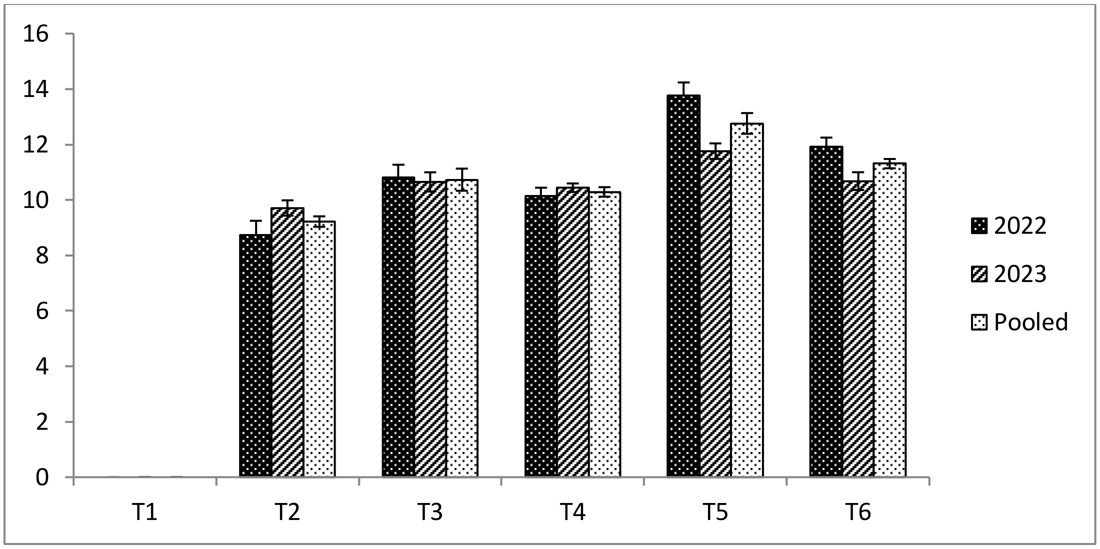

Fig. 4.54: Effect of full spectrum light on Plant spread (N-S) at 90 DAP under vertical farming system in indoor conditions

The treatments significantly affected the plant spread on all observation days (30, 60 and 90 days after planting, Table 3) which supports dependence of plant spread on light duration and levels of verticals under indoor condition. The plants subjected with 6 hours of full spectrum light have wider spread of plant (E-W and N-S) at third level (T_5) in comparison to T_3, T_4 and T_6 except 30 days after planting. In T_1 after 45 days the plants die due to insufficient light. The duration of full spectrum light in a vertical farming system can significantly affect the spread of plants and the number of leaves in strawberries. Longer durations of full spectrum light exposure can promote plant growth and increase the spread of plants in each direction, resulting in larger overall plant growth (Madhavi *et al.*, 2023).

Like plant height, the impact of light intensity and duration was not clear during initial 30 days after planting; however, it has become more defined at later stage of growth (at 60 and 90 days after planting) which could be due to development of sufficient leaves to respond the available light for improvement in nutrient uptake and photosynthesis. Thus, light mediated growth response in strawberry plants is associated with activation of phytochrome by different light duration resulting in regulation of activities of transcription factors (Helizon *et al.,* 2018). Alteration of light environment can bring change in morphogenesis which could be associated with auxin homeostasis as it plays a crucial role in regulation of plant growth and development. Further, light stimulates auxin transport to roots resulting light induced elongation of primary roots for efficient nutrient uptake (Lee *et al.,* 2017).

4.2.5 Number of leaves (30, 60 and 90 DAP)

Number of leaves were highest (9.20, 10.40 and 9.80) in T5 is combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (7.53, 10.20 and 8.87) and T6 (full spectrum light (8 hours) + natural light + second level) (6.97, 9.20 and 8.08) in year 2022, 2023 and in pooled data at 30 DAP. Treatment T3 and T5 were at par in year 2023 and in pooled data. However, lowest (5.67, 7.63 and 6.65) number of leaves were observed in T1 (natural light + fourth level) or where full spectrum light was not provided followed by T2 (full spectrum light (4 hours) + natural light + third level) (6.97, 8.27 and 7.62) in year 2022, 2023 and in pooled data (Table 4.20).

Table 4.20, shows the recorded data of number of leaves and confirms significant variation along with different treatments grown. At 60 days of planting, treatment T5 (full spectrum light (6 hours) + natural light +third level) showed significant result (12.53, 11.33 and 11.93) in year 2022, 2023 and in pooled data followed by T6 (full spectrum light (8 hours) + natural light + second level) (10.50, 11.57 and 11.03) and T3 (full spectrum light (6 hours) + natural light + second level) (10.80, 10.60 and 10.70). Treatment T4 and T6 were at par in year 2022, 2023 and in pooled data. Though lowest (7.93, 9.53 and 8.73) number of leaves were noticed in T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + fourth level) (10.20, 11.10 and 10.65) in year 2022, 2023 and in pooled data.

Further after 90 DAP, the highest (12.23, 11.13 and 11.68) number of leaves in year 2022, 2023 and pooled data was observed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (11.17, 10.20 and 10.68) and T4 (full spectrum light (8 hours) + natural light + fourth level) (9.78, 10.60 and 10.23). While minimum (8.13, 9.97 and 9.05) number of leaves noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) and T6 (full spectrum light (8 hours) + natural light + second level) (9.93, 9.97 and 9.95) in year 2022, 2023 and in pooled data (Table 4.20).

The observations recorded for average number of leaves (Table 4.20) was significantly affected by treatments given at all days of observations (30, 60 and 90 days after planting where the plants subjected to full spectrum light for 6 hours have grown a greater count of leaves when plants were at third level) (T_5) (9.69, 11.93 and 11.68 cm) and were superior in comparison to T_3, T_4 and T_6. Plants grown with addition full spectrum light gave more significant number of leaves than natural light.

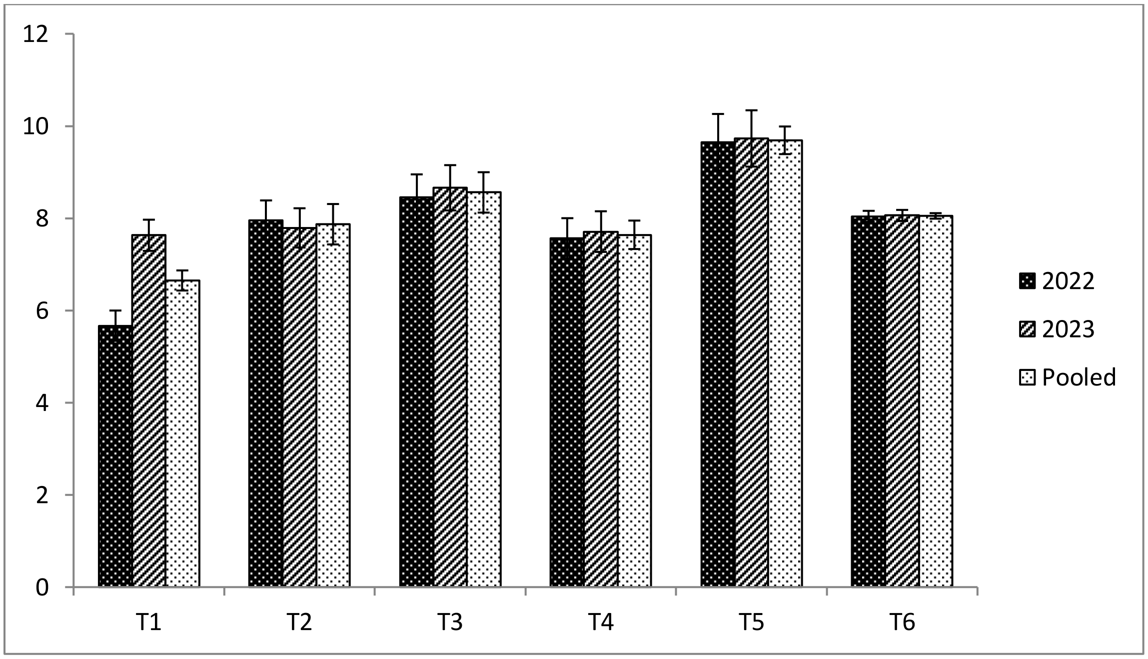

Fig. 4.55: Effect of full spectrum light on number of leaves at 30 DAP under vertical farming system in indoor conditions

Table 4.20: Effect of full spectrum light on number of leaves under vertical farming system in indoor conditions.

	Number of Leaves 30 days			**Number of Leaves 60 days**			**Number of Leaves 90 days**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	5.67 ± 0.328^{c}	7.63 ± 0.338^{c}	6.65 ± 0.218^{c}	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	6.97 ± 0.426^{bc}	8.27 ± 0.426^{bc}	7.62 ± 0.438^{bc}	7.93 ± 0.333^{c}	9.53 ± 0.677^{c}	8.73 ± 0.426^{c}	8.13 ± 0.240^{c}	9.97 ± 0.120^{b}	9.05 ± 0.104^{d}
T3	7.53 ± 0.491^{b}	10.20 ± 0.491^{ab}	8.87 ± 0.438^{ab}	10.80 ± 0.231^{b}	10.60 ± 0.115^{b}	10.70 ± 0.153^{b}	11.17 ± 0.186^{a}	10.20 ± 0.400^{b}	10.68 ± 0.188^{b}
T4	5.53 ± 0.441^{c}	10.20 ± 0.441^{ab}	7.87 ± 0.309^{b}	10.20 ± 0.416^{b}	11.10 ± 0.208^{ab}	10.65 ± 0.180^{b}	9.87 ± 0.176^{b}	10.60 ± 0.306^{ab}	10.23 ± 0.176^{bc}
T5	9.20 ± 0.611^{a}	10.40 ± 0.611^{a}	9.80 ± 0.300^{a}	12.53 ± 0.481^{a}	11.33 ± 0.067^{ab}	11.93 ± 0.219^{a}	12.23 ± 0.318^{a}	11.13 ± 0.067^{a}	11.68 ± 0.130^{a}
T6	6.97 ± 0.120^{bc}	9.20 ± 0.120^{b}	8.08 ± 0.060^{b}	10.50 ± 0.208^{b}	11.57 ± 0.328^{a}	11.03 ± 0.192^{b}	9.93 ± 0.240^{b}	9.97 ± 0.426^{b}	9.95 ± 0.325^{c}
SEM±	0.46	0.32	0.32	0.35	0.28	0.23	0.20	0.27	0.18
CD=5%	1.43	1.01	1.00	1.09	0.88	0.74	0.64	0.86	0.57
CV%	11.30	5.95	6.77	6.91	5.35	4.59	4.08	5.45	3.63

*Plant dies after 40 days of planting

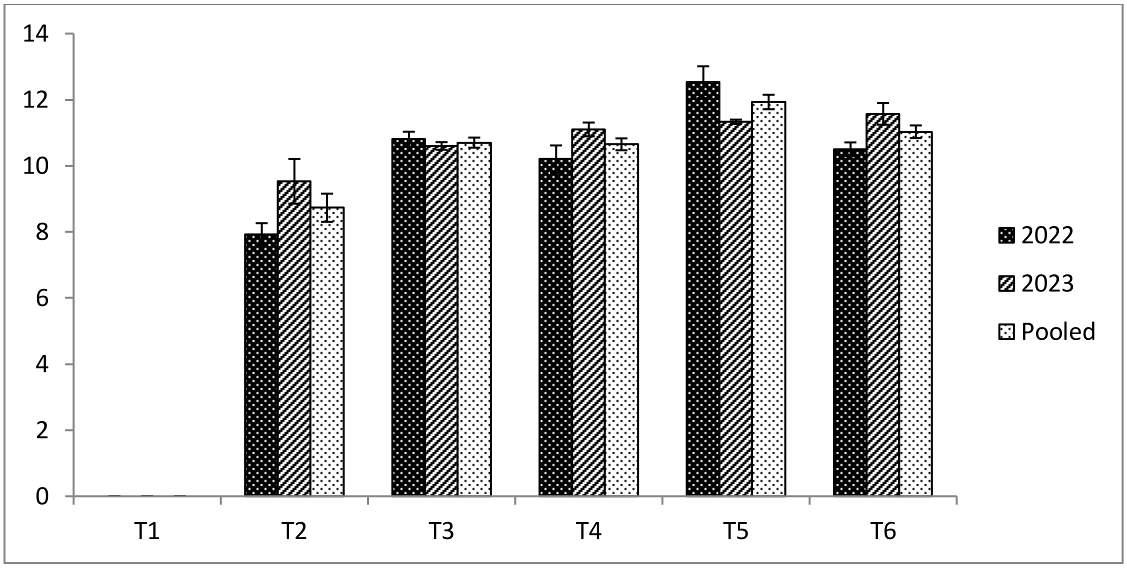

Fig. 4.56: Effect of full spectrum light on number of leaves at 60 DAP under vertical farming system in indoor conditions

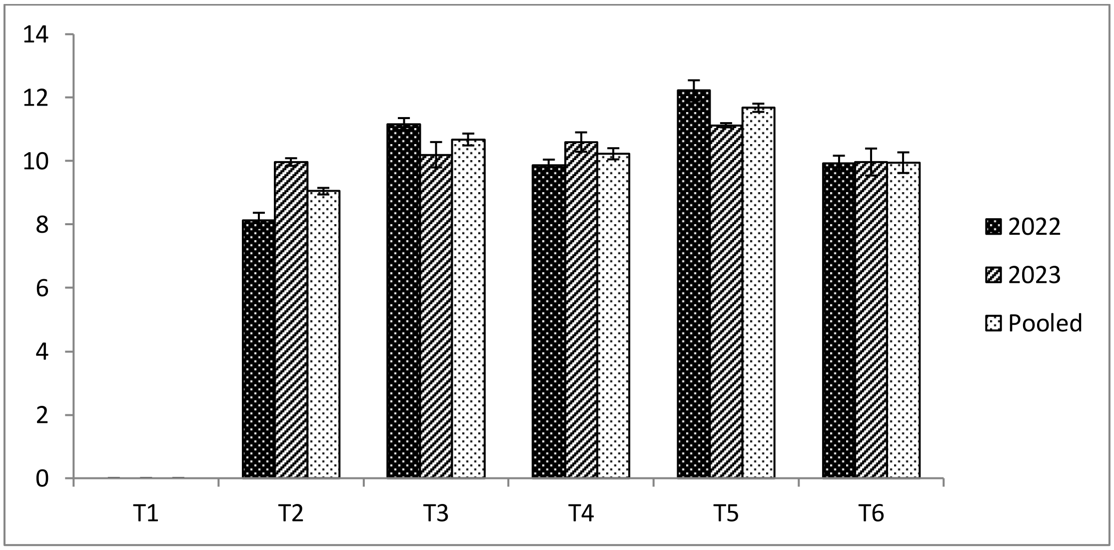

Fig. 4.57: Effect of full spectrum light on number of leaves at 90 DAP under vertical farming system in indoor conditions

Additionally, extended exposure to full spectrum light might have stimulated leaf production, leading to an increased number of leaves in strawberry plants (Peng *et al.*, 2020). The dependence of plant spread on lux value at different levels of verticals could be associated with alteration in water use efficiency and stomatal conductance of strawberry plants under indoor condition (Pennisi *et al.,* 2019). Improvement in water use efficiency could be associated with increased biomass production due to reduced stomatal conductance and controlled leaf transpiration (Baroli *et al.,* 2008). Thus, the indoor cultivation of plants with artificial light is associated with high water use efficiency and is main driving factor to promote vertical farming (Kozai, 2013).

4.2.6 Leaf area (sq cm)

As shown in Table.4.21, maximum (191.30, 191.33 and 191.32 sq cm) leaf area was estimated in treatment T4 (full spectrum light (8 hours) + natural light + fourth level) followed by T6 (full spectrum light (8 hours) + natural light + second level) (191.03, 190.97 and 191.00 sq cm) and T3 (full spectrum light (6 hours) + natural light + second level) (190.60, 191.30 and 190.95 sq cm) in year 2022, 2023 and in pooled data. Moreover, minimum (190.40, 190.63 and 190.52 sq cm) leaf area revealed in T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T2 (full spectrum light (4 hours) + natural light + third level) (190.37, 191.13 and 190.75 sq cm) and T1 (natural light + fourth level) or where full spectrum light was not provided (190.50, 191.07 and 190.78 sq cm) in year 2022, 2023 and in pooled data. In 2022, 2023 and in pooled data, treatment T4 and T6 were at par.

4.2.7 Chlorophyll content index

In year 2022, 2023 and in pooled data, highest (54.85, 54.75 and 54.80) chlorophyll content index found in T6 (full spectrum light (8 hours) + natural light + second level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (55.70, 53.50 and 54.60) and T5 (full spectrum light (6 hours) + natural light +third level) (55.45, 51.52 and 53.48) while lowest (48.50, 49.57 and 49.03) chlorophyll content index noticed in treatment T1 (natural light + fourth level) followed by T4 (full spectrum light (8 hours) + natural light + fourth level) (55.60, 48.03 and 51.82) and T2 (full spectrum light (4 hours) + natural light

+ third level) (52.22, 53.98 and 53.10). In 2022, treatment T3 and T6 were at par in 2022,2023 and in pooled data (Table 4.21).

Table 4.21: Effect of full spectrum light on leaf area (sq cm) and chlorophyll content index under vertical farming system in indoor conditions.

	Leaf Area (sq cm)			**Chlorophyll content index**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1	190.50 ± 0.115^{b}	191.07 ± 0.448^{ab}	190.78 ± 0.172^{bc}	48.50 ± 0.535^{c}	49.57 ± 0.059^{c}	49.03 ± 0.282^{c}
T2	190.37 ± 0.132^{b}	191.13 ± 0.135^{ab}	190.75 ± 0.029^{bc}	52.22 ± 0.824^{b}	53.98 ± 0.423^{a}	53.10 ± 0.572^{ab}
T3	190.60 ± 0^{b}	191.30 ± 0.206^{a}	190.95 ± 0.130^{b}	55.70 ± 1.370^{a}	53.50 ± 0.409^{a}	54.60 ± 0.889^{a}
T4	191.30 ± 0.263^{a}	191.33 ± 0.188^{a}	191.32 ± 0.073^{a}	55.60 ± 1.370^{a}	48.03 ± 0.744^{d}	51.82 ± 1.031^{b}
T5	190.40 ± 0.037^{b}	190.63 ± 0.184^{b}	190.52 ± 0.041^{c}	55.45 ± 0.465^{a}	51.52 ± 0.570^{b}	53.48 ± 0.351^{ab}
T6	191.03 ± 0.300^{ab}	190.97 ± 0.124^{ab}	191.00 ± 0.206^{ab}	54.85 ± 0.967^{a}	54.75 ± 0.225^{a}	54.80 ± 0.393^{a}
SEM±	0.19	0.21	0.11	0.78	0.49	0.56
CD=5%	0.59	0.64	0.35	2.45	1.53	1.77
CV%	0.20	0.22	0.10	2.51	1.62	1.84

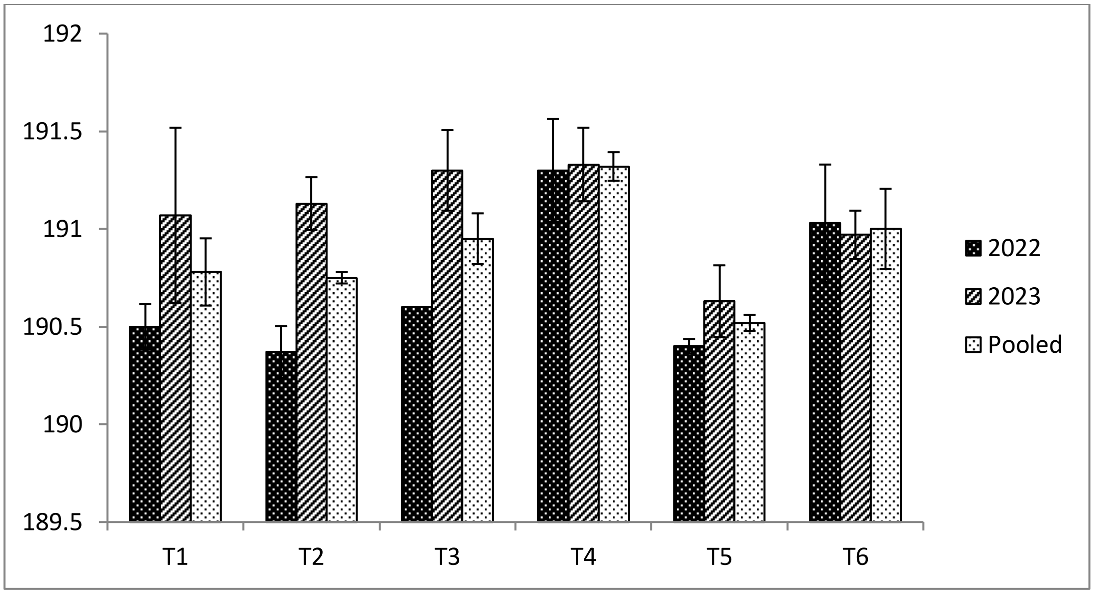

Fig. 4.58: Effect of full spectrum light on leaf area (sq cm) under vertical farming system in indoor conditions

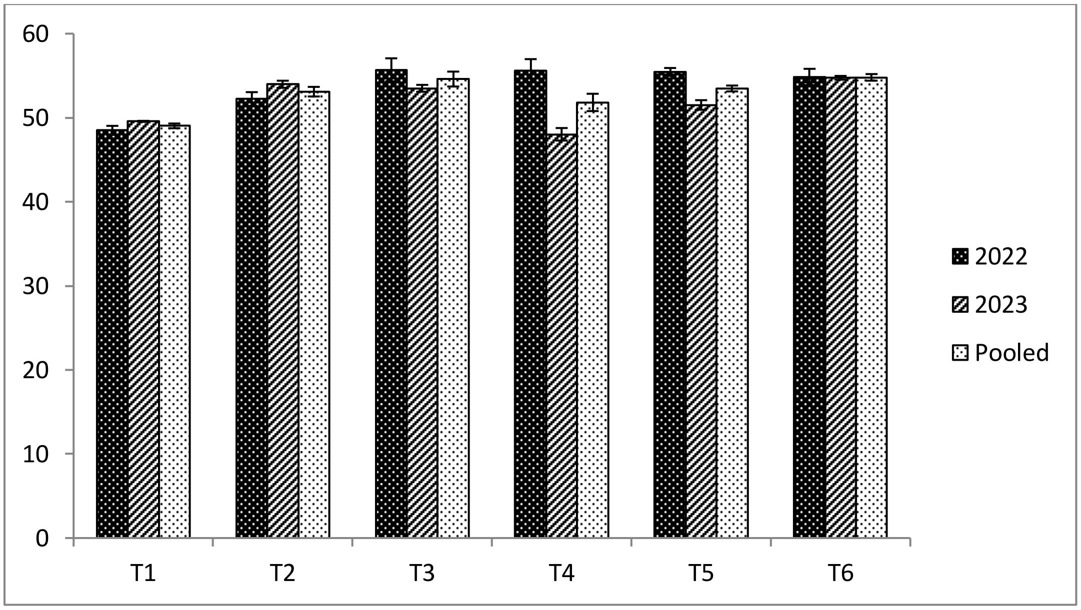

Fig. 4.59: Effect of full spectrum light on chlorophyll content index under vertical farming system in indoor conditions

In case of indoor condition (Table 4.21) where more hours of full-spectrum light were provided to the plants, the leaf area was significantly superior in T_4which was at par with T_6 and were followed by T_3. Similarly, in case of indoor condition (Table 2), treatments in which 8 hour full spectrum light (T_4 and T_6) was provided resulted in highest CCI and were at par with (T_3) where 6 hours full spectrum light was given for the plants grown at second level. The normal physiological condition of leaves is also expressed through SPAD values, which are used to evaluate chlorophyll content and reflect the biochemical status of the leaves (Le *et al.,* 2021). Under indoor condition, specific light spectra emitted by LEDs can promote leaf expansion and increase leaf area which might be responsible. For example, red and blue light spectra have been shown to enhance leaf growth in strawberry plants (Nadalini *et al.,* 2017). The combination of red and blue LEDs, commonly used in vertical farming, has been found to stimulate leaf area expansion and overall plant development. The red light stimulates the photosynthetic apparatus and phytochromes (Kochetova et al. 2018) which regulates the activities of transcription factors (Helizon et al. 2018), photosynthesis and biomass accumulation (Chen et al. 2017a); the blue component of LED light effectively stimulates phytochromes as well as cryptochromes and phototropins (Kochetova et al. 2018) which regulates photomorphogenesis, stomatal movement, biosynthesis of chlorophyll and anthocyanin as well as biomass accumulation (Chen et al. 2017a); while the green component of AFSL regulates leaf expansion, stem stretching and stomatal conductance (Chen et al. 2017b) which could have played a significant role in the spread of strawberry plants.

4.2.8 Days to bud formation

The data pertaining days to bud formation of strawberry plants, presented in Table 4.22, confirms significant variation among different treatments grown under indoor conditions. Maximum (68.00, 68.33 and 68.17) number of days for bud formation took by treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (67.83, 67.00 and 67.42) and T6 (full spectrum light (8 hours) + natural light + second level) (67.67, 67.00 and 67.33) while minimum

(66.67, 65.67 and 66.17) days to bud formation took by treatment T3 (full spectrum light (6 hours) + natural light + second level) and T5 combination of full spectrum light (6 hours) + natural light +third level) (66.33, 66.00 and 66.17). Treatment T2, T4 and T6 were at par in year 2022.

4.2.9 Days to flowering

As shown in Table 4.22, maximum (77.00, 77.33 and 77.17) days to flowering in strawberry plant was estimated in treatment T2 (full spectrum light (4 hours) + natural light + second level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (76.17, 76.67 and 76.42) and T6 (full spectrum light (8 hours) + natural light + second level) (75.00, 76.33 and 75.67) in year 2022, 2023 and in pooled data. Moreover, minimum (74.83, 74.67 and 74.75) days to flowering were noticed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (74.83, 75.00 and 74.92). In 2022 and 2023 treatment T2 and T4 were at par.

4.2.10 Days to maturity

Maximum (88.67, 88.33 and 88.50) days to maturity found under treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (88.50, 87.67 and 88.08) and T6 (full spectrum light (8 hours) + natural light + second level) (87.00, 87.83 and 87.42) in year 2022, 2023 and in pooled data. Furthermore, minimum (86.83, 86.33 and 86.58) days to maturity found in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (86.83, 86.67 and 88.08) in year 2022, 2023 and in pooled data (Table 4.22). Treatment T2 and T4 were at par in 2022, 2023 and in pooled data.

Table 4.22: Effect of full spectrum light on flowering traits under vertical farming system indoor conditions.

	Days to bud formation			**Days to flowering**			**Days to maturity**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	68.00 ± 0.289^{a}	68.33 ± 0.166^{a}	68.17 ± 0.167^{a}	77.00 ± 0.500^{a}	77.33 ± 0.166^{a}	77.17 ± 0.221^{a}	88.67 ± 0.167^{a}	88.33 ± 0.166^{a}	88.50 ± 0^{a}
T3	66.67 ± 0.167^{b}	65.67 ± 0.167^{c}	66.17 ± 0.084^{c}	74.83 ± 0.333^{b}	75.00 ± 0.289^{b}	74.92 ± 0.084^{d}	86.83 ± 0.333^{b}	86.67 ± 0.167^{b}	86.75 ± 0.144^{c}
T4	67.83 ± 0.441^{a}	67.00 ± 0.289^{b}	67.42 ± 0.084^{b}	76.17 ± 0.167^{a}	76.67 ± 0.441^{a}	76.42 ± 0.221^{b}	88.50 ± 0.289^{a}	87.67 ± 0.441^{a}	88.08 ± 0.333^{a}
T5	66.33 ± 0.166^{b}	66.00 ± 0.289^{c}	66.17 ± 0.084^{c}	74.83 ± 0.166^{b}	74.67 ± 0.167^{b}	74.75 ± 0.144^{d}	86.83 ± 0.441^{b}	86.33 ± 0.166^{b}	86.58 ± 0.166^{c}
T6	67.67 ± 0.167^{a}	67.00 ± 0.500^{b}	67.33 ± 0.166^{b}	75.00 ± 0.289^{b}	76.33 ± 0.441^{ab}	75.67 ± 0.084^{c}	87.00 ± 0.289^{b}	87.83 ± 0.333^{a}	87.42 ± 0.221^{b}
SEM±	0.26	0.30	0.12	0.29	0.32	0.16	0.30	0.26	0.19
CD at 5%	0.83	0.95	0.38	0.90	1.01	0.50	0.93	0.81	0.60
CV%	0.81	0.94	0.37	0.79	0.88	0.43	0.70	0.61	0.45

*Plant dies after 40 days of planting

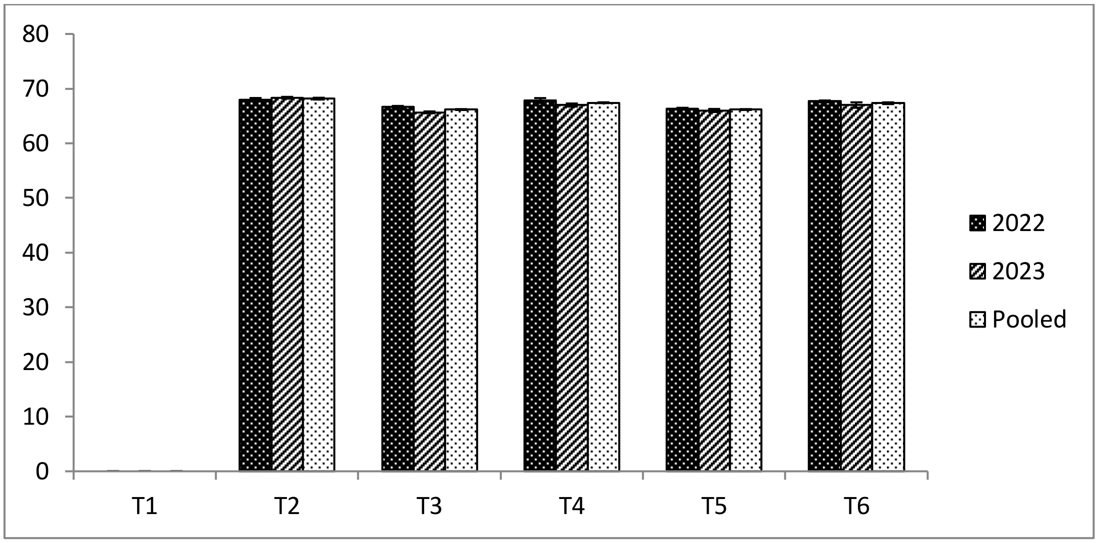

Fig. 4.60: Effect of full spectrum light on days to bud formation under vertical farming system in indoor conditions

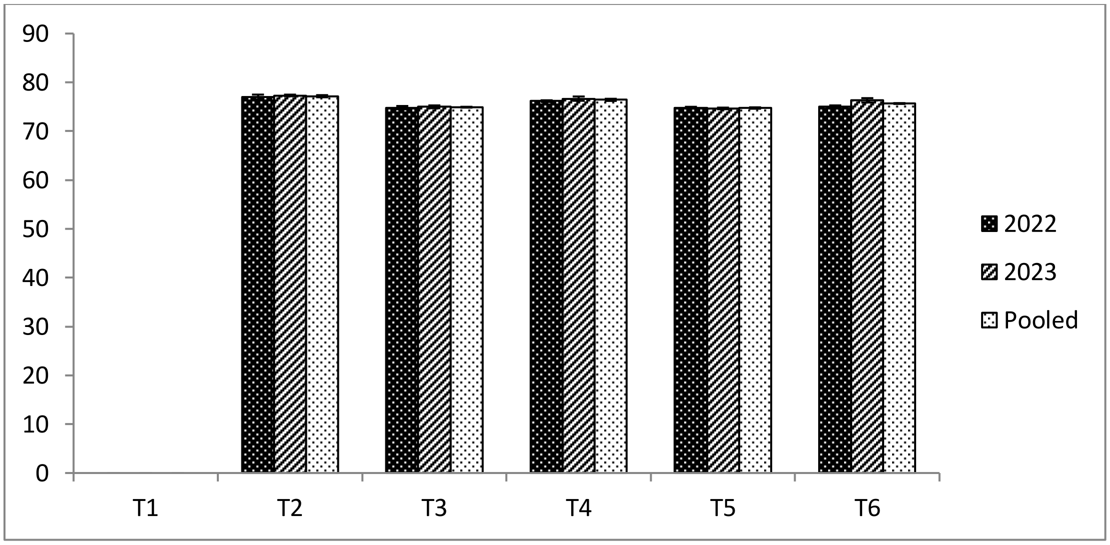

Fig. 4.61: Effect of full spectrum light on days to flowering under vertical farming system in indoor conditions

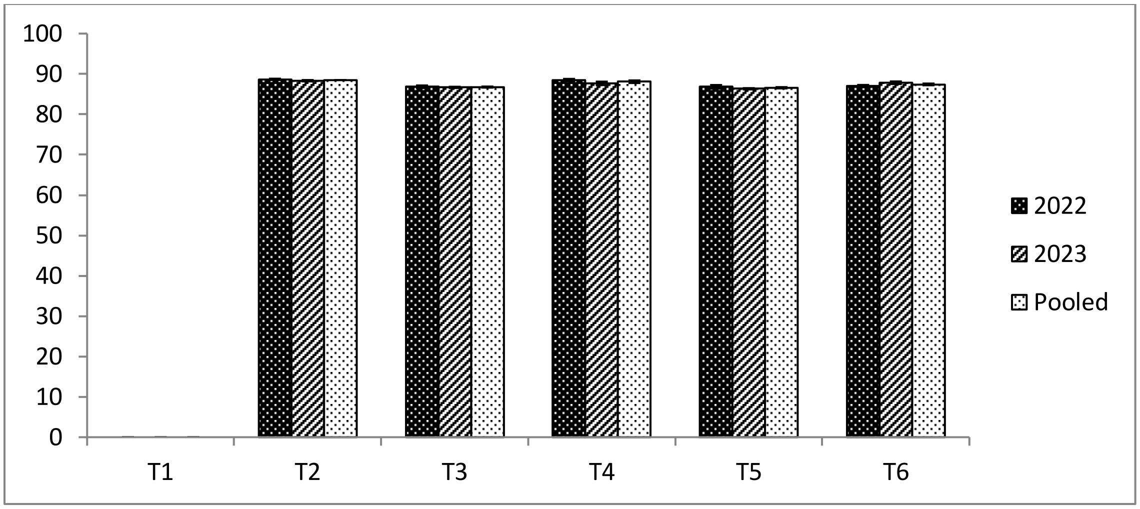

Fig. 4.62: Effect of full spectrum light on days to maturity under vertical farming system in indoor conditions

The plants exposed to full spectrum light grew earlier when plants were at the third level (T_3 and T_5) and was superior in comparison to other treatments (Table 4.22). These plants also performed well and exhibited earlier bud development, maximum number of buds per plant and early flowering than those grown in natural light. Further, these treatments have also induced maximum number of flowers (17.35) while T_2 have minimum flower numbers (14.83). The duration of full spectrum light in a vertical farming system can influence both the number of bud formations and the time it takes for buds to form in strawberries grown indoors as well as accelerate the onset of flowering and reduce the no. of days required for strawberries to grasp the flowering phase.

Longer durations of full spectrum light exposure, particularly during the flowering stage, can promote increased bud formation and potentially reduce the time it takes for buds to develop. Providing sufficient light during the appropriate growth stages is crucial for optimal bud development and flower production (Sabzalian *et al.*, 2014; Murad *et al.*, 2021). Extended exposure to full spectrum light, particularly during the flowering stage, can promote flower induction and increase the overall number of flowers produced by strawberry plants. Providing sufficient light duration and intensity is crucial for stimulating flower development and enhancing flowering in indoor vertical farming systems (Xu *et al.*, 2020). The increased photoperiod results in differential physiological responses related to flowering **(**Chen *et al.,* 2017) which could be associated with the availability of full spectrum light for different duration in the current investigation.

4.2.11 Number of bud formation

In year 2022, 2023 and in pooled data highest (8.22, 18.56 and 18.39) number of bud formation observed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (17.89, 17.67 and 17.78) and T6 (full spectrum light (8 hours) + natural light + second level) (17.22, 17.11 and 17.17). However, lowest (16.22, 15.67 and 15.94) number of buds noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by treatment T4 (full spectrum light (8 hours) + natural light + first level) (16.78, 16.44 and 16.61). T3 and T5 were at par in year 2022, 2023 and in pooled data (Table 4.23).

4.2.12 Number of flowers

In year 2022, 2023 and in pooled data, maximum (17.36, 17.33 and 17.35) number of flowers was observed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (16.81, 17.00 and 16.91) and T6 (full spectrum light (8 hours) + natural light + second level) (16.00, 15.89 and 15.94) while minimum (15.11, 14.56 and 14.83) number of flowers noticed in T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (15.67, 15.78 and 15.72). Treatment T3 and T5 were at par in year 2022, 2023 and in pooled data (Table 4.23).

4.2.13 Number of fruits

Maximum no. of fruits (16.56, 16.56 and 16.56) observed in treatment T5 (full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) +

natural light + second level) (15.89, 16.00 and 15.94) and T6 (full spectrum light (8 hours) + natural light + second level) (15.33, 15.22 and 15.28) in year 2022, 2023 and in pooled data. However, minimum number of fruits (14.00, 13.44 and 13.72) were found in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (14.56, 14.44 and 14.50). In 2022, treatment T3 and T5 were at par as well as in year 2023 and in pooled data (Table 4.23).

The duration of full spectrum light in a vertical farming system can influence both the number of bud formations and the time it takes for buds to form in strawberries grown indoors as well as accelerate the onset of flowering and reduce the no. of days required for strawberries to grasp the flowering period. Providing sufficient light duration and intensity during the appropriate growth stages is crucial for stimulating flower development and enhancing flowering in indoor vertical farming systems (Sabzalian et al. 2014; Xu and Hernandez 2020; Al Murad et al. 2021).

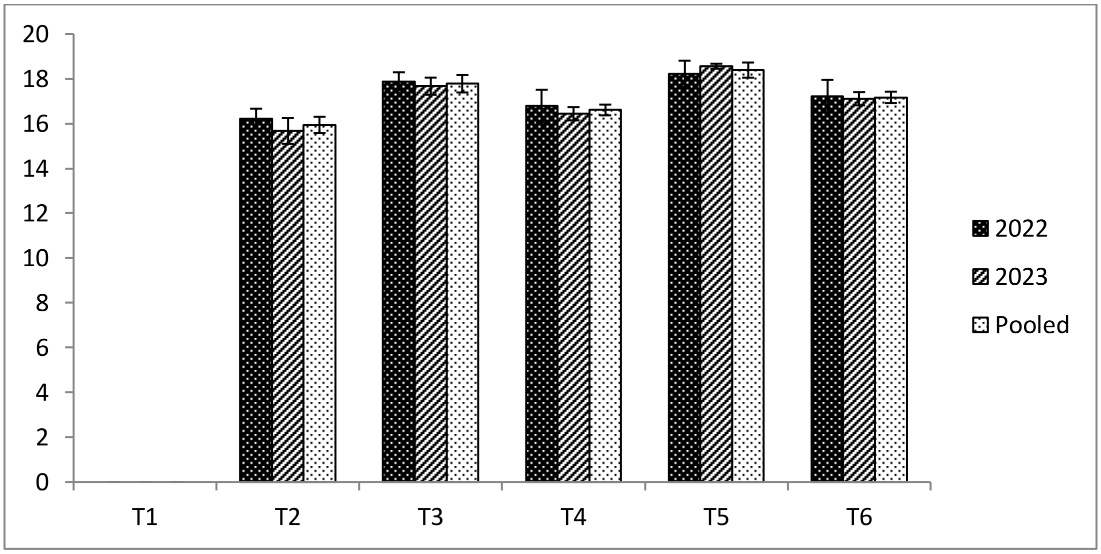

Fig. 4.63: Effect of full spectrum light on number of bud formation under vertical farming system in indoor conditions

Table 4.23: Effect of full spectrum light on number of bud formation, flowering and fruiting under vertical farming system in indoor conditions.

	Number of bud formation			**Number of flowers**			**Number of fruits**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	16.22 ± 0.447^{b}	15.67 ± 0.577^{c}	15.94 ± 0.365^{c}	15.11 ± 0.220^{b}	14.56 ± 0.588^{c}	14.83 ± 0.333^{c}	14.00 ± 0.191^{c}	13.44 ± 0.483^{c}	13.72 ± 0.222^{d}
T3	17.89 ± 0.402^{ab}	17.67 ± 0.384^{ab}	17.78 ± 0.388^{ab}	16.81 ± 0.097^{ab}	17.00 ± 0.333^{a}	16.91 ± 0.212^{a}	15.89 ± 0.22^{ab}	16.00 ± 0.333^{ab}	15.94 ± 0.278^{a}
T4	16.78 ± 0.730^{ab}	16.44 ± 0.294^{bc}	16.61 ± 0.241^{bc}	15.67 ± 0.507^{b}	15.78 ± 0.294^{b}	15.72 ± 0.147^{b}	14.56 ± 0.483^{bc}	14.44 ± 0.294^{c}	14.50 ± 0.096^{c}
T5	18.22 ± 0.588^{a}	18.56 ± 0.113^{a}	18.39 ± 0.339^{a}	17.36 ± 0.499^{a}	17.33 ± 0.193^{a}	17.35 ± 0.289^{a}	16.56 ± 0.588^{a}	16.56 ± 0.113^{a}	16.56 ± 0.338^{a}
T6	17.22 ± 0.730^{ab}	17.11 ± 0.294^{b}	17.17 ± 0.256^{b}	16.00 ± 0.333^{b}	15.89 ± 0.220^{b}	15.94 ± 0.147^{b}	15.33 ± 0.193^{b}	15.22 ± 0.294^{bc}	15.28 ± 0.147^{bc}
SEM±	0.54	0.36	0.29	0.33	0.35	0.21	0.31	0.32	0.21
CD=5%	1.70	1.14	0.91	1.03	1.09	0.66	0.98	1.01	0.65
CV%	6.51	4.41	3.50	4.20	4.48	2.68	4.22	4.40	2.81

*Plant dies after 40 days of planting

The increased photoperiod through AFSL under indoor conditions optimizes the photosynthetic activities and differential physiological responses (Chen et al. 2017a, b) which results in changes in internal rhythms to bring morphological and reproductive changes like flower bud differentiation or improves the biosynthesis and accumulation of plant metabolites necessary for defense against biotic and abiotic stresses (Cavallaro and Muleo 2022).

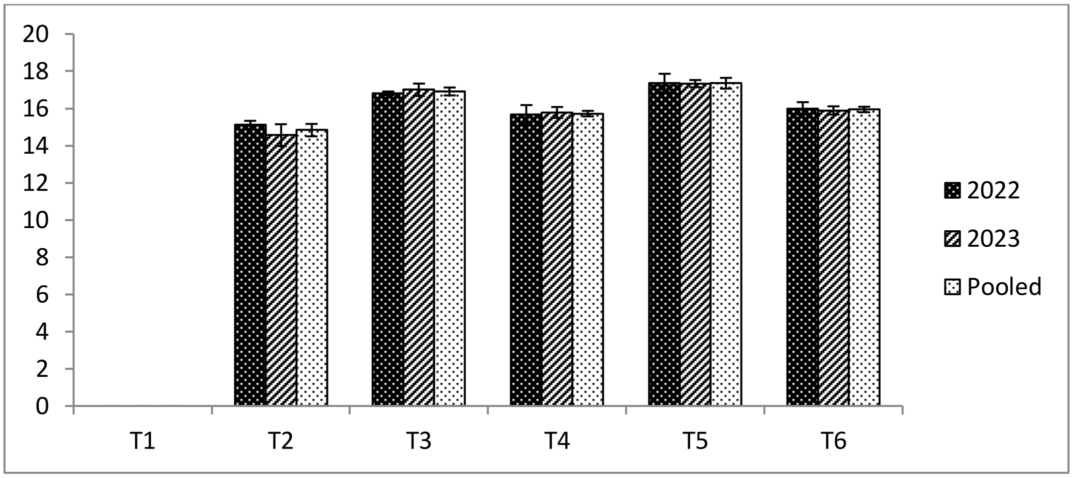

Fig 4.64: Effect of full spectrum light on number of flowering under vertical farming system in indoor conditions

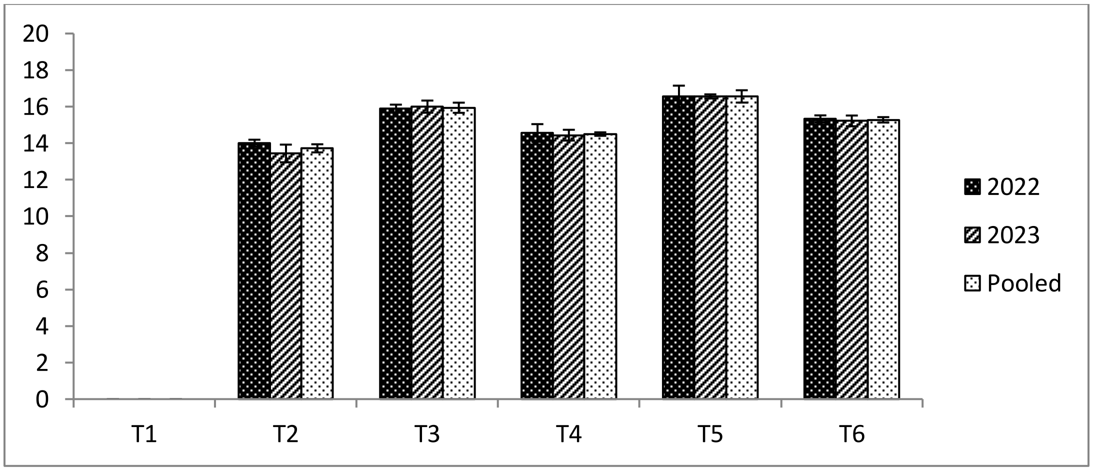

Fig. 4.65: Effect of full spectrum light on number of fruits under vertical farming system in indoor conditions

4.2.14 Fruit set (%)

As shown in Table.4.24, highest fruit set (%) (95.87%, 95.80% and 95.84%) in strawberry plant was estimated in treatment T6 (full spectrum light (8 hours) + natural light + second level) followed by T5 (full spectrum light (6 hours) + natural light +third level) (95.34%, 95.52% and 95.43%) and T3 (full spectrum light (6 hours) + natural light + second level) (94.49%, 94.11% and 94.30%) in year 2022, 2023 and in pooled data. Moreover, treatment T4 (full spectrum light (8 hours) + natural light + first level) has the lowest fruit set (%) (92.94%, 91.54% and 92.24%) followed by T2 (full spectrum light (4 hours) + natural light + third level) (92.65%, 92.40% and 92.53%). In 2022, 2023 and in pooled data treatment T5 and T6 were at par.

4.2.15 Fruit volume (cm^3)

Highest fruit volume (14.24, 13.51 and 13.88 cm^3) was revealed in treatment T6 (full spectrum light (8 hours) + natural light + second level) followed by T5 combination of full spectrum light (6 hours) + natural light +third level) (13.44, 13.53 and 13.49 cm^3) and T4 (full spectrum light (8 hours) + natural light + first level) (13.52, 13.38 and 13.45 cm^3) in year 2022, 2023 and in pooled data (Table 4.24). On the other hand, lowest (12.61, 12.57 and 12.59 cm^3) fruit volume revealed in T2 (full spectrum light (4 hours) + natural light + third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (13.04, 13.16 and 13.10 cm^3). Treatment T4, T5 and T6 were at par in year 2022, 2023 and in pooled data.

The quantity of fruits and fruit set in strawberries grown indoors can be affected by the length of full spectrum light in a vertical farming system. Longer periods of exposure to full spectrum light, especially during the flowering and fruiting stages, can encourage pollination, boost fruit set and ultimately result in strawberry plants producing more fruits. In order to support the reproductive development and successful fruiting of indoor-grown strawberries, adequate light duration and intensity are critical (Nadalini *et al.,* 2017 and Toscano *et al.,* 2019). The plants exposed to full spectrum light for 6 hours mature earlier when plants were at the third level) (T_5) followed by T_3 and was superior in comparison to other treatments. But treatment (T_2) with 4 hours lights took maximum days for maturing from all the treatment. Similarly, T_6 performed better in terms of fruit volume than the rest of treatments but in overall performance T_5 was superior than T_3 and T_6.

4.2.16 Average berry weight (g)

The data pertaining to average berry weight of strawberry plants, presented in Table 4.24, confirms significant variation among different treatments grown under indoor conditions. Maximum average berry weight (15.13g, 15.01g and 15.07g) observed in treatment T3 (full spectrum light (6 hours) + natural light + second level) followed by T5 combination of full spectrum light (6 hours) + natural light +third level) (14.38g, 14.63g and 14.51g) and T6 (full spectrum light (8 hours) + natural light + second level) (14.49g, 14.47g and 14.48g) in year 2022, 2023 and in pooled data while minimum (12.78g, 13.16g and 12.97g) average berry weight was noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (13.54g, 13.71g and 13.63g). In year 2022, 2023 and in pooled data treatment T3, T5 and T6 were at par.

The quantity of fruits and fruit set in strawberries grown indoors can be affected by the length of full spectrum light in a vertical farming system. Longer periods of exposure to full spectrum light, especially during the flowering and fruiting stages, can encourage pollination, boost fruit set and ultimately result in strawberry plants producing more fruits. In order to support the reproductive development and successful fruiting of indoor-grown strawberries, adequate light duration and intensity are critical (Nadalini *et al.,* 2017 and Toscano *et al.,* 2019). The plants exposed to full spectrum light for 6 hours mature earlier when plants were at the third level (T_5) followed by T_3 and was superior in comparison to other treatments. But treatment (T_2) with 4 hours lights took maximum days for maturing from all the treatment. Similarly, T_6 performed better in terms of fruit volume than the rest of treatments but in overall performance T_5 was superior than T_3 and T_6.

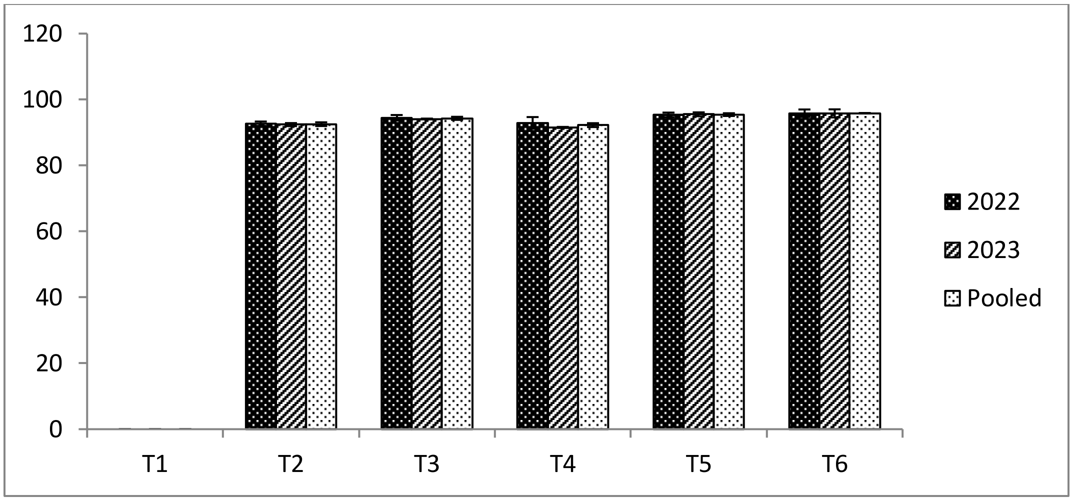

Fig. 4.66: Effect of full spectrum light on fruit set (%) under vertical farming system in indoor conditions

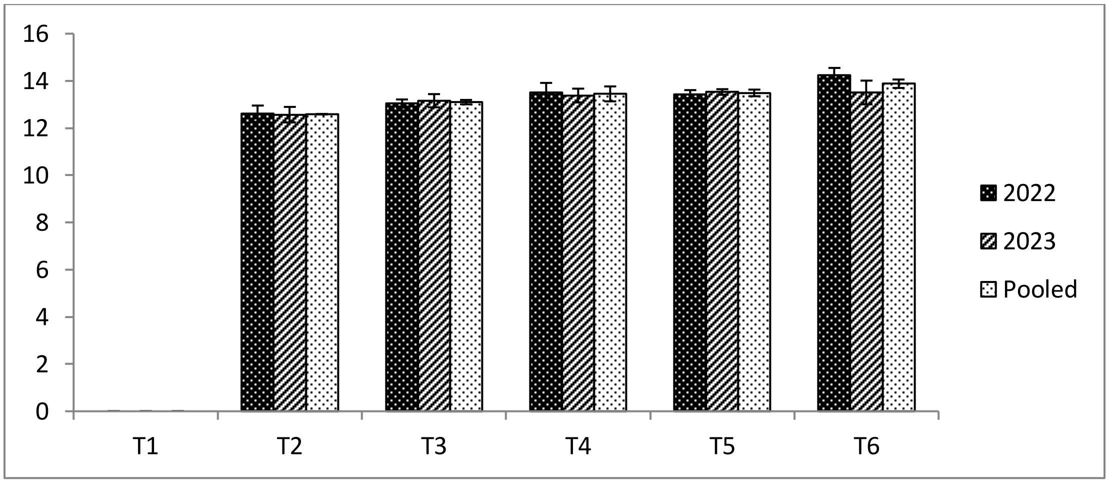

Fig. 4.67: Effect of full spectrum light on fruit volume under vertical farming system in indoor conditions

Various factors, such as genetics, environmental conditions and cultivation practices, can influence fruit volume in strawberries. Optimal light quality and intensity are influential factors in determining fruit size and volume under indoor cultivation of strawberries as exposure to AFSL ensures better photosynthetic activities, translocation of photosynthates and their accumulation in storage sites like fruits. Studies indicated that optimizing the light

Table 4.24: Effect of full spectrum light on yield parameters under vertical farming system in indoor conditions.

	Fruit set %			**Fruit volume (cm^3)**			**Average berry Weight (g)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	92.65 ± 0.682^{b}	92.40 ± 0.464^{b}	92.53 ± 0.564^{c}	12.61 ± 0.345^{b}	12.57 ± 0.328^{b}	12.59 ± 0.01^{b}	12.78 ± 0.407^{b}	13.16 ± 0.192^{b}	12.97 ± 0.289^{b}
T3	94.49 ± 0.817^{ab}	94.11 ± 0.112^{ab}	94.30 ± 0.464^{b}	13.04 ± 0.174^{b}	13.16 ± 0.280^{ab}	13.10 ± 0.093^{b}	15.13 ± 0.478^{a}	15.01 ± 0.414^{a}	15.07 ± 0.372^{a}
T4	92.94 ± 1.745^{b}	91.54 ± 0.157^{b}	92.24 ± 0.857^{c}	13.52 ± 0.394^{ab}	13.38 ± 0.292^{ab}	13.45 ± 0.316^{ab}	13.54 ± 0.205^{b}	13.71 ± 0.274^{b}	13.63 ± 0.086^{b}
T5	95.34 ± 0.702^{a}	95.52 ± 0.592^{a}	95.43 ± 0.420^{ab}	13.44 ± 0.169^{ab}	13.53 ± 0.119^{a}	13.49 ± 0.141^{ab}	14.38 ± 0.074^{ab}	14.63 ± 0.165^{a}	14.51 ± 0.101^{a}
T6	95.87 ± 1.119^{a}	95.80 ± 1.228^{a}	95.84 ± 0.056^{a}	14.24 ± 0.309^{a}	13.51 ± 0.502^{a}	13.88 ± 0.179^{a}	14.49 ± 0.289^{ab}	14.47 ± 0.152^{ab}	14.48 ± 0.088^{a}
SEM±	0.79	0.64	0.40	0.26	0.30	0.18	0.32	0.24	0.21
CD at 5%	2.48	2.02	1.25	0.82	0.93	0.56	1.00	0.77	0.67
CV%	1.73	1.42	0.88	4.02	4.66	2.79	4.68	3.56	3.15

*Plant dies after 40 days of planting

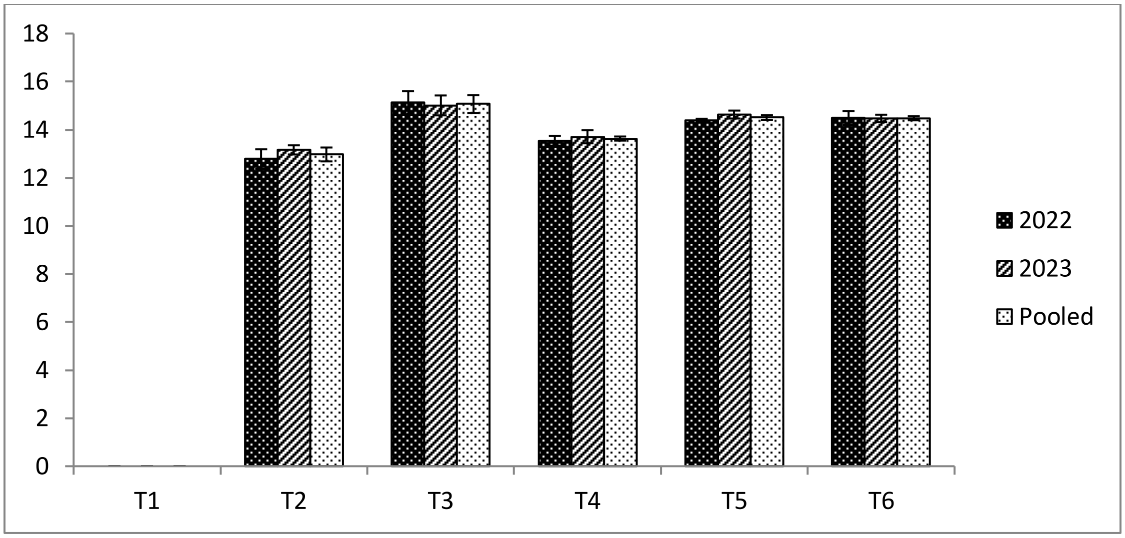

Fig. 4.68: Effect of full spectrum light on average berry weight under vertical farming system in indoor conditions

spectrum and intensity can contribute to increased fruit volume in strawberries cultivated under controlled environments (Samuolienė et al. 2010).

4.2.17 Average yield (g per plant)

The data pertaining to average yield of strawberry plants, presented in Table 4.25, confirms significant variation among different treatments grown under indoor conditions. In year 2022, 2023 and in pooled data, maximum average yield (238.12, 242.20 and 240.16g per plant) revealed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (240.24, 239.93 and 240.08g per plant) and T6 (full spectrum light (8 hours) + natural light + second level) (222.26, 220.29 and 221.27g per plant) while minimum average yield (178.75, 176.88 and 177.82g per plant) observed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (197.09, 198.17 and 197.63g per plant). Treatment T3 and T5 were at par in year 2022, 2023 and in pooled data.

4.2.18 Estimated Yield (Kg per 1000sqm)

In Table 4.25, highest estimated yield (4807.20, 4889.55 and 4848.37Kg per 1000sqm) revealed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (4850.00, 4843.82 and 4846.91Kg per 1000sqm) and T6 (full spectrum light (8 hours) + natural light + second level) (4487.12, 4447.24 and 4467.18Kg per 1000sqm) in year 2022, 2023 and in pooled data. However, the lowest (3608.70, 3570.95 and 3589.82Kg per 1000sqm) estimated yield observed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (3978.90, 4000.81 and 3989.85Kg per 1000sqm) in year 2022. T3 and T5 were at par in year 2022, 2023 and in pooled data.

The average berry weight in T_3 (15.07g/plant) was superior in comparison to T_5, T_6 and T_4. Moreover, average yield of strawberry also increased under full spectrum light in which T_5 (240.16g/plant) where 6 hours light provided was superior than other treatments. The average yield of T_3 is also near about the T_5 which was followed by treatment T_4 and T_6 where 8 hours of light was provided. The maximum estimated yield was observed in treatment T_5 (4848.37kg per 1000sqm) while T_2 had the minimum estimated yield (3589.82kg per 1000sqm) respectively. The average berry weight and fruit yield of strawberries grown indoors can be affected by the length of full spectrum light in a vertical farming system. Increased photosynthesis, nutrient uptake and general plant growth can be facilitated by longer periods of full-spectrum light exposure. This may result in larger average berry weights. Additionally, by encouraging flower pollination and fruit set, a longer period of full spectrum light can also help to increase fruit yield (Tang et al. 2020; Stuemky and Uchanski 2020). The artificial full-spectrum light has the potential to enhance photosynthesis and overall plant vitality under indoor farming, which could result in larger berry sizes (Zheng et al. 2021).

Full spectrum light, provided by technologies like full spectrum LEDs, can optimize plant growth and development, potentially leading to increased yields in vertical farming systems. Research has demonstrated the beneficial impact of AFSL on plant yield in various crops including strawberries under greenhouse (Touliatos et al. 2016; Fangfang et al. 2021).

Table 4.25: Effect of full spectrum light on yield under vertical farming system in indoor conditions.

	Average yield (g per plant)			**Estimated Yield (kg per 1000sqm)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	178.75 ± 3.231^{b}	176.88 ± 6.134^{d}	177.82 ± 4.152^{d}	3608.70 ± 65.250^{b}	3570.95 ± 123.860^{d}	3589.82 ± 83.870^{d}
T3	240.24 ± 5.457^{a}	239.93 ± 3.093^{a}	240.08 ± 2.027^{a}	4850.00 ± 110.140^{a}	4843.82 ± 62.420^{a}	4846.91 ± 40.930^{a}
T4	197.09 ± 7.608^{b}	198.17 ± 7.242^{c}	197.63 ± 0.348^{c}	3978.90 ± 153.600^{b}	4000.81 ± 146.220^{c}	3989.85 ± 7.120^{c}
T5	238.12 ± 8.471^{a}	242.20 ± 1.514^{a}	240.16 ± 3.493^{a}	4807.20 ± 171.05^{a}	4889.55 ± 30.570^{a}	4848.37 ± 70.520^{a}
T6	222.26 ± 5.554^{a}	220.29 ± 3.683^{b}	221.27 ± 3.338^{b}	4487.12 ± 112.10^{a}	4447.24 ± 74.380^{b}	4467.18 ± 67.360^{b}
SEM±	5.93	4.40	2.93	119.66	88.88	59.17
CD at 5%	18.68	13.87	9.24	381.92	283.68	188.86
CV%	5.72	4.25	2.83	5.72	4.25	2.83

*Plant dies after 40 days of planting

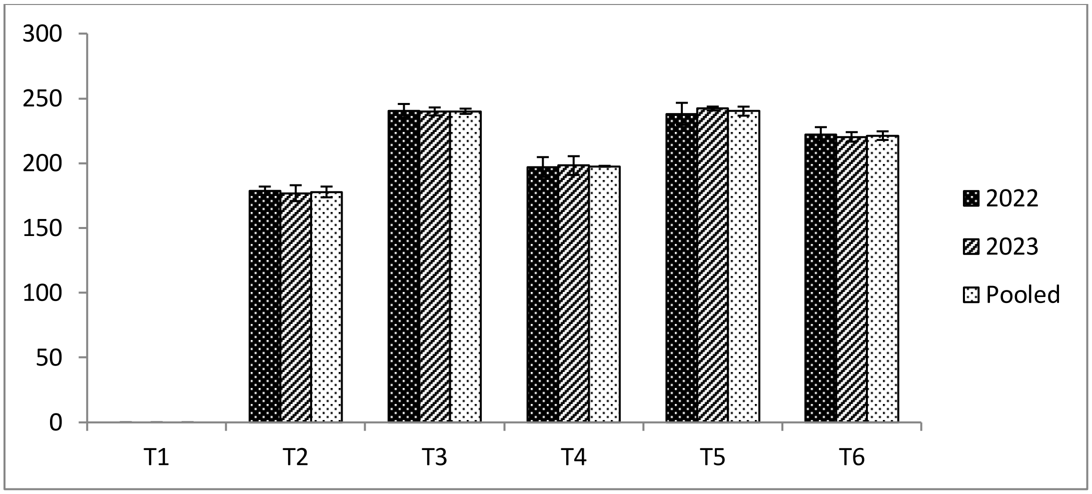

Fig. 4.69: Effect of full spectrum light on average yield per plant under vertical farming system in indoor conditions

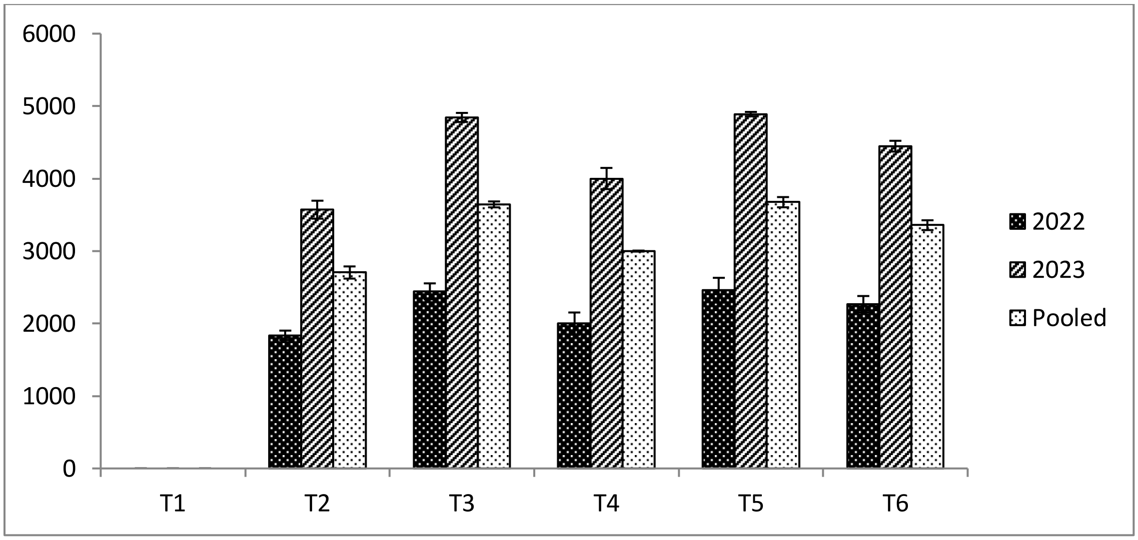

Fig.4.70: Effect of full spectrum light on estimated yield under vertical farming system in indoor conditions

4.9.19 TSS (˚Brix)

As shown in Table 4.26, maximum (10.07, 10.08 and 10.08 ˚Brix) total soluble solids were observed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (10.04, 10.06 and 10.05 ˚Brix) and T6 (full spectrum light (8 hours) + natural light + second level) (10.03, 10.03 and 10.03 ˚Brix) in year 2022, 2023 and in pooled data. Further, lowest (9.92, 9.99 and 9.95 ˚Brix) total soluble solids found in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (9.98, 10.01 and 9.99 ˚Brix). In 2022, 2023 and in pooled data, treatment T3 and T5 were at par.

4.2.20 Titrable acidity (%)

In 2022, 2023 and in pooled data, highest (0.73%, 0.72% and 0.72%) titrable acidity observed in T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (0.71%, 0.70% and 0.71%) and T6 (full spectrum light (8 hours) + natural light + second level) (0.69%, 0.69% and 0.69%) whiles lowest titrable acidity (0.66%, 0.65% and 0.66%) noticed in treatment T3 (full spectrum light (6 hours) + natural light + second level) and T5 (full spectrum light (6 hours) + natural light +third level) (0.67%, 0.64% and 0.66%). In 2022, 2023 and in pooled data treatment T2 and T4 were at par (Table 4.26).

4.2.21 Vitamin C (mg/100g)

Highest Vitamin C content (50.60, 52.15 and 51.38 mg/100g) observed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (50.20, 51.91 and 51.06mg/100g) and T6 (full spectrum light (8 hours) + natural light + second level) (51.12, 50.86 and 50.99 mg/100g) in year 2022, 2023 and in pooled data. Moreover, lowest (48.88, 49.66 and 49.27 mg/100g) vitamin C content noticed in treatment T4 (full spectrum light (8 hours) + natural light + first level) followed by T2 (full spectrum light (4 hours) + natural light + third level) (49.99, 49.30 and 49.64 mg/100g) in year 2022, 2023 and in pooled data. Treatment T3, T5 and T6 were at par in year 2022, 2023 and in pooled data (Table 4.26).

The total soluble solids of strawberry grown under indoor condition with additional supply of light was significantly affected by the levels of verticals and the duration of full spectrum light provided. The plants subjected with full spectrum light with 6 hours have grown better when plants were at third level (T_5) and was superior in comparison to T_3, T_4 and T_6. Similarly, the titrable acidity of the plants that have been exposed to full spectrum light for 4 hours have maximum titrable acidity when plants were at third level (T_2) and were superior in comparison to other treatments. On the other hand, plants subjected with full spectrum light with 6 hours have grown better when plants were at second level (T_3) and superior in comparison to other treatments. Thus, TSS, titrable solids and ascorbic acid (Vit C) of strawberries were suggestively influenced by the length of the full spectrum light in an indoor vertical farming system where longer exposure times to full spectrum light enhanced the quality of fruit.

It was reported that photosynthetic production under LED supplemental lighting was higher which resulted into increased TSS (Maeda and Ito, 2020 and Jiang *et al.,* 2023). Wysocki et al. (2017) had reported increase in contents of extract sugar, anthocyanin, polyphenols, vitamin C. Numerous variables affect TSS, TA and Vit C, including the soils fertility, the strawberry variety, the age of the plantation, the time of harvest, the cultivation method (organic, conventional, integrated, hydroponic, tunnel, or in the open field) and the storage conditions following harvest (El-Beltagi *et al.,* 2022). It was also found that in 3-tiered vertical system highest TSS was present and it performs better than other system (Madhavi *et al.,*2023). Organic strawberries frequently have higher vitamin C content than conventional fruits (Taghavi *et al.,*2019 and Newerli-Guz *et al.,* 2023). Single-spectral red or blue LEDs increased the accumulation of primary and secondary plant metabolites (such as soluble sugars, starch, vitamin-C, soluble protein and polyphenol) when compared to white light (Singh, 2022).

Table 4.26: Effect of full spectrum light on biochemical traits under vertical farming system in indoor conditions.

	TSS (^{0}Brix)			**Titrable Acidity (%)**			**Vitamin C (mg/100g)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	9.92 ± 0.011^{b}	9.99 ± 0.022^{b}	9.95 ± 0.018^{d}	0.73 ± 0.009^{a}	0.72 ± 0.003^{a}	0.72 ± 0.003^{a}	49.99 ± 0.080^{b}	49.30 ± 0.499^{b}	49.64 ± 0.281^{b}
T3	10.04 ± 0.014^{a}	10.06 ± 0.008^{ab}	10.05 ± 0.004^{ab}	0.66 ± 0.007^{c}	0.65 ± 0.006^{b}	0.66 ± 0.006^{c}	50.20 ± 0.212^{a}	51.91 ± 0.727^{a}	51.06 ± 0.331^{a}
T4	9.98 ± 0.030^{b}	10.01 ± 0.024^{b}	9.99 ± 0.013^{c}	0.71 ± 0.009^{ab}	0.70 ± 0.006^{a}	0.71 ± 0.006^{ab}	48.88 ± 0.080^{c}	49.66 ± 0.442^{b}	49.27 ± 0.183^{b}
T5	10.07 ± 0.005^{a}	10.08 ± 0.011^{a}	10.08 ± 0.006^{a}	0.67 ± 0.012^{bc}	0.64 ± 0.003^{b}	0.66 ± 0.006^{c}	50.60 ± 0.503^{ab}	52.15 ± 0.092^{a}	51.38 ± 0.213^{a}
T6	10.03 ± 0.015^{a}	10.03 ± 0.006^{b}	10.03 ± 0.006^{b}	0.69 ± 0.006^{b}	0.69 ± 0.019^{a}	0.69 ± 0.012^{b}	51.12 ± 0.390^{a}	50.86 ± 0.353^{ab}	50.99 ± 0.283^{a}
SEM±	0.02	0.01	0.01	0.01	0.01	0.01	0.30	0.43	0.25
CD at 5%	0.05	0.04	0.03	0.02	0.03	0.02	0.95	1.35	0.78
CV%	0.34	0.27	0.19	2.29	2.57	1.90	1.25	1.75	1.01

*Plant dies after 40 days of planting

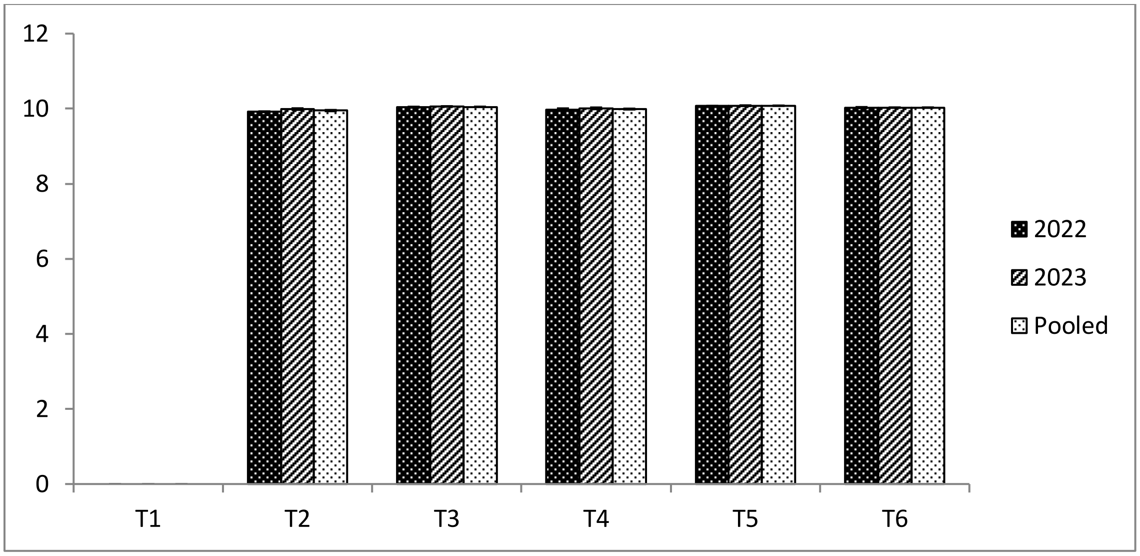

Fig. 4.71: Effect of full spectrum light on TSS under vertical farming system in indoor conditions

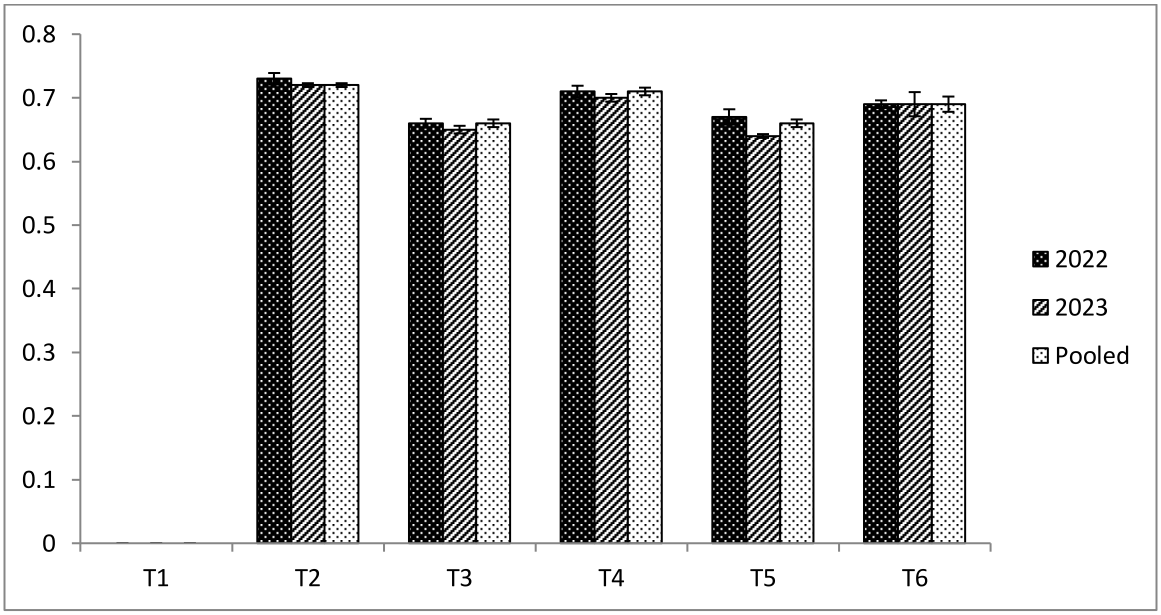

Fig. 4.72: Effect of full spectrum light on titrable acidity under vertical farming system in indoor conditions

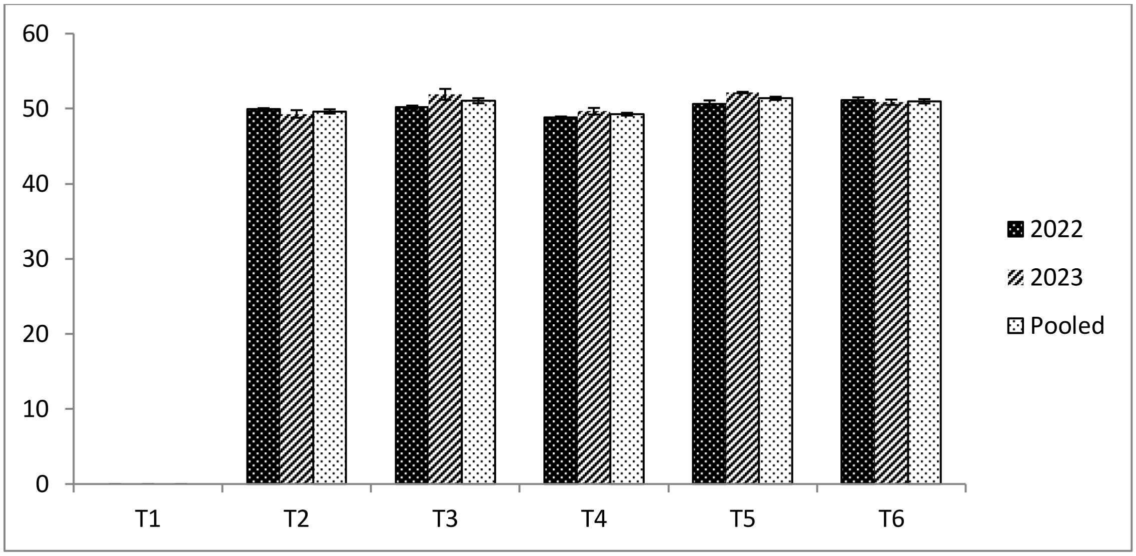

Fig. 4.73: Effect of full spectrum light on vitamin C under vertical farming system in indoor conditions

4.2.22 Reducing sugar (%)

Table 4.27, represents the highest reducing sugar (2.74%, 2.76% and 2.75%) in T3 (full spectrum light (6 hours) + natural light + second level) followed by T5 combination of full spectrum light (6 hours) + natural light +third level) (2.75%, 2.74% and 2.75%) and T4 (full spectrum light (8 hours) + natural light + first level) (2.73%, 2.73% and 2.73%) while lowest reducing sugar content (2.70%, 2.70% and 2.70%) noticed in T2 (full spectrum light (4 hours) + natural light + third level) and T6 (full spectrum light (8 hours) + natural light + second level) (2.72%, 2.71% and 2.72%). In 2022, 2023 and in pooled data, treatment T3 and T5 were at par.

4.2.23 Non-reducing sugar (%)

Highest non-reducing sugar (6.46%, 6.47% and 6.47%) was observed in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) in year 2022, 2023 and in pooled data followed by T3 (full spectrum light (6 hours) + natural light + second level) (6.44%, 6.46% and 6.45%) and T6 (full spectrum light (8 hours) + natural light + second level) (6.42%, 6.43% and 6.43%). However lowest (6.38%, 6.39% and 6.38%) non reducing sugar noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (6.41%, 6.42% and 6.41%) in year 2022, 2023 and in pooled data. Treatment T3 and T5 were at par in 2022, 2023 and in pooled data (Table 4.27).

4.2.24 Total sugars (%)

In Table 4.27, highest total sugars content (9.21%, 9.21% and 9.21%) was found in treatment T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (9.19%, 9.21% and 9.20%) in year 2022, 2023 and in pooled data, while lowest total sugar content (9.08%, 9.09% and 9.09%) revealed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (9.14%, 9.15% and 9.14%) and T6 (full spectrum light (8 hours) + natural light + second level) (9.15%, 9.13% and 9.14%). In year 2022, 2023 and pooled data treatment T3 and T5 were at par.

The treatments significantly affected the reducing sugar, non-reducing sugar and total sugars which supports dependence of sugars on light duration and levels of verticals under indoor condition. The plants subjected with 6 hours of full spectrum light have more content of reducing sugar at the second level (T_3), non-reducing sugar and total sugars at third level (T_5) in comparison to T2, T_4 and T_6. In T_1 after 45 days the plants die due to insufficient light. The duration of full spectrum light in a vertical farming system can significantly affect the sugar content in strawberries.

Particularly during the late harvest season, the supplemental light significantly raised the strawberry fruits concentration of glucose, fructose and total sugar (Xu *et al.,* 2023). As with strawberry fruit weight, supplement light increased accumulation of total sugar, sucrose and reducing sugar. This may be due to the large input of photosynthetic

Table 4.27: Effect of full spectrum light on sugars under vertical farming system in indoor conditions.

	Reducing sugar (%)			**Non Reducing Sugar (%)**			**Total Sugars (%)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	2.70 ± 0.012^{b}	2.70 ± 0.009^{c}	2.70 ± 0.003^{b}	6.38 ± 0.009^{c}	6.39 ± 0.009^{c}	6.38 ± 0.009^{c}	9.08 ± 0.020^{c}	9.09 ± 0.006^{c}	9.09 ± 0.009^{c}
T3	2.74 ± 0.024^{ab}	2.76 ± 0.003^{a}	2.75 ± 0.009^{a}	6.44 ± 0.003^{ab}	6.46 ± 0.009^{ab}	6.45 ± 0.006^{ab}	9.19 ± 0.022^{ab}	9.21 ± 0.009^{a}	9.20 ± 0.008^{a}
T4	2.73 ± 0.015^{ab}	2.73 ± 0.009^{b}	2.73 ± 0.003^{ab}	6.41 ± 0.006^{b}	6.42 ± 0.003^{bc}	6.41 ± 0.003^{b}	9.14 ± 0.009^{b}	9.15 ± 0.006^{b}	9.14 ± 0.003^{b}
T5	2.75 ± 0.003^{a}	2.74 ± 0.006^{ab}	2.75 ± 0^{ab}	6.46 ± 0.011^{a}	6.47 ± 0.012^{a}	6.47 ± 0.012^{a}	9.21 ± 0.015^{a}	9.21 ± 0.007^{a}	9.21 ± 0.008^{a}
T6	2.72 ± 0.026^{ab}	2.71 ± 0.003^{bc}	2.72 ± 0.012^{b}	6.42 ± 0.009^{b}	6.43 ± 0.009^{b}	6.43 ± 0.009^{b}	9.15 ± 0.018^{b}	9.13 ± 0.006^{b}	9.14 ± 0.006^{b}
SEM±	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CD=5%	0.04	0.02	0.02	0.02	0.03	0.02	0.05	0.02	0.03
CV%	1.01	0.45	0.48	0.21	0.27	0.22	0.33	0.12	0.18

*Plant dies after 40 days of planting

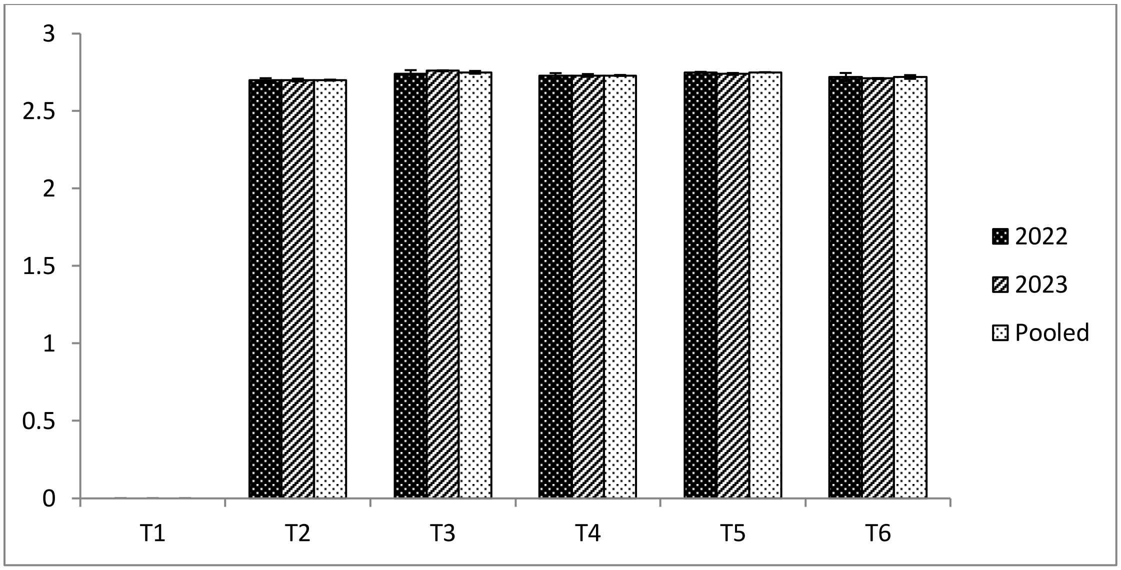

Fig. 4.74: Effect of full spectrum light on reducing sugar under vertical farming system in indoor conditions

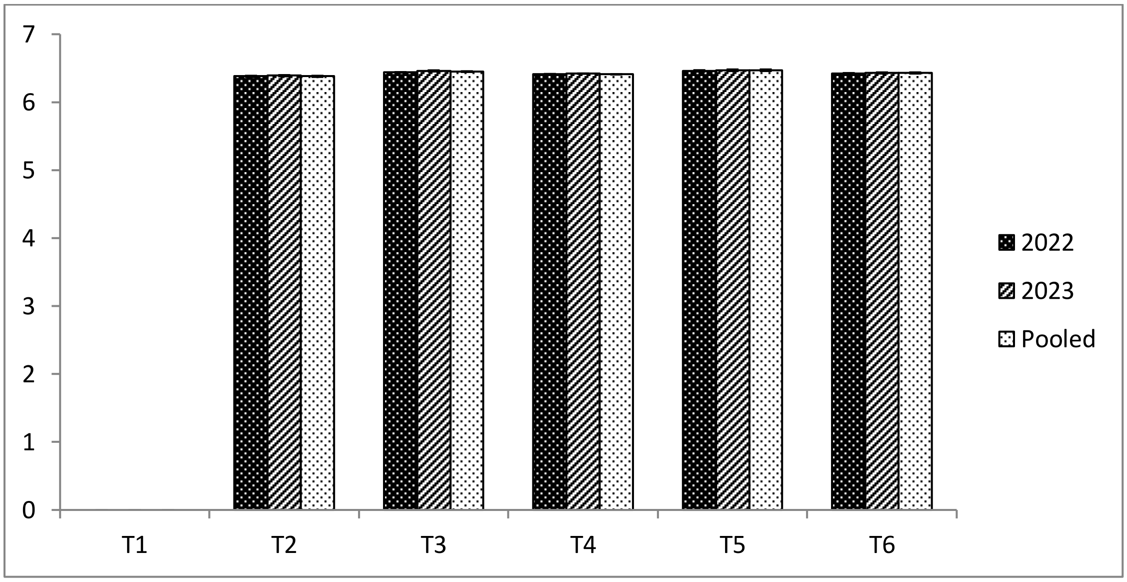

Fig. 4.75: Effect of full spectrum light on non-reducing sugar under vertical farming system in indoor conditions

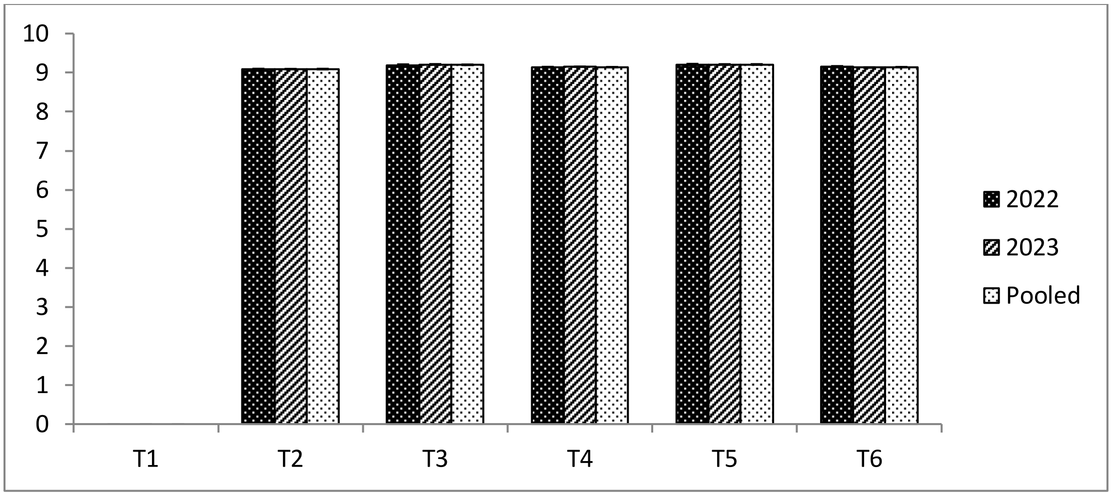

Fig. 4.76: Effect of full spectrum light on total sugars under vertical farming system in indoor conditions

products provided by the large leaves and high photosynthetic abilities under light (Peng *et al.,* 2020). Duration of light is also important for increasing and decreasing the total sugar content in the fruit (Abarca *et al.*,2022).

4.2.25 Antioxidant (%)

As shown in Table 4.28, highest antioxidant content (78.06%, 78.39% and 78.22%) observed in treatment T3 (full spectrum light (6 hours) + natural light + second level) followed by T5 combination of full spectrum light (6 hours) + natural light +third level) (77.84%, 77.80% and 77.82%) and T6 (full spectrum light (8 hours) + natural light + second level) (77.35%, 77.07% and 77.21%). However, lowest (75.90%, 75.28% and 75.59%) antioxidant content found in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (76.64%, 76.76% and 76.70%).

4.2.26 Flavonoids (mg QE per 100 g)

In Table 4.28, data shows that in 2022, 2023 and in pooled data highest flavonoids content (47.64, 47.84 and 47.74 mg QE per 100 g) present in T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (46.60, 47.23 and 46.92mg QE per 100 g) and T6 (full spectrum light (8 hours) + natural light + second level) (45.99, 46.48 and 46.23mg QE per 100 g) while lowest (44.49, 45.00 and 44.75mg QE per 100 g) flavonoids content noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (45.81, 45.68 and 45.74mg QE per 100 g). In 2023, T3 and T5 were at par.

4.2.27 Total Phenols (mg GAE per 100g)

In treatment T5 combination of full spectrum light (6 hours) + natural light +third level) highest phenols content (143.73, 143.44 and 143.59mg GAE per 100g) was observed in year 2022, 2023 and in pooled data followed by T6 (full spectrum light (8 hours) + natural light + second level) (143.27, 142.61 and 142.94mg GAE per 100g) and T3 (full spectrum light (6 hours) + natural light + second level) (142.37, 142.41 and 142.39mg GAE per 100g). Moreover, lowest phenols content (142.22, 142.36 and 142.29mg GAE per 100g) observed in T2 (full spectrum light (4 hours) + natural light + third level) and T4 (full spectrum light (8 hours) + natural light + first level) (142.30, 142.35 and 142.32mg GAE per 100g) in year 2022, 2023 and in pooled data. Treatment T5 and T6 were at par in year 2022, 2023 and in pooled data (Table 4.28).

The antioxidant content, flavonoids and total phenols content of strawberry grown under indoor condition with additional supply of light was significantly affected by the levels of verticals and the duration of full spectrum light provided. The plants subjected with full spectrum light with 6 hours have more content when plants were at second level (T_3) in antioxidants while in flavonoids and phenols when plants were at third level (T_5) performs better and was superior in comparison to T_2, T_4 and T_6. Thus, the antioxidant , flavonoid and phenols content of strawberries were significantly influenced by the length of the full spectrum light in an indoor vertical farming system where longer exposure times to full spectrum light. This could be associated with the efficient utilization of nutrients provided to the plants and balanced metabolic processes under higher lux value.

It was found that to control fruit maturation time as well as to increase the sugar, flavonoids content and antioxidant contents of fruits, a voluntary adoption of LED light wavelength would be necessary (Choi Hyogil *et al.*,2013; Sharma *et al.*, 2019; Lauria *et al.*, 2021). Additionally, it was studied that contents of total flavonoids, phenolics, anthocyanins, proanthocyanidins and total antioxidant capacities treated with supplement light helps to kept the fruit at stable levels throughout the entire storage (Zhang *et al.*,2022 and Jiang *et al.*, 2023). Use of LED increases the accumulations of flavonoids in strawberry plant if flavonoids content increases than it will also enhance the production of antioxidant as well as anthocyanin content (Sharma *et al.*, 2019). LED also helps to reduce the antioxidant scavenging capacity due to which phenols, flavonoids and anthocyanin content in fruit will increase and also helps to reduce the damage caused by reactive oxygen species (Abarca *et al.*,2022).

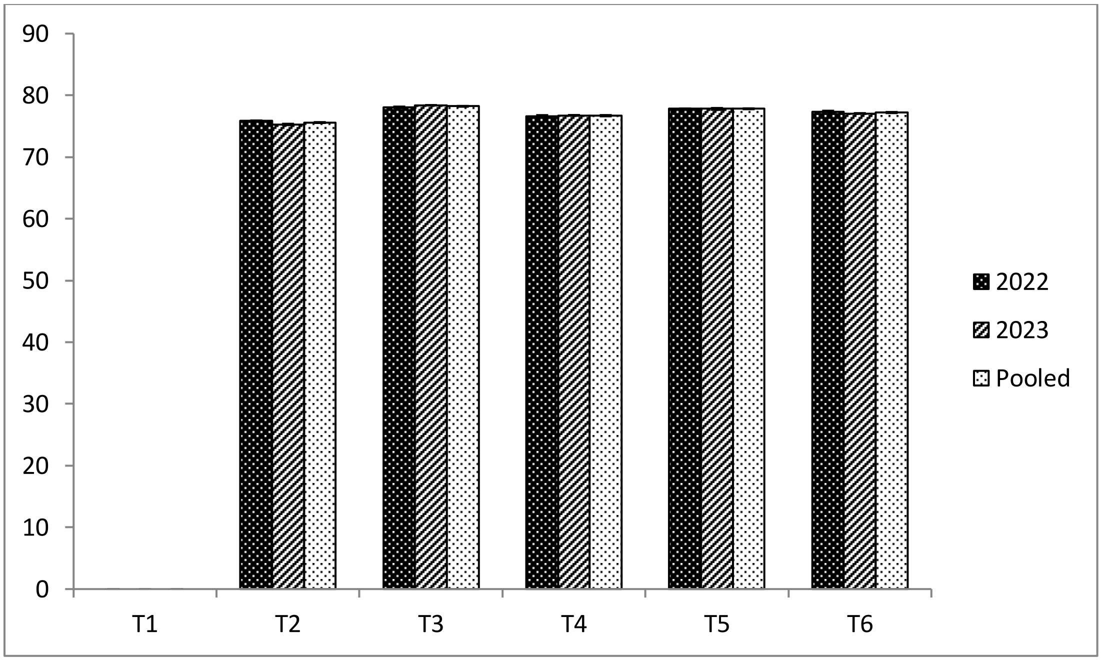

Fig. 4.77: Effect of full spectrum light on antioxidants under vertical farming system in indoor conditions

Table 4.28: Effect of full spectrum light on biochemical traits under vertical farming system in indoor conditions.

	Antioxidant (%)			**Flavonoids (mg QE per 100g)**			**Total phenols (mg GAE per 100g)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0 ± 0	0 ± 0	0.00 ± 0
T2	75.90 ± 0.030^{e}	75.28 ± 0.116^{e}	75.59 ± 0.073^{e}	44.49 ± 0.100^{d}	45.00 ± 0.056^{d}	44.75 ± 0.028^{e}	142.22 ± 0.213^{b}	142.36 ± 0.317^{b}	142.29 ± 0.252^{b}
T3	78.06 ± 0.118^{a}	78.39 ± 0.026^{a}	78.22 ± 0.070^{a}	46.60 ± 0.314^{b}	47.23 ± 0.067^{a}	46.92 ± 0.188^{b}	142.37 ± 0.358^{b}	142.41 ± 0.695^{b}	142.39 ± 0.485^{b}
T4	76.64 ± 0.156^{d}	76.76 ± 0.060^{d}	76.70 ± 0.103^{d}	45.81 ± 0.133^{c}	45.68 ± 0.306^{c}	45.74 ± 0.113^{d}	142.30 ± 0.282^{b}	142.35 ± 0.242^{b}	142.32 ± 0.215^{b}
T5	77.84 ± 0.035^{a}	77.80 ± 0.154^{b}	77.82 ± 0.073^{b}	47.64 ± 0.173^{a}	47.84 ± 0.133^{a}	47.74 ± 0.151^{a}	143.73 ± 0.423^{a}	143.44 ± 0.264^{a}	143.59 ± 0.319^{a}
T6	77.35 ± 0.158^{b}	77.07 ± 0.051^{c}	77.21 ± 0.095^{c}	45.99 ± 0.187^{c}	46.48 ± 0.175^{b}	46.23 ± 0.149^{c}	143.27 ± 0.402^{a}	142.61 ± 0.494^{ab}	142.94 ± 0.427^{ab}
SEM±	0.10	0.09	0.08	0.17	0.17	0.13	0.25	0.28	0.22
CD=5%	0.32	0.29	0.24	0.53	0.53	0.42	0.78	0.88	0.69
CV%	0.27	0.25	0.21	0.76	0.75	0.60	0.36	0.41	0.32

*Plant dies after 40 days of planting

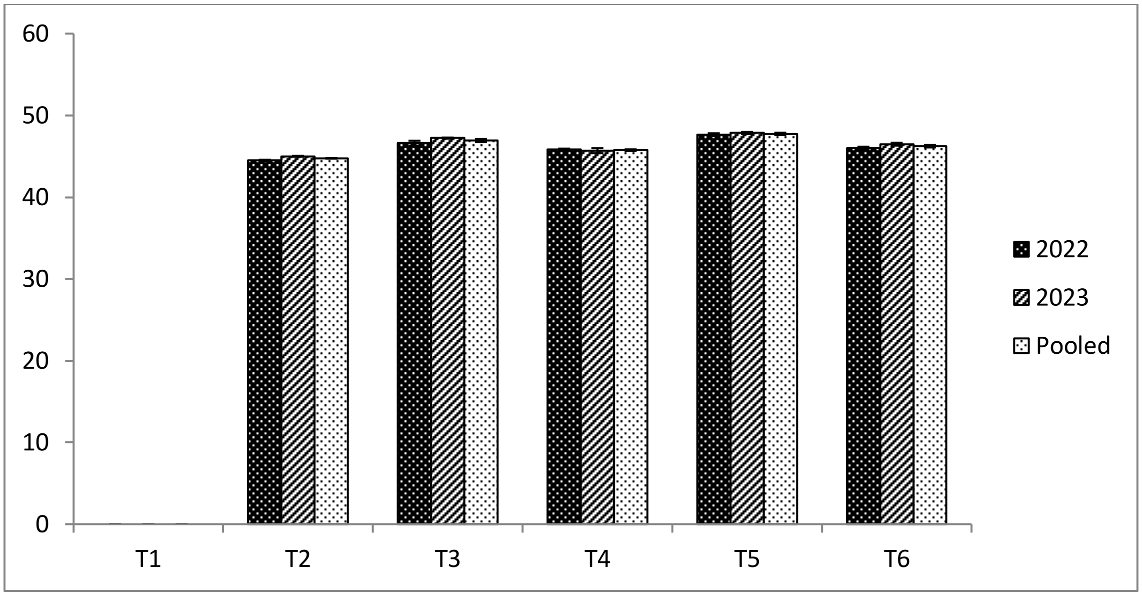

Fig. 4.78: Effect of full spectrum light on flavonoids under vertical farming system in indoor conditions

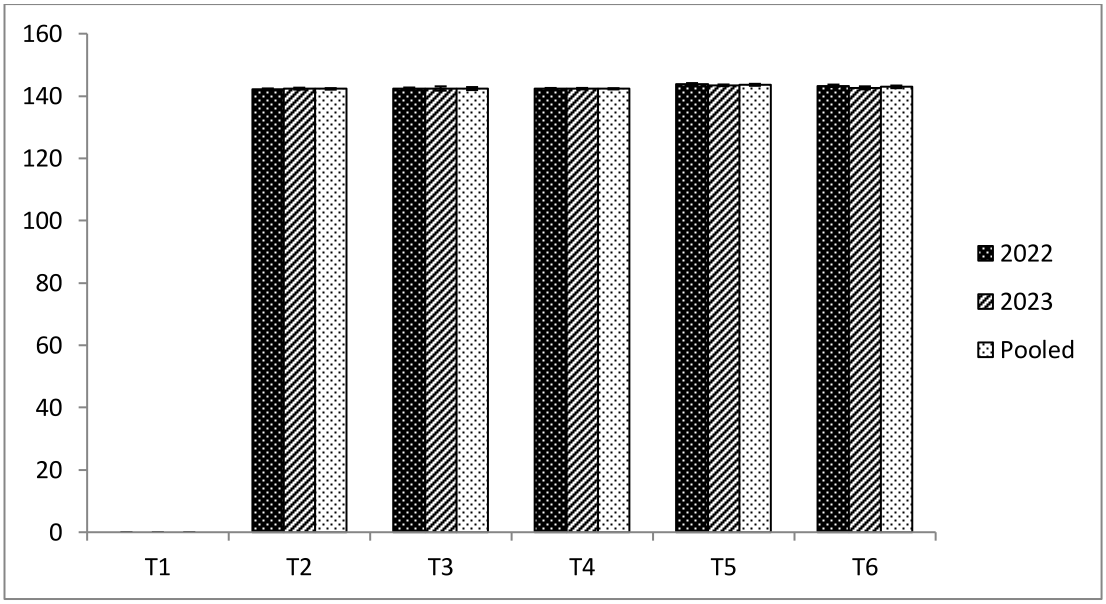

Fig. 4.79: Effect of full spectrum light on total phenols under vertical farming system in indoor conditions

4.2.28 Chlorophyll-a (mg per g)

Maximum (1.18, 1.18 and 1.18mg per g) chlorophyll a content in strawberry plant was estimated in treatment T5 (full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (1.17, 1.14 and 1.16mg per g) and T6 (full spectrum light (8 hours) + natural light + second level) (1.16, 1.16 and 1.16mg per g) in year 2022, 2023 and pooled data while lowest content (1.09, 1.10 and 1.09mg per g) noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) and T4 (full spectrum light (8 hours) + natural light + first level) (1.12, 1.13 and 1.12mg per g). Moreover, T1 plants died after 45 days of planting. Treatment T5 and T6 were at par in 2022, 2023 and in pooled data (Table 4.29).

4.2.29 Chlorophyll-b (mg per g)

The data pertaining to chl b of strawberry plants, presented in Table 4.29, confirms significant variation among different treatments grown under indoor conditions. In 2022, 2023 and in pooled data highest chlorophyll b content) (2.06, 2.07 and 2.07mg per g) observed in T5 combination of full spectrum light (6 hours) + natural light +third level followed by T3 (full spectrum light (6 hours) + natural light + second level) (2.05, 2.07 and 2.06 mg per g) and T6 (full spectrum light (8 hours) + natural light + second level) (2.07, 2.05 and 2.06mg per g). However, lowest (1.99, 1.98 and 1.99mg per g) content found in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (2.01, 2.03 and 2.02mg per g). Plants of T1 were not survived more than 45 days after planting. T3, T5 and T6 were at par in year 2022, 2023 and in pooled data.

4.2. 30 Total Chlorophyll (mg per g)

Table 4.29, shows the recorded data of total chlorophyll content in year 2022, 2023 and in pooled data, highest total chlorophyll content (4.17, 4.19 and 4.18mg per g) found in T5 combination of full spectrum light (6 hours) + natural light +third level) followed by T3 (full spectrum light (6 hours) + natural light + second level) (4.17, 4.17 and 4.17mg per g) and T6 (full spectrum light (8 hours) + natural light + second level) (4.15, 4.13 and 4.14mg per g) while lowest total chlorophyll content (4.10, 4.09 and 4.10mg per g) found in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (4.13, 4.13 and 4.13mg per g). In 2022 and 2023 as well as in pooled data T3, T5 and T6 were at par.

In case of indoor condition, irrespective to growing level, the treatments where 6 hours full spectrum light (T_3 and T_5) was provided were at par to the treatments with 8 hours of full spectrum light at the second level (T_6) for the chlorophyll content. However, these were significantly superior to other treatments (T_2 and T_4). Plants grown under indoor condition were significantly influenced by additional light hours which could be due to lower availability of natural light under a dark condition so light might have become the limiting factor for the activation of chlorophyll synthesis and stimulation of the photosynthetic process.

The relative abundance of chlorophyll-a and chlorophyll-b is a light-dependent phenomenon. Under sufficient light intensity the relative abundance of chlorophyll-a is 3 to 4 times higher than the chlorophyll-b while under the dark condition, the relative abundance of chlorophyll-b is increased (Evans and Von Caemmerer, 2010-2018). In the current study, the availability of additional light had been reported to affect the chlorophyll-a content more prominently in comparison to chlorophyll-b which can be justified by the significant correlation of chlorophyll-a with lux reading which was non-significant between chlorophyll-b and lux reading. Similar results were noticed in the research study of many researchers (Choi *et al.,* 2015; Costa *et al.,* 2012; Xu *et al.,* 2023). Compared to monochromatic light sources, full-spectrum light often encourages higher chlorophyll concentration in plants. Full-spectrum light, which has a well-balanced spectrum of wavelengths, allows diverse chlorophyll pigments, including chlorophyll a and chlorophyll b, to absorb light at their maximum efficiency (Bantis *et al.,* 2018). The plants' general development and ability to perform photosynthetically can both benefit from this higher chlorophyll content.

Table 4.29: Effect of full spectrum light on photosynthetic activities under vertical farming system in indoor conditions.

	Chlorophyll a (mg per g)			**Chlorophyll b (mg per g)**			**Total Chlorophyll (mg per g)**		
Average yield	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0 ± 0	0.00 ± 0	0.00 ± 0
T2	1.09 ± 0.006^{c}	1.10 ± 0.009^{c}	1.09 ± 0.003^{c}	1.99 ± 0.022^{b}	1.98 ± 0.006^{b}	1.98 ± 0.012^{c}	4.10 ± 0.009^{c}	4.09 ± 0.013^{c}	4.10 ± 0.009^{c}
T3	1.17 ± 0.012^{a}	1.14 ± 0.009^{b}	1.16 ± 0.01^{a}	2.05 ± 0.007^{ab}	2.07 ± 0.012^{a}	2.06 ± 0.006^{a}	4.17 ± 0.007^{a}	4.17 ± 0.009^{a}	4.17 ± 0.006^{a}
T4	1.12 ± 0.006^{b}	1.13 ± 0.003^{b}	1.12 ± 0.003^{b}	2.01 ± 0.034^{ab}	2.03 ± 0.04^{ab}	2.02 ± 0.012^{b}	4.13 ± 0.009^{b}	4.13 ± 0.007^{b}	4.13 ± 0.009^{b}
T5	1.18 ± 0.006^{a}	1.18 ± 0.007^{a}	1.18 ± 0.006^{a}	2.06 ± 0.003^{a}	2.07 ± 0.003^{a}	2.07 ± 0^{a}	4.17 ± 0.006^{a}	4.19 ± 0.007^{a}	4.18 ± 0.006^{a}
T6	1.16 ± 0.009^{a}	1.16 ± 0.007^{ab}	1.16 ± 0.007^{a}	2.07 ± 0.006^{a}	2.05 ± 0.006^{a}	2.06 ± 0^{a}	4.15 ± 0.006^{ab}	4.13 ± 0.009^{b}	4.14 ± 0.007^{b}
SEM±	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01
CD at 5%	0.02	0.02	0.02	0.06	0.06	0.03	0.02	0.02	0.02
CV%	1.37	1.12	1.09	1.86	1.85	0.83	0.34	0.38	0.33

*Plant dies after 40 days of planting

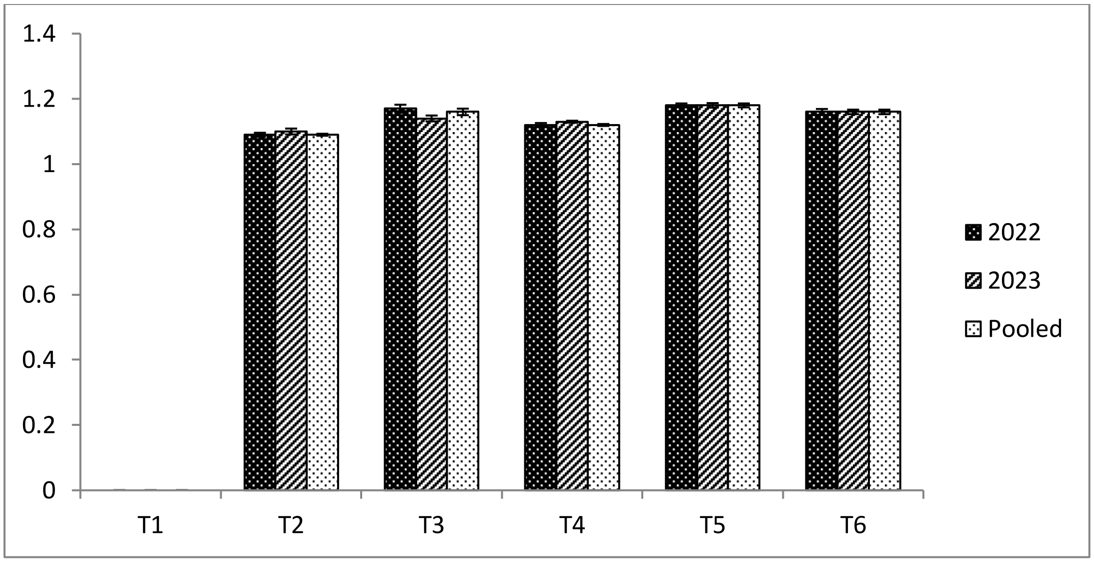

Fig. 4.80: Effect of full spectrum light on chlorophyll a under vertical farming system in indoor conditions

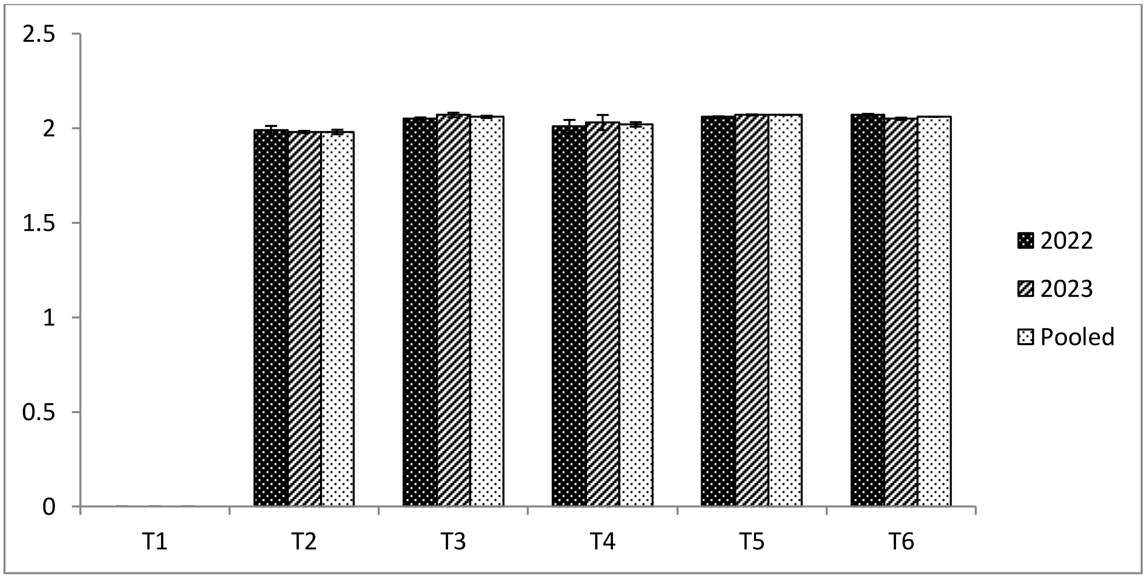

Fig. 4.81: Effect of full spectrum light on chlorophyll b under vertical farming system in indoor conditions

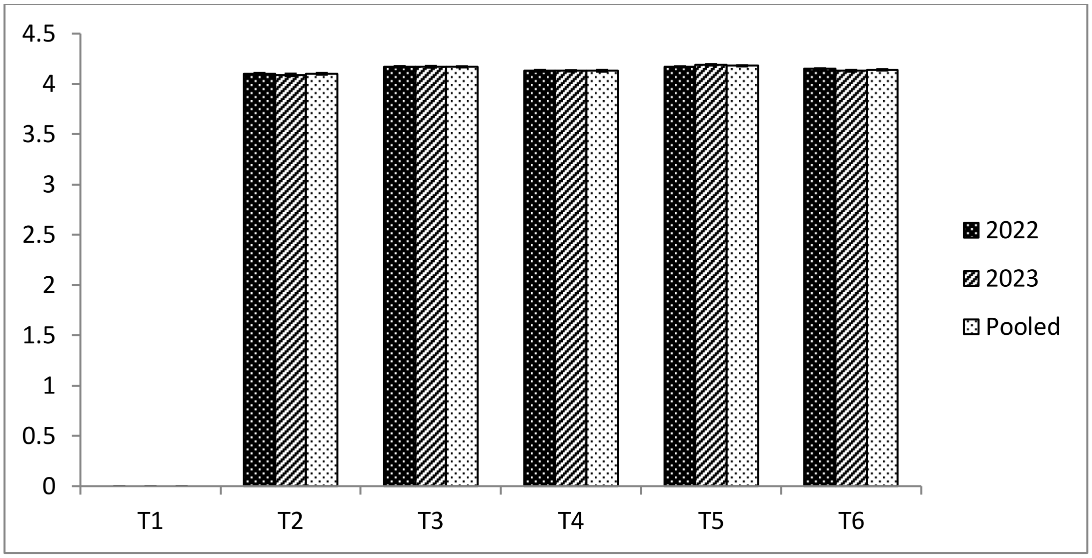

Fig. 4.82: Effect of full spectrum light on total chlorophyll under vertical farming system in indoor conditions

4.2.31 Total Anthocyanin Content (mg per 100g)

Table 4.30, shows the recorded data of Total anthocyanin content and confirms significant variation along with different treatments grown under indoor conditions. The highest content (54.14, 54.21 and 54.18mg per 100g) was observed in treatment T5 combination of full spectrum light (6 hours) + natural light + third level) in year 2022, 2023 and in pooled data followed by T6 (full spectrum light (8 hours) + natural light + second level) (52.66, 52.99 and 52.83mg per 100g) and T3 (full spectrum light (6 hours) + natural light + second level) (53.34, 52.53 and 52.93mg per 100g) while lowest (50.67, 50.42 and 50.54mg per 100g) content was noticed in treatment T2 (full spectrum light (4 hours) + natural light + third level) followed by T4 (full spectrum light (8 hours) + natural light + first level) (52.05, 51.40 and 51.73mg per 100g). Although, plants of T1 treatment were not survived after 45 days of planting.

In indoor conditions T_3 and T_5 (6 hours full spectrum light is provided at second and third level) were superior to T_6 and T_4. Strawberries (*Fragaria* × *ananassa* Duch.), among other fruits, have vibrant red, purple and blue hues due to anthocyanins, which are natural pigments. Anthocyanins are known for their potential health benefits, such as antioxidant and anti-inflammatory properties, in addition to their aesthetic appeal. It has been researched whether full spectrum light, which closely resembles natural sunlight, could be used to increase the anthocyanin content of different crops. Understanding how full spectrum light affects the anthocyanin content of strawberries will help growers make the most of the fruits aesthetic appeal and potential health benefits (Zhang *et al.,* 2018). Anthocyanin also helps in ripening of strawberry and helps to increase its production or yield (Song et al. 2015; Sharma *et al.,* 2019). Wysocki *et al.,* (2017) had also reported increase in contents of extract sugar, anthocyanins, polyphenols, vitamin C.

4.2.32 Total Carotenoids Content (mg per g)

Total carotenoids content data for strawberry plants under experiment is presented in Table 4.30, it was observed that treatment T5 combination of full spectrum light (6 hours) + natural light +third level) has highest carotenoids content (0.92, 0.95 and 0.94mg per g) followed by T3 (full spectrum light (6 hours) + natural light + second level) (0.93, 0.92 and 0.93mg per g) and T6 (full spectrum light (8 hours) + natural light + second level) (0.94, 0.93 and 0.93mg per g) in year 2022, 2023 and in pooled data. And the lowest carotenoids content (0.89, 0.91 and 0.90mg per g) found in treatment T2 (full spectrum light (4 hours) + natural light + third level) and T4 (full spectrum light (8 hours) + natural light + first level) (0.90, 0.90 and 0.90mg per g). However, T1 plants died after 45 days of planting. In 2022, T3, T5 and T6 were at par as well as in year 2023 and in pooled data.

In case of indoor condition, the plants grown without any supplementary dose of light were all died (T_1). Though plants grown with supply of additional full spectrum light survived, the carotenoid content was high only when the growing level was high (L_3 and L_2) and duration of light was 6 hours (T_5 and T_3) or 8 hours (T_6). These treatments were significantly different from others. Anthocyanins and carotenoids, two types of compounds that are photoprotective, are produced in response to stimulation by blue light photoreceptors. As observed in microgreens, anthocyanins have a tendency to accumulate more in yellow, green and blue light, protecting chloroplasts. LED lights in red and blue

(R:B = 1:4) increase the levels of carotenoid, while monochromatic red and blue lights increase the production of anthocyanins (Appolloni *et al.*, 2022; Al-Murad *et al.*, 2021; Dou 2019). Anthocyanins, betalains, flavonoids and carotenoids are examples of specialized metabolites that contribute to the pigmentation of flowers, fruits and plant tissues. Higher light intensities boost the biosynthesis of carotenoids, enhancing their photoprotective functions. As a result, carotenoid content increases in response to red, blue and far-red light supplementation (Appolloni *et al.*, 2022).

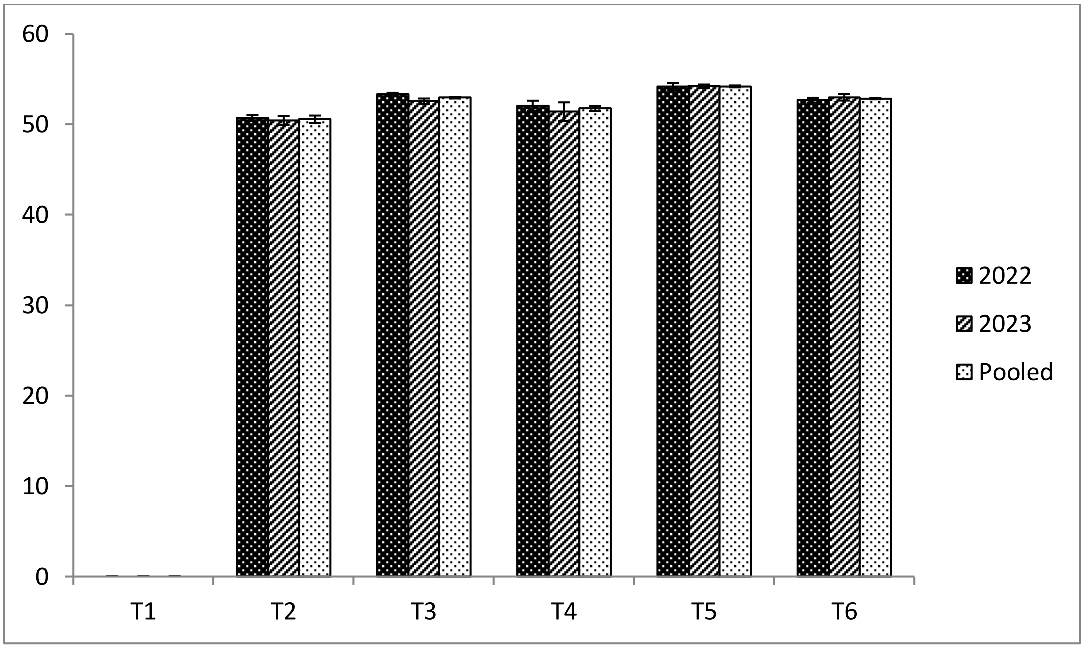

Fig. 4.83: Effect of full spectrum light on total anthocyanins under vertical farming system in indoor conditions

Table 4.30: Effect of full spectrum light on biochemical traits under vertical farming system in indoor conditions.

	Total anthocyanin (mg per 100g)			**Total carotenoids content (mg per g)**		
Treatment Name	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T1*	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0	0.00 ± 0
T2	50.67 ± 0.341^{c}	50.42 ± 0.500^{c}	50.54 ± 0.419^{d}	0.89 ± 0.006^{b}	0.91 ± 0.015^{b}	0.90 ± 0.007^{b}
T3	53.34 ± 0.142^{ab}	52.53 ± 0.313^{b}	52.93 ± 0.089^{b}	0.93 ± 0.003^{a}	0.92 ± 0.010^{ab}	0.93 ± 0.007^{a}
T4	52.05 ± 0.554^{b}	51.40 ± 1.015^{bc}	51.73 ± 0.298^{c}	0.90 ± 0.013^{b}	0.90 ± 0.013^{b}	0.90 ± 0.013^{b}
T5	54.14 ± 0.392^{a}	54.21 ± 0.18^{a}	54.18 ± 0.107^{a}	0.92 ± 0.003^{ab}	0.95 ± 0.003^{a}	0.94 ± 0.003^{a}
T6	52.66 ± 0.268^{b}	52.99 ± 0.374^{ab}	52.83 ± 0.079^{b}	0.94 ± .003^{a}	0.93 ± 0.006^{ab}	0.93 ± 0.003^{a}
SEM±	0.31	0.47	0.23	0.01	0.01	0.01
CD=5%	0.97	1.48	0.72	0.02	0.03	0.02
CV%	1.22	1.86	0.90	1.43	2.14	1.60

*Plant dies after 40 days of planting

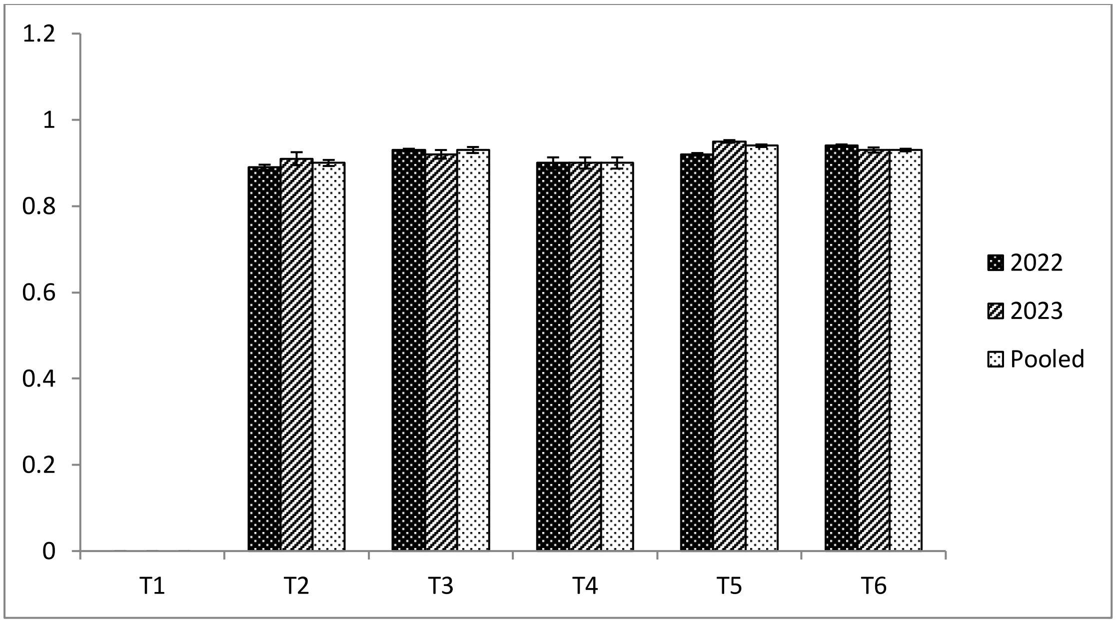

Fig. 4.84: Effect of full spectrum light on total carotenoids under vertical farming system in indoor conditions

CHAPTER-V

SUMMARY AND CONCLUSION

Strawberry (*Fragaria* × *ananassa* Duch.) has achieved the position of being one of the most valuable soft fruits of the world. It is one of the most popular fruits because of its delicacy in flavour, rich in vitamins and minerals and gives quickest revert in the shortest feasible time. Keeping in view of economic importance of strawberry, the present investigation entitled "Effect of Full Spectrum Supplementary Light on Growth, Yield and Quality Attributes of Strawberry (*Fragaria X ananassa* Duch.) Under Vertical Farming System" was undertaken at Agricultural Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab during 2022-2023. The study of chemical attributes was carried in Laboratories of Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab.

The vertical farming trial was conducted during two consecutive years, 2020-21 and 2021-22 in Randomized Block Design with three replications on strawberry cv. Winter Dawn. The experiment was conducted in two conditions i.e., outdoor conditions (OC) and indoor conditions (IC). Under both conditions the light intensity was 3340-10000 lux under open conditions and 1560-6450 lux under indoor conditions.

The data were recorded from five plants from each treatment per replication for different growth, yield and quality parameters viz., Plant height (cm), Plant spread (cm), Petiole length (cm), Number of leaves, Leaf area, Chlorophyll content index, Days to bud formation, Days to flowering, Days to maturity, Number of bud formation, Number of Flowers, Number of Fruiting, Fruit Set (%), Average berry weight(g), Fruit volume (cm^3), Average berry weight(g), Yield (g/plant), Estimated Yield (kg per 1000 sqm), Total soluble solids (˚Brix), Titratable acidity (%), Ascorbic acid (mg per 100g pulp), Reducing sugar (%), Non-Reducing Sugar (%), Total Sugars (%), Total flavonoids content (mg QE per g), Total phenols content (mg GAE per g), Antioxidants (%), Chlorophyll a (mg/g), Chlorophyll b (mg/g), Total Chlorophyll content (mg/g), Total Anthocyanin Content (mg/100g), Total Caretenoids Content (mg/g).

The study consisted of two experiments. For first the treatment combination was prepared under outdoor conditions and for second experiment, the treatment combination was performed under indoor conditions. The treatment details of both the experiment are mentioned below:

The silent features of the experiment are summarized below:

Outdoor Conditions

1. After 30 days of planting, T2 (13.09, 14.25 and 13.67 cm) exhibited the highest plant height in 2022, 2023 and overall. With full spectrum light, T7 (12.81, 14.12 and 13.46 cm) showed the tallest plants, while T3 (11.72, 12.8 and 12.26 cm) had lowest plant height. After 60 days, T1 (22.81, 23.49 and 23.15 cm) had the tallest plants under natural light, while T5 (21.59, 21.12 and 21.36 cm) excelled with full spectrum light. By 90 days of planting, T1 (17.67, 17.97 and 17.82 cm) displayed the maximum height and T6 (19.19, 21.16 and 20.17 cm) performed best with full spectrum light. While T2 (14.55, 15.67 and 15.11 cm) had the shortest plant height at 90 days of planting.
2. After 30 days, T2 took the lead with the longest petiole length under natural light (12.83, 13.30, and 13.06 cm), while T7 excelled under full-spectrum light (12.53, 13.27, and 12.90 cm). By the 60-day mark, T1 dominated in natural light with impressive petiole lengths (22.33, 17.73, and 20.03 cm), while T5 stood out under full-spectrum light (21.33, 17.93, and 19.63 cm). Meanwhile, T4 lagged behind with the shortest petioles (16.85, 15.23, and 16.04 cm). At 90 days, T1 (17.27, 13.25, and 15.26 cm) once again had the longest petioles under natural light, with T6 taking the top spot under full-spectrum light (18.87, 16.08, and 17.47 cm). In contrast, T3 recorded the shortest petiole lengths at both 30 and 90 days (11.45, 11.95, and 11.70 cm; 15.23, 14.25, and 14.74 cm), highlighting its slower growth

in comparison to the other treatments.

3. T1 (7.06, 8.21 and 7.63 cm) showed the greatest plant spread (E-W) under natural light after 30 days, while T6 (6.75, 7.39 and 7.07 cm) performed best under full spectrum light. After 60 days, T1 (15.19, 17.32 and 16.26 cm) naturally displayed a wider spread, while T6 (17.68, 16.83 and 17.25 cm) performed best in full spectrum light. T2 (11.53, 13.31 and 12.42 cm) had lowest plant spread at 60 DAP. After ninety days of planting, T1 16.83, 20.99 and 18.91 cm) showed the greatest spread when exposed to natural light, while T5 (16.38, 19.14 and 17.76 cm) performed better in full spectrum light. While T4 (5.60, 6.75 and 6.18 cm) (12.42, 17.20 and 14.81 cm) showed the lowest Plant spread from east to west at 30 and 60 days of planting.
4. When exposed to natural light for 30 days, T1 (7.42, 6.45 and 6.94 cm) showed the greatest north-south plant spread, whereas T5 (8.00, 7.35 and 7.68 cm) performed best when exposed to full spectrum light but T7 (6.18, 4.59 and 5.38 cm) has the minimum plant spread north to south. After 60 days, T1(13.27, 15.62 and 14.44 cm) naturally displayed a wider spread, while T6 (16.62, 15.59 and 16.11 cm) performed best in full spectrum light. After 90 DAP, T1 (11.21, 22.22 and 16.71 cm) showed the greatest spread when exposed to natural light, while T5 (13.15, 21.67 and 17.41 cm) performed better in full spectrum light. T5 showed the greatest overall north-south plant spread (N-S) in the study, while T3 (12.07, 10.68 and 11.38 cm) (8.79, 16.57 and 12.68 cm) showed the lowest at 60 and 90 DAP.
5. After 30 days, T1 led the pack with the highest number of leaves under natural light (10.67, 15.93, and 13.30), while T5 outperformed others under full-spectrum light (12.93, 16.53, and 14.73). On the other hand, T4 recorded the fewest leaves (10.87, 10.67, and 10.77). At 60 days, T1 continued to show strong leaf growth under natural light (14.47, 19.40, and 16.93), while T6 (16.80, 13.87, and 15.33) and T7 (16.53, 14.13, and 15.33) excelled under full-spectrum light. However, T4 again had the lowest leaf count (10.80, 13.87, and 12.33). By the 90-day mark, T1 maintained its lead with the most leaves under natural light (17.20, 17.00, and

17.10), while T6 performed best under full-spectrum light (19.80, 16.60, and 18.20), achieving the highest overall leaf count in the study. T4 consistently trailed behind, finishing with the fewest leaves (13.27, 13.73, and 13.50).

6. In 2022, 2023 and pooled data, T3 (190.90, 191.43 and 191.17 sqcm) had the largest leaf area when exposed to natural light. T5 (191.20, 191.63 and 191.42 sqcm) had the largest leaf area under full spectrum light. T5 had the highest leaf area overall, while T6 (191.20, 191.63 and 191.42 sqcm) had the lowest.
7. Under natural light, treatment T2 (54.22, 53.40 and 53.81) had the highest chlorophyll content index and under full spectrum light, treatment T6 (58.45, 50.35 and 54.40) had the maximum content. T6 showed the highest overall chlorophyll content index in the study, while T4 (45.43, 51.78 and 48.61) had the lowest.
8. Under natural light, T3 (62.17, 60.83, and 61.50) and T4 (61.67, 61.33, and 61.50) took the longest time for bud formation, indicating a slower progression. When full-spectrum light was added, T6 (61.33, 61.67, and 61.50) needed the most days for buds to appear. Overall, T3 and T4 consistently showed the longest duration to bud formation, while T5 (61.50, 60.17, and 60.83) reached this stage the fastest, highlighting its efficiency in the budding process.
9. T4 (67.00, 66.17 and 66.58) needed the most days to flower, while T7 (66.50, 66.17, 66.33) needed the longest under full spectrum light. T4 showed the longest time to flowering overall, while T1 (65.50, 64.67 and 65.08) showed the shortest time.
10. Under natural light, T4 (75.50, 73.83, and 74.67) took the most days to reach maturity, lagging behind the other treatments. When full-spectrum light was introduced, T7 (76.00, 74.83, and 75.42) took even longer to mature. Overall, T7 required the longest time to mature, while T1 (72.50, 72.33, and 72.42) reached maturity the quickest, demonstrating its superior efficiency in the maturation process.
11. T3 (24.83, 24.44 and 24.64) had the greatest number of bud formations under natural light. But when full spectrum light was added, T5 (25.33, 26.78 and 26.06) displayed the greatest number of bud formations. T5 showed the most bud

formations overall, while T4 (22.50, 25.00 and 23.75) showed the fewest.

12. T1 (23.11, 24.00 and 23.56) and T2 (22.67, 24.44 and 23.56) had maximum number of flowers under natural light. On the other hand, T5 (22.00, 25.67 and 23.83) showed the greatest number of flowers under full spectrum light, while T7 (21.89, 22.33 and 22.11) showed the fewest in overall performance.
13. Under natural light, treatment T1(21.78, 22.89 and 22.33) performed better than all other treatments in maximum number of fruits. T5 (20.67, 24.78 and 22.72) performed better in full spectrum light. In the study, T5 showed the maximum number of fruits, while T6 (19.67, 21.33 and 20.50) showed the lowest.
14. T1 (94.22%, 95.36% and 94.79%) had the largest percentage of fruit set under natural light. But when full spectrum light was added, T5 (93.94%, 96.53% and 95.23%) has the highest fruit set. T5 showed the highest overall fruit set percentage in the study, while T4 (89.83%, 94.87% and 92.35%) had the lowest.
15. T1 (14.00, 14.24, and 14.12 cm^3) had the largest fruit volume when exposed to natural light. T5 (14.40, 13.89, and 14.14 cm^3) showed the highest fruit volume after full spectrum light was added. Overall, T4 (12.88, 12.83, and 12.86 cm^3) had the lowest fruit volume in the study.
16. Treatment T1 (16.10g, 16.43g and 16.26g) exhibited the highest average berry weight under natural light. With the addition of full spectrum light, T6 (16.80g, 15.88g and 16.34g) showed the maximum average berry yield. Overall, T6 demonstrated superior performance, while T4 (15.54, 14.21 and 14.88g) had the lowest average berry weight in the study.
17. T1 (350.34, 375.67 and 362.54g per plant) had the highest average yield when exposed to the outdoors. But when full spectrum light was added, T5 (345.70, 381.08 and 363.64g per plant) performed better than other treatments. When looking for overall results, T1 and T5 showed maximum average yields that were similar, but T4 (303.67, 319.87 and 311.06 g per plant) had the lowest yield when it came to outdoor conditions.
18. Under natural light conditions, T1 (7072.72, 7584.17 and 7319.15kg/1000sqm) has

the highest yield. With full spectrum light, T5 (6979.16, 7693.33 and 7341.25 kg/1000sqm) showed the maximum estimated yield. On the other hand, T4 (6130.67, 6457.76 and 6279.73 kg/1000sqm) had the lowest yield in the study.

19. Treatment T3 (11.11, 10.88 and 11.00 ^{0}Brix) exhibited the highest total soluble solids under natural light. With additional full spectrum light, T6 showed the maximum total soluble solids. Overall, T6 (11.53, 11.47 and 11.50 ^{0}Brix) demonstrated superior performance, while T1 (10.01, 11.45 and 10.73 ^{0}Brix) performed less effectively in terms of total soluble solids content.
20. T3 (0.68%, 0.69% and 0.69%) and T4 (0.69%, 0.68% and 0.69%) showed the highest titratable acidity under natural light. T7 (0.67%, 0.67% and 0.67%) had the highest titratable acidity with more full spectrum light. T5 (0.62%, 0.63% and 0.62%) had the lowest titratable acidity content in the study.
21. T1 (51.11, 51.97 and 51.54mg per 100g) had the highest Vitamin C content when exposed to natural light. T5 (51.99, 50.92 and 51.33mg per 100g) had the highest level of Vitamin C under full spectrum light. T1 performed better overall in terms of vitamin C content, while T4 (49.09, 48.11 and 48.60 mg per 100g) had the lowest content because of insufficient exposure to light.
22. T1 (2.94%, 2.93%, and 2.93%) initially showcased the highest reducing sugar content under natural light. However, when full-spectrum light was added, T5 (2.99%, 2.97%, and 2.98%) outperformed, surpassing the natural light levels. Combining natural light with full-spectrum light, T5 achieved the peak reducing sugar content overall. In contrast, T4 (2.87%, 2.88%, and 2.87%) consistently had the lowest reducing sugar content throughout the study.
23. T1 (9.58%, 9.56% and 9.57%) showed the highest amount of non-reducing sugar under natural light. T5 (9.64%, 9.60% and 9.62%) displayed the highest non-reducing sugar after full spectrum light was added. But T4 (6.52%, 6.55% and 6.53%) has the lowest amount of non-reducing sugar.
24. Under natural light, T1 (9.58%, 9.56%, and 9.57%) boasted the highest total sugar content. However, with the addition of full-spectrum light, T5 (9.64%, 9.60%, and

9.62%) achieved even greater total sugar levels. Throughout the study, T5 emerged as the top performer in overall sugar content, while T4 (9.39%, 9.43%, and 9.41%) recorded the lowest sugar content.

25. Under natural light, T1 (80.84%, 81.08% and 80.96%) in the study had the highest antioxidant content. T5 (81.08%, 81.11% and 81.09%) suppressed other treatments with the highest antioxidant content when full spectrum light was used in addition. T4 (75.74%, 77.17% and 76.46%) having the lowest content during the investigation.
26. T1(49.44, 50.35 and 49.89mg QE per g) had the highest flavonoid content when exposed to natural light. But T5 (50.34, 50.72 and 50.53 mg QE per g), which had the highest flavonoid content in the study, performed better when full spectrum light was added. T3 (47.83, 48.39 and 48.11 mg QE per g) had the lowest flavonoid content overall, while T5 had the highest.
27. According to the study, T1 (148.31, 146.77 and 147.54 mg GAE/100 g) had the highest total phenol content when exposed to natural light. T5(147.67, 147.84 and 147.75 mg GAE/100 g) superior to other treatments with an increased phenol content when full spectrum light was added. Overall, T5 showed the fruit's highest phenol content, while T4 (140.69, 140.33 and 140.51 mg GAE/100 g) showed the lowest amount throughout the investigation.
28. T1 (1.20, 1.19 and 1.19 mg per g) had the highest chlorophyll a content when exposed to natural light. When full spectrum light was added T5 (1.24, 1.25 and 1.25 mg per g) showed the highest chlorophyll a content, outperforming natural light treatments. But T4 (1.09, 1.10 and 1.09 mg per g) showed lowest chlorophyll a content.
29. T1 (1.95, 1.99 and 1.97 mg per g) and T3 (1.97, 1.96 and 1.97 mg per g) had the highest chlorophyll b content when exposed to natural light. But when full spectrum light was used, T5 (2.31, 2.30 and 2.31 mg per g) exceeded other treatments in terms of chlorophyll b content. In the study, T5 showed the highest overall content of chlorophyll b, while T4 (1.89, 1.91 and 1.90 mg per g) showed the lowest

content.

30. T1 (3.99, 4.00 and 3.99 mg per g) had the highest total chlorophyll content in strawberry plants grown outdoors in 2022, 2023 and pooled data. T5 (4.21, 4.22 and 4.22 mg per g) had the highest chlorophyll content after full spectrum light was added. On the other hand T4 (3.95, 3.94 and 3.95 mg per g) has the lowest total chlorophyll content.
31. Under natural light, Treatment T1 (56.98, 56.34, and 56.66 mg/100g) led with the highest anthocyanin content. When full-spectrum light was introduced, Treatment T5 (57.67, 57.94, and 57.80 mg/100g) excelled, surpassing all others. In contrast, Treatment T4 (53.69, 54.76, and 54.22 mg/100g) consistently had the lowest anthocyanin levels throughout the study.
32. In outdoor conditions, Treatment T1 (0.94, 0.95, and 0.94 mg/g) consistently boasted the highest carotenoid content in 2022, 2023, and across pooled data. When full-spectrum light was added, Treatment T5 (0.95, 0.96, and 0.96 mg/g) outshone both T6 (0.94, 0.95, and 0.95 mg/g) and T7 (0.91, 0.91, and 0.91 mg/g), demonstrating superior carotenoid levels throughout all years and pooled data.

Indoor conditions

1. With pooled data confirming overall T6 (15.87, 16.93 and 16.40cm) as the tallest and T1 (10.23, 10.12 and 10.17 cm) as the shortest at 30 DAP. Again T6 (19.44, 18.48 and 18.96 cm) had the highest height at 60 DAP, while T2 (14.67, 14.57 and 14.62 cm) displayed the lowest height. At 90 DAP T6 (15.79, 16.40 and 16.09 cm) recorded the highest height, while T4 (12.24, 13.18 and 12.71 cm) recorded the lowest heights under all conditions.
2. In T6 (14.81, 15.98 and 15.40 cm) treatment longest petiole was recorded at 30 DAP and T1 (9.24, 9.32 and 9.28 cm) had the shortest petioles. T6 (18.66, 17.59 and 18.13 cm) once more had the longest petiole length at 60 DAP and T2 (13.62, 13.64 and 13.63 cm) had the shortest. T4 (11.60, 11.87 and 11.73 cm) had the shortest petiole lengths by 90 DAP, while T6 (15.21, 15.77 and 15.49 cm) continued to have the longest.

3. At 30 days after planting, Treatment T2 (4.27, 6.05, and 5.16 cm) boasted the widest plant spread from east to west, while T4 (1.27, 6.15, and 3.71 cm) had the narrowest. By 60 days, T5 (9.62, 11.52, and 10.57 cm) achieved the broadest spread, with T2 (6.87, 9.69, and 8.28 cm) showing the least. This trend continued at 90 days, with T5 (11.75, 12.41, and 12.8 cm) maintaining the largest spread, whereas T2 (7.98, 7.77, and 7.88 cm) had the smallest.
4. T3 (3.50, 4.17 and 3.18 cm) had the maximum plant spread (N-S) at 30 DAP, whereas T1 (2.94, 2.85 and 2.89 cm) had the least spread. T5 (10.86, 11.43 and 11.15 cm) had the largest plant spread after 60 DAP, while T2 (7.08, 8.50 and 7.79 cm) showed the smallest spread. T5 (13.77, 11.76 and 12.76 cm) had the greatest plant spread (N-S) at 90 DAP, while T2 (8.73, 9.71 and 9.22 cm) had the lowest.
5. At 30 days after planting, Treatment T5 (9.20, 10.40, and 9.80) led with the highest number of leaves, while T1 (5.67, 7.63, and 6.65) lagged behind with the fewest. By 60 days, T5 (12.53, 11.33, and 11.93) continued to exhibit impressive leaf growth. This trend persisted at 90 days, with T5 (12.23, 11.13, and 11.68) still showing the greatest leaf count. In contrast, T2 (8.13, 9.97, and 9.05) and T6 (9.93, 9.97, and 9.95) had the lowest leaf numbers at this stage.
6. In 2022, 2023 and the pooled data, T4 (191.30, 191.33 and 191.32 sq cm) had the largest leaf area. T5 (190.40, 190.63 and 190.52 sq cm) had the lowest leaf area.
7. In the pooled data, 2022 and 2023, T6 (54.85, 54.75 and 54.80) continuously showed the highest CCI. The CCI was lowest for T1 (48.50, 49.57 and 49.03) in 2022 and 2023, respectively, as well as in the pooled data.
8. Bud formation took the longest days under treatment T2 (68.00, 68.33 and 68.17) showed the shortest duration while minimum days were taken by T3 (66.67, 65.67 and 66.17).
9. Treatment T5 (74.83, 74.67, and 74.75 days) achieved the fastest time to flowering, while T2 (77.00, 77.33, and 77.17 days) had the longest delay. This significant variation highlights how different indoor treatments can affect the flowering schedules of strawberry plants, with T2 notably taking the longest to bloom.

10. T2 (88.67, 88.33 and 88.50) showed the highest number of days to maturity in 2022, 2023 and the pooled data. On the other hand, T5 (86.83, 86.33 and 86.58) and T3 (86.83, 86.67 and 88.08) had the lowest days to maturity.
11. In 2022, 2023 and the pooled data, T5 (18.22, 18.56 and 18.39) had the maximum buds. T2 (16.22, 15.67 and 15.94) had the fewest buds during the same time periods.
12. In both 2022, 2023, and across pooled data, Treatment T5 (17.36, 17.33, and 17.35 flowers) consistently led with the highest number of flowers. In contrast, T2 (15.11, 14.56, and 14.83 flowers) lagged behind with the fewest.
13. Over the same periods, T5 (16.56, 16.56, and 16.56 fruits) also excelled by producing the most fruits, while T2 (14.00, 13.44, and 13.72 fruits) fell short with the lowest fruit count.
14. When it came to fruit set percentage, T6 (95.87%, 95.80%, and 95.84%) topped the charts in 2022, 2023, and the pooled data. Meanwhile, T4 (92.94%, 91.54%, and 92.24%) consistently recorded the lowest fruit set percentage during the same periods.
15. The outcomes showed that throughout 2022, 2023 and the pooled data, treatment T6 (14.24, 13.51 and 13.88 cm^3) continuously had the largest fruit volume. On the other hand, T2(12.61, 12.57 and 12.59 cm^3) had the lowest fruit volume.
16. The results showed that throughout 2022, 2023 and the pooled data, treatment T3 (15.13g, 15.01g and 15.07g) continuously showed the highest average berry weight while T2 (12.78g, 13.16g and 12.97g) had the lowest average berry weight.
17. In indoor conditions significant variation in average yield between treatments was observed from which T2 (178.75, 176.88 and 177.82g per plant) had the lowest yields and T5 (238.12, 242.20 and 240.16g per plant) had the highest average yield per plant.
18. The treatment T5 (4807.20, 4889.55 and 4848.37Kg per 1000sqm) consistently demonstrated the highest estimated yield in 2022 and 2023, according to the results while T2 4487.12, 4447.24 and 4467.18Kg per 1000sqm) had the lowest estimated

yield.

19. Total soluble solids for treatment T5 (10.07, 10.08 and 10.08 ^{0}Brix) were highest, while T2 (9.92, 9.99 and 9.95 ^{0}Brix) had the lowest levels. T5 continuously showed better total soluble solids content in the years 2022, 2023 and pooled data.
20. The titratable acidity of T2 (0.73%, 0.72% and 0.72%) was consistently higher and T5 (0.67%, 0.64% and 0.66%) was the lowest.
21. The results revealed that throughout 2022, 2023 and the pooled data, treatment T5(50.60, 52.15 and 51.38mg per 100g) continuously had the highest Vitamin C content while T4(48.88, 49.66 and 49.27mg per 100g) had the lowest Vitamin C content.
22. The treatment T3 (2.74%, 2.76% and 2.75%) consistently displayed the highest reducing sugar content in 2022, 2023 and the pooled data, according to the results. On the other hand, T2 (2.70%, 2.70% and 2.70%) had the least amount of reducing sugar.
23. In treatment T5 (6.46%, 6.47% and 6.47%), the highest non-reducing sugar content was consistently found in strawberry plants grown indoors in 2022, 2023 and the pooled data. On the other hand, T2 (6.38%, 6.39% and 6.38%) had the least amount of non-reducing sugar.
24. While treatments T2 (9.08%, 9.09% and 9.09%) showed lower levels of total sugar content, treatment T5 (9.21%, 9.21% and 9.21%) showed the highest levels.
25. T3 (78.06%, 78.39% and 78.22%) showed the highest antioxidant content in 2022, 2023 and the pooled data. On the other hand, T2 (75.90%, 75.28% and 75.59%) had the least content of antioxidants.
26. Highest flavonoids content in strawberry plants varied depending on the treatment. In 2022 and 2023, treatment T5 (47.64, 47.84 and 47.74mg QE per g) continuously showed the highest content of flavonoids. On the other hand, T2 (44.49, 45.00 and 44.75mg QE per g) had the lowest levels of flavonoids, respectively.
27. In 2022, 2023, and across pooled data, Treatment T5 (143.73, 143.44, and 143.59 mg GAE/100 g FW) stood out with the highest phenol content. In contrast, T2

(142.22, 142.36, and 142.29 mg GAE/100 g FW) and T4 (142.30, 142.35, and 142.32 mg GAE/100 g FW) exhibited the lowest levels of phenols.

28. Across both years, T5 (1.18 mg per g) consistently achieved the highest chlorophyll a levels, while T2 (1.09, 1.10, and 1.09 mg per g) showed the lowest. The pooled data reinforced that T5 had the most robust concentrations of chlorophyll a and b, whereas T2 had the least.
29. For chlorophyll b content, T5 (2.06, 2.07, and 2.07 mg per g) led the way with the highest levels, while T2 (1.99, 1.98, and 1.98 mg per g) recorded the lowest in both 2022, 2023, and the pooled data.
30. T5 (4.17, 4.19, and 4.18 mg per g) consistently demonstrated the highest total chlorophyll content across the pooled data, 2022, and 2023. In contrast, T2 (4.10, 4.09, and 4.10 mg per g) had the lowest overall chlorophyll levels.
31. In both the pooled data and individual years of 2022 and 2023, Treatment T5 stood out with the highest anthocyanin content, recording values of 54.14 and 54.21 mg/g, respectively. On the flip side, T2 and T4 fell short, with T2 showing lower levels at 50.67 and 50.42 mg/g, and T4 at 52.05 and 51.40 mg/g.
32. In 2022 and 2023, T5 (0.92 and 0.95 mg per g) showed the highest content of carotenoids. On the other hand, T2 (0.89 and 0.91 mg per g) and T4 (0.90 and 0.90 mg per g) had the least number of carotenoids.

Future Studies: While this research establishes a foundation for understanding full-spectrum light's influence on vertical strawberry farming, further investigations are warranted. Future studies could explore:

- The impact of varying light intensities and spectral compositions on strawberry growth and development.
- The interaction of full-spectrum light with other environmental factors, such as temperature, humidity and nutrient levels.
- The economic viability and scalability of implementing full-spectrum lighting solutions in commercial vertical farms.

CONCLUSION

This study bridges critical gaps in the understanding of full-spectrum light's impact on strawberry cultivation within vertical farming systems. It reveals that strategic light manipulation, both outdoors and indoors, can significantly boost strawberry growth, yield, and quality. Outdoors, natural light paired with optimal nutrients (T1) led to superior vegetative growth. Indoors, a combination of 6 hours of full-spectrum light, natural light, and the third nutrient level (T5) excelled in enhancing fruit quality and nutritional value. These results underscore the importance of tailoring light treatments to optimize strawberry production in vertical farming environments. In the outdoor experiment, natural light treatments generally promoted plant height and petiole length, with T1 performing best overall. Among AFSL treatments, T5 consistently outperformed others in most metrics. In indoor conditions, 8 hours of full-spectrum light combined with natural light produced the best growth and consistently yielded the highest quality fruits. Overall, this research provides valuable insights into maximizing strawberry production in vertical farms, contributing to sustainable agriculture and food security.

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APPENDICES

APPENDIX-I

ANOVA TABLE

Experiment 1: Outdoor Condition

Plant height (cm) 30 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.175886	0.087943	0.559716	3.885294	
	Treatment	6	6.262895	1.043816	6.643404	2.99612	0.00280
	Error	12	1.885448	0.157121			
	Total	20	8.324229				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.586324	0.293162	3.815793	3.885294	
	Treatment	6	5.141829	0.856971	11.15433	2.99612	0.0003
	Error	12	0.921943	0.076829			
	Total	20	6.650095				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.308067	0.154033	3.316111	3.885294	
	Treatment	6	5.096	0.849333	18.28489	2.99612	0.00000
	Error	12	0.5574	0.04645			
	Total	20	5.961467				

Plant height (cm) 60 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.239581	0.11979	0.608927	3.885294	
	Treatment	6	106.8402	17.8067	90.51627	2.99612	0.00000
	Error	12	2.360686	0.196724			
	Total	20	109.4405				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.17101	0.085505	0.37249	3.885294	
	Treatment	6	67.71912	11.28652	49.1682	2.99612	0.00000
	Error	12	2.75459	0.229549			
	Total	20	70.64472				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.0128	0.0064	0.034304	3.885294	

	Treatment	6	85.09923	14.1832	76.02218	2.99612	0.00000
	Error	12	2.2388	0.186567			
	Total	20	87.35083				

Plant height (cm) 90 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.141981	0.07099	0.269867	3.885294	
	Treatment	6	77.35806	12.89301	49.0122	2.99612	0.00000
	Error	12	3.156686	0.263057			
	Total	20	80.65672				
2023	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.046438	0.523219	0.815778	3.885294	
	Treatment	6	87.31996	14.55333	22.69084	2.99612	0.00000
	Error	12	7.696495	0.641375			
	Total	20	96.0629				
Pooled	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.272267	0.136133	0.342512	3.885294	
	Treatment	6	80.72256	13.45376	33.84972	2.99612	0.00000
	Error	12	4.769467	0.397456			
	Total	20	85.7643				

Petiole length (cm) 30 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.121638	0.060819	0.36497	3.885294	
	Treatment	6	6.083848	1.013975	6.084775	2.99612	0.004
	Error	12	1.999695	0.166641			
	Total	20	8.205181				
2023	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.184152	0.592076	2.239898	3.885294	
	Treatment	6	5.842448	0.973741	3.683785	2.99612	0.02600
	Error	12	3.171981	0.264332			
	Total	20	10.19858				
Pooled	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.4662	0.2331	2.231334	3.885294	
	Treatment	6	5.28135	0.880225	8.425893	2.99612	0.00100
	Error	12	1.2536	0.104467			

	Total	20	7.00115				

Petiole length (cm) 60 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.1176	0.0588	0.304874	3.885294	
	Treatment	6	102.8997	17.14994	88.92124	2.99612	0.00000
	Error	12	2.3144	0.192867			
	Total	20	105.3317				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.307352	0.153676	0.491347	3.885294	
	Treatment	6	66.27859	11.04643	35.31862	2.99612	0.00000
	Error	12	3.753181	0.312765			
	Total	20	70.33912				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.3458	0.1729	0.950435	3.885294	
	Treatment	6	44.73351	7.455586	40.98352	2.99612	0.00000
	Error	12	2.183	0.181917			
	Total	20	47.26231				

Petiole length (cm) 90 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.147352	0.073676	0.307342	3.885294	
	Treatment	6	75.67432	12.61239	52.61286	2.99612	0.00000
	Error	12	2.876648	0.239721			
	Total	20	78.69832				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.7784	0.3892	0.597116	3.885294	
	Treatment	6	89.49303	14.9155	22.88356	2.99612	0.0058
	Error	12	7.8216	0.6518			
	Total	20	98.09303				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.537381	0.26869	1.281673	3.885294	
	Treatment	6	21.05971	3.509952	16.74272	2.99612	0
	Error	12	2.515686	0.20964			
	Total	20	24.11278				

Plant spread (E-W) (cm) 30 DAP

2022	Source	Df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.6048	0.3024	0.606931	3.885294	
	Treatment	6	11.49592	1.915987	3.845476	2.99612	0.0225
	Error	12	5.98	0.498244			
	Total	20	18.08				
2023	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.391124	0.195562	1.003993	3.885294	
	Treatment	6	6.286248	1.047708	5.378816	2.99612	0.0066
	Error	12	2.34	0.194784			
	Total	20	9.01				
Pooled	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.159838	0.079919	0.328169	3.885294	
	Treatment	6	4.700295	0.783383	3.216778	2.99612	0.0403
	Error	12	2.92	0.24353			
	Total	20	7.78				

Plant spread (E-W) (cm) 60 DAP

2022	Source	Df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.417638	0.208819	0.503048	3.885294	
	Treatment	6	76.10773	12.68462	30.55741	2.99612	0.00000
	Error	12	4.981295	0.415108			
	Total	20	81.50667				
2023	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.713752	0.356876	0.319029	3.885294	
	Treatment	6	73.55105	12.25851	10.95848	2.99612	0.0003
	Error	12	13.42358	1.118632			
	Total	20	87.68838				
Pooled	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.142543	0.071271	0.283486	3.885294	
	Treatment	6	67.05436	11.17573	44.45214	2.99612	0.00000
	Error	12	3.016924	0.25141			
	Total	20	70.21383				

Plant spread (E-W) (cm) 90 DAP

2022	Source	Df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.07021	0.035105	0.146464	3.885294	
	Treatment	6	69.19352	11.53225	48.1147	2.99612	0.00000
	Error	12	2.87619	0.239683			
	Total	20	72.13992				
2023	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.48	1.24	1.009571	3.885294	
	Treatment	6	28.5941	4.765683	3.880077	2.99612	0.0375
	Error	12	14.73893	1.228244			
	Total	20	45.81303				
Pooled	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.225838	0.612919	1.774108	3.885294	
	Treatment	6	42.36867	7.061444	20.43951	2.99612	0
	Error	12	4.145762	0.34548			
	Total	20	47.74027				

Plant spread (N-S) (cm) 30 DAP

2022	Source	Df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.880038	0.440019	1.725586	3.885294	
	Treatment	6	20.03352	3.338921	13.09397	2.99612	0.0001
	Error	12	3.059962	0.254997			
	Total	20	23.97352				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.120838	0.060419	0.401197	3.885294	
	Treatment	6	22.05958	0.060419	24.41351	2.99612	0.00000
	Error	12	1.807162	0.150597			
	Total	20	23.98758				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.121895	0.060948	0.730127	3.885294	
	Treatment	6	11.78332	1.963887	23.52654	2.99612	0.00000
	Error	12	1.001705	0.083475			
	Total	20	12.90692				

Plant spread (N-S) (cm) 60 DAP

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.926667	0.463333	1.1775	3.885294	

	Treatment	6	51.85916	8.643194	21.96553	2.99612	0.00000
	Error	12	4.721867	0.393489			
	Total	20	57.5077				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.220788	0.610394	0.507999	3.885294	
	Treatment	6	121.3256	20.22093	16.82883	2.99612	0.00000
	Error	12	14.41878	1.201565			
	Total	20	136.9651				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.216304	0.108152	0.239657	3.885294	
	Treatment	6	72.19019	12.0317	26.66138	2.99612	0.00000
	Error	12	5.415337	0.451278			
	Total	20	77.82183				

Plant spread (N-S) (cm) 90 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.055467	0.027733	0.056924	3.885294	
	Treatment	6	41.39463	6.899105	14.16072	2.99612	0.0001
	Error	12	5.8464	0.4872			
	Total	20	47.2965				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	8.044829	4.022414	1.808736	3.885294	
	Treatment	6	133.1379	22.18965	9.977896	2.99612	0.0004
	Error	12	26.68657	2.223881			
	Total	20	167.8693				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.166388	1.083194	1.603855	3.885294	
	Treatment	6	62.99631	10.49938	15.54614	2.99612	0.0001
	Error	12	8.104429	0.675369			
	Total	20	73.26712				

Number of leaves 30 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.902857	0.451429	0.966689	3.885294	
	Treatment	6	21.03619	3.506032	7.507818	2.99612	0.0016
	Error	12	5.60381	0.466984			

	Total	20	27.54286				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	6.582857	3.291429	1.117723	3.885294	
	Treatment	6	66.82286	11.13714	3.782018	2.99612	0.0238
	Error	12	35.33714	2.944762			
	Total	20	108.7429				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.145714	1.072857	1.029864	3.885294	
	Treatment	6	27.91619	4.652698	4.46625	2.99612	0.0133
	Error	12	12.50095	1.041746			
	Total	20	42.56286				

Number of leaves 60 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.912381	1.95619	1.759566	3.885294	
	Treatment	6	90.62476	15.10413	13.58595	2.99612	0.0001
	Error	12	13.34095	1.111746			
	Total	20	107.8781				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.255238	0.127619	0.141301	3.885294	
	Treatment	6	80.30476	13.38413	14.81898	2.99612	0.0001
	Error	12	10.8381	0.903175			
	Total	20	91.3981				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.14	0.57	0.944751	3.885294	
	Treatment	6	44.55143	7.425238	12.30702	2.99612	0.0002
	Error	12	7.24	0.603333			
	Total	20	52.93143				

Number of leaves 90 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.445714	0.222857	0.885246	3.885294	
	Treatment	6	101.299	16.88317	67.06431	2.99612	0.00000
	Error	12	3.020952	0.251746			
	Total	20	104.7657				

2023	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	6.952381	3.47619	1.268389	3.885294	
	Treatment	6	69.6381	11.60635	4.234913	2.99612	0.0161
	Error	12	32.88762	2.740635			
	Total	20	109.4781				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.692381	0.84619	1.198247	3.885294	
	Treatment	6	58.54286	9.757143	13.81659	2.99612	0.0001
	Error	12	8.474286	0.70619			
	Total	20	68.70952				

Leaf Area (sq cm)

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.018095	0.009048	0.154681	3.885294	
	Treatment	6	1.318095	0.219683	3.755767	2.99612	0.0244
	Error	12	0.701905	0.058492			
	Total	20	2.038095				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	11.86881	5.934405	4.20436	3.885294	
	Treatment	6	35.48286	5.91381	4.189769	2.99612	0.0191
	Error	12	16.93786	1.411488			
	Total	20	64.28952				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.133095	0.066548	1.212581	3.885294	
	Treatment	6	1.44	0.24	4.373102	2.99612	0.0143
	Error	12	0.658571	0.054881			
	Total	20	2.231667				

Chlorophyll content index

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	12.215	6.1075	0.805813	3.885294	
	Treatment	6	283.4748	47.24579	6.233525	2.99612	0.0036
	Error	12	90.95167	7.579306			
	Total	20	386.6414				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	11.86881	5.934405	4.20436	3.885294	

	Treatment	6	35.48286	5.91381	4.189769	2.99612	0.02
	Error	12	16.93786	1.411488			
	Total	20	64.28952				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	8.259286	4.129643	1.234999	3.885294	
	Treatment	6	76.5753	12.76255	3.81673	2.99612	0.0232
	Error	12	40.12613	3.343844			
	Total	20	124.9607				

Days to bud formation

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.285714	0.142857	0.533333	3.885294	
	Treatment	6	3	0.5	1.866667	2.99612	0.1683
	Error	12	3.214286	0.267857			
	Total	20	6.5				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.52381	1.761905	8	3.885294	
	Treatment	6	4.571429	0.761905	3.459459	2.99612	0.032
	Error	12	2.642857	0.220238			
	Total	20	10.7381				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.166667	0.583333	6.72	3.885294	
	Treatment	6	1.35119	0.225198	2.594286	2.99612	0.0754
	Error	12	1.041667	0.086806			
	Total	20	3.559524				

Days to flowering

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.928571	0.464286	2.316832	3.885294	
	Treatment	6	6.238095	1.039683	5.188119	2.99612	0.0075
	Error	12	2.404762	0.200397			
	Total	20	9.571429				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.142857	0.571429	1.858065	3.885294	
	Treatment	6	5.738095	0.956349	3.109677	2.99612	0.0447
	Error	12	3.690476	0.30754			

	Total	20	10.57143				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.875	0.4375	5.478261	3.885294	
	Treatment	6	4.166667	0.694444	8.695652	2.99612	0.0008
	Error	12	0.958333	0.079861			
	Total	20	6				

Days to maturity

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	
	Replication	2	2.571429	1.285714	3.620112	3.885294	
	Treatment	6	32.95238	5.492063	15.46369	2.99612	0.0001
	Error	12	4.261905	0.355159			
	Total	20	39.78571				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.928571	0.464286	1.21875	3.885294	
	Treatment	6	12.28571	2.047619	5.375	2.99612	0.0066
	Error	12	4.571429	0.380952			
	Total	20	17.78571				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.410714	0.705357	7.770492	3.885294	
	Treatment	6	16.75	2.791667	30.7541	2.99612	0.00000
	Error	12	1.089286	0.090774			
	Total	20	19.25				

Number of bud formation

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.595238	1.297619	1.056543	3.885294	
	Treatment	6	45.90476	7.650794	6.229402	2.99612	0.0036
	Error	12	14.7381	1.228175			
	Total	20	63.2381				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.851984	0.925992	0.949322	3.885294	
	Treatment	6	19.66168	3.276947	3.359507	2.99612	0.0351
	Error	12	11.7051	0.975425			
	Total	20	33.21876				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**

	Replication	2	0.853652	0.426826	0.848699	3.885294	
	Treatment	6	10.14552	1.69092	3.362221	2.99612	0.0353
	Error	12	6.035013	0.502918			
	Total	20	17.03419				

Number of flowers

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	6.126984	3.063492	11.20645	3.885294	
	Treatment	6	10.65608	1.776014	6.496774	2.99612	0.003
	Error	12	3.280423	0.273369			
	Total	20	20.06349				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.91472	0.95736	0.96242	3.885294	
	Treatment	6	27.61553	4.602589	4.626915	2.99612	0.0117
	Error	12	11.93691	0.994743			
	Total	20	41.46716				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.335585	1.167792	3.65812	3.885294	
	Treatment	6	10.12843	1.688072	5.2879	2.99612	0.0069
	Error	12	3.830795	0.319233			
	Total	20	16.29481				

Number of fruits

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	8.98413	4.49206	12.83123	3.88529	
	Treatment	6	16.14815	2.69136	7.68766	2.99612	0.00150
	Error	12	4.20106	0.35009			
	Total	20	29.33333				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.666667	1.333333	1.576642	3.885294	
	Treatment	6	29.43915	4.906526	5.801877	2.99612	0.0048
	Error	12	10.14815	0.845679			
	Total	20	42.25397				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.865079	1.93254	7.103728	3.885294	
	Treatment	6	12.82275	2.137125	7.855754	2.99612	0.0013

	Error	12	3.26455	0.272046			
	Total	20	19.95238				

Fruit set (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	28.66311	14.33156	3.548183	3.885294	
	Treatment	6	88.17991	14.69665	3.638572	2.99612	0.0269
	Error	12	48.46951	4.039126			
	Total	20	165.3125				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.956047	0.978023	1.815312	3.885294	
	Treatment	6	13.82265	2.303775	4.276044	2.99612	0.0156
	Error	12	6.465157	0.538763			
	Total	20	22.24385				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	11.12718	5.56359	4.972612	3.885294	
	Treatment	6	29.3421	4.890351	4.370885	2.99612	0.0144
	Error	12	13.42616	1.118847			
	Total	20	53.89544				

Fruit volume

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.114603	0.057302	0.236489	3.885294	
	Treatment	6	8.469206	1.411534	5.825527	2.99612	0.0048
	Error	12	2.907619	0.242302			
	Total	20	11.49143				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.370668	0.185334	1.366154	3.885294	
	Treatment	6	4.568331	0.761389	5.612434	2.99612	0.0055
	Error	12	1.627932	0.135661			
	Total	20	6.566931				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.101667	0.050833	0.979191	3.885294	
	Treatment	6	5.619339	0.936556	18.04068	2.99612	0.013
	Error	12	0.622963	0.051914			
	Total	20	6.343968				

Average berry weight (g)

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	4.512382	2.256191	13.35447	3.885294	
	Treatment	6	8.204559	1.367426	8.09384	2.99612	0.0011
	Error	12	2.027359	0.168947			
	Total	20	14.7443				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.590976	0.795488	1.73094	3.885294	
	Treatment	6	8.367285	1.394547	3.034462	2.99612	0.0484
	Error	12	5.514839	0.45957			
	Total	20	15.4731				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.864654	1.432327	8.572993	3.885294	
	Treatment	6	5.749117	0.958186	5.735088	2.99612	0.005
	Error	12	2.004892	0.167074			
	Total	20	10.61866				

Average yield per plant (g)

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	11.0067	5.50335	0.734324	3.885294	
	Treatment	6	5525.14	920.8566	122.8719	2.99612	0.00000
	Error	12	89.93336	7.494446			
	Total	20	5626.08				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	714.9767	357.4883	5.557849	3.885294	
	Treatment	6	10750.15	1791.692	27.85532	2.99612	0.00000
	Error	12	771.8562	64.32135			
	Total	20	12236.98				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	134.9362	67.46809	5.813035	3.885294	
	Treatment	6	7437.578	1239.596	106.8033	2.99612	0.00000
	Error	12	139.2761	11.60634			
	Total	20	7711.79				

Estimated yield (kg per 1000 sqm)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	4486.029	2243.014	0.734324	3.885294	
	Treatment	6	2251895	375315.9	122.8719	2.99612	0.00000
	Error	12	36654.36	3054.53			
	Total	20	2293036				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	291404.8	145702.4	5.557849	3.8852938	
	Treatment	6	4381466	730244.3	27.85532	2.9961204	0.00000
	Error	12	314587.4	26215.61			
	Total	20	4987458				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	54996.28	27498.14	5.813035	3.885294	
	Treatment	6	3031352	505225.4	106.8033	2.99612	0.00000
	Error	12	56765.12	4730.427			
	Total	20	3143114				

TSS (^{0}Brix)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.006438	0.003219	0.011247	3.885294	
	Treatment	6	7.396514	1.232752	4.307024	2.99612	0.0151
	Error	12	3.434629	0.286219			
	Total	20	10.83758				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.19961	0.599805	4.361713	3.885294	
	Treatment	6	2.472295	0.412049	2.996376	2.99612	0.05
	Error	12	1.65019	0.137516			
	Total	20	5.322095				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.341874	0.170937	1.193606	3.885294	
	Treatment	6	2.163931	0.360655	2.518357	2.99612	NS
	Error	12	1.718526	0.143211			
	Total	20	4.224331				

Titrable acidity (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.0002	0.0001	0.642857	3.885294	

	Treatment	6	0.012933	0.002156	13.85714	2.99612	0.00000
	Error	12	0.001867	0.000156			
	Total	20	0.015				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.00061	0.000305	0.597201	3.885294	
	Treatment	6	0.009248	0.001541	3.020218	2.99612	0.0488
	Error	12	0.006124	0.00051			
	Total	20	0.015981				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000279	0.000139	0.934754	3.885294	
	Treatment	6	0.010598	0.001766	11.85353	2.99612	0.0001
	Error	12	0.001788	0.000149			
	Total	20	0.012664				

Vitamin C (mg per 100g)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.077895	0.038948	1.88023	3.885294	
	Treatment	6	17.37943	2.896571	139.8345	2.99612	0
	Error	12	0.248571	0.020714			
	Total	20	17.7059				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.562352	0.781176	0.967077	3.885294	
	Treatment	6	28.96198	4.826997	5.975702	2.99612	0.0043
	Error	12	9.693248	0.807771			
	Total	20	40.21758				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.319657	0.159829	0.777746	3.885294	
	Treatment	6	17.79302	2.965504	14.43052	2.99612	0.0001
	Error	12	2.466026	0.205502			
	Total	20	20.57871				

Reducing sugar (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	
	Replication	2	0.002181	0.00109	0.891051	3.885294	
	Treatment	6	0.029257	0.004876	3.984436	2.99612	0.0199
	Error	12	0.014686	0.001224			

	Total	20	0.046124				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000371	0.000186	0.625668	3.885294	
	Treatment	6	0.019724	0.003287	11.07487	2.99612	0.0003
	Error	12	0.003562	0.000297			
	Total	20	0.023657				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.001088	0.000544	1.173801	3.885294	
	Treatment	6	0.022324	0.003721	8.027397	2.99612	0.0015
	Error	12	0.005562	0.000463			
	Total	20	0.028974				

Non-reducing sugar

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.001181	0.00059	1.556485	3.885294	
	Treatment	6	0.046162	0.007694	20.28033	2.99612	0.00000
	Error	12	0.004552	0.000379			
	Total	20	0.051895				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.003114	0.001557	2.851744	3.885294	
	Treatment	6	0.024733	0.004122	7.549419	2.99612	0.0016
	Error	12	0.006552	0.000546			
	Total	20	0.0344				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.002002	0.001001	4.219064	3.885294	
	Treatment	6	0.033674	0.005612	23.6505	2.99612	0.00000
	Error	12	0.002848	0.000237			
	Total	20	0.038524				

Total sugars (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.004581	0.00229	1.200999	3.885294	
	Treatment	6	0.131657	0.021943	11.50562	2.99612	0.0002
	Error	12	0.022886	0.001907			
	Total	20	0.159124				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**

	Replication	2	0.004067	0.002033	1.054755	3.885294	
	Treatment	6	233.4763	38.91272	20185.27	2.99612	0.00000
	Error	12	0.023133	0.001928			
	Total	20	233.5035				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.003781	0.00189	2.33816	3.885294	
	Treatment	6	0.101583	0.016931	20.93988	2.99612	0.00000
	Error	12	0.009702	0.000809			
	Total	20	0.115067				

Antioxidants (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.668086	0.334043	1.899907	3.885294	
	Treatment	6	72.49212	12.08202	68.71788	2.99612	0.00000
	Error	12	2.109848	0.175821			
	Total	20	75.27006				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.185552	0.092776	0.341537	3.885294	
	Treatment	6	47.26623	7.877705	29.00023	2.99612	0.00000
	Error	12	3.259714	0.271643			
	Total	20	50.7115				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.045552	0.022776	0.368283	3.885294	
	Treatment	6	57.73755	9.622925	155.5994	2.99612	0.00000
	Error	12	0.742131	0.061844			
	Total	20	58.52523				

Flavonoids (mg QE per 100g of FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	5.703438	2.851719	9.411368	3.885294	
	Treatment	6	8.092448	1.348741	4.451175	2.99612	0.0021
	Error	12	3.636095	0.303008			
	Total	20	17.43198				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.920867	1.960433	7.140244	3.885294	
	Treatment	6	11.68212	1.947021	7.091393	2.99612	0.0021

	Error	12	3.294733	0.274561			
	Total	20	18.89772				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.362867	1.181433	16.34354	3.885294	
	Treatment	6	9.997964	1.666327	23.05139	2.99612	0.00001
	Error	12	0.86745	0.072287			
	Total	20	13.22828				

Total phenols (mg GAE per 100g of FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.141188	1.570594	1.808568	3.885294	
	Treatment	6	185.9669	30.99448	35.6907	2.99612	0.00000
	Error	12	10.42103	0.868419			
	Total	20	199.5291				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.07485	1.037425	1.285571	3.885294	
	Treatment	6	141.7441	23.62401	29.27473	2.99612	0.00000
	Error	12	9.683714	0.806976			
	Total	20	153.5026				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.578666	1.289333	3.859919	3.885294	
	Treatment	6	161.0615	26.84358	80.36252	2.99612	0.00000
	Error	12	4.008373	0.334031			
	Total	20	167.6485				

Chlorophyll a (µg of Chl per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000295	0.000148	0.280967	3.885294	
	Treatment	6	0.047295	0.007883	15.00302	2.99612	0.0001
	Error	12	0.006305	0.000525			
	Total	20	0.053895				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000457	0.000229	1.777778	3.885294	
	Treatment	6	0.052114	0.008686	67.55556	2.99612	0.00000
	Error	12	0.001543	0.000129			
	Total	20	0.054114				

Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000331	0.000165	1.155125	3.885294	
	Treatment	6	0.049231	0.008205	57.27701	2.99612	0.00000
	Error	12	0.001719	0.000143			
	Total	20	0.051281				

Chlorophyll b (µg of Chl per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.00361	0.001805	0.829019	3.885294	
	Treatment	6	0.652848	0.108808	49.98104	2.99612	0.00000
	Error	12	0.026124	0.002177			
	Total	20	0.682581				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.01241	0.006205	2.402581	3.885294	
	Treatment	6	0.554581	0.09243	35.79041	2.99612	0.00000
	Error	12	0.03099	0.002583			
	Total	20	0.597981				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.002257	0.001129	0.584764	3.885294	
	Treatment	6	0.600098	0.100016	51.82297	2.99612	0.00000
	Error	12	0.02316	0.00193			
	Total	20	0.625514				

Total chlorophyll (µg of Chl per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.001067	0.000533	0.376471	3.885294	
	Treatment	6	0.273457	0.045576	32.17143	2.99612	0.00000
	Error	12	0.017	0.001417			
	Total	20	0.291524				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.006552	0.003276	5.973951	3.885294	
	Treatment	6	0.324448	0.054075	98.60203	2.99612	0.00000
	Error	12	0.006581	0.000548			
	Total	20	0.337581				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.001486	0.000743	1.001873	3.885294	
	Treatment	6	0.297524	0.049587	66.87717	2.99612	0.00000
	Error	12	0.008898	0.000741			

	Total	20	0.307907				

Total anthocyanins (mg per g)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.175506	1.087753	4.135596	3.885294	
	Treatment	6	33.29687	5.549478	21.09891	2.99612	0.00000
	Error	12	3.156265	0.263022			
	Total	20	38.62864				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.625871	0.812935	1.513739	3.885294	
	Treatment	6	29.93364	4.98894	9.289734	2.99612	0.0006
	Error	12	6.444455	0.537038			
	Total	20	38.00396				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.655377	0.827688	2.801958	3.885294	
	Treatment	6	29.80133	4.966889	16.81431	2.99612	0
	Error	12	3.544758	0.295397			
	Total	20	35.00147				

Total carotenoids (µg per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000267	0.000133	0.666667	3.885294	
	Treatment	6	0.004114	0.000686	3.428571	2.99612	0.03277
	Error	12	0.0024	0.0002			
	Total	20	0.006781				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000238	0.000119	0.3	3.885294	
	Treatment	6	0.007781	0.001297	3.268	2.99612	0.0383
	Error	12	0.004762	0.000397			
	Total	20	0.012781				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000221	0.000111	0.783708	3.885294	
	Treatment	6	0.00564	0.00094	6.654494	2.99612	0.0041
	Error	12	0.001695	0.000141			
	Total	20	0.007557				

Experiment: 2 Indoor Conditions

Plant height (cm) 30 DAP

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	1.899244	0.949622	3.237398	4.102821	
	Treatment	6	57.58151	11.5163	39.26072	3.325835	0.00000
	Error	12	2.933289	0.293329			
	Total	20	62.41404				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.343511	0.671756	2.618363	4.102821	
	Treatment	6	81.01084	16.20217	63.15267	3.325835	0.00000
	Error	12	2.565556	0.256556			
	Total	20	84.91991				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.879078	0.439539	2.672854	4.102821	
	Treatment	6	68.17264	13.63453	82.91212	3.325835	0.00000
	Error	12	1.644456	0.164446			
	Total	20	70.69618				

Plant height (cm) 60 DAP

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.893378	0.446689	1.646139	4.102821	
	Treatment	6	744.3262	148.8652	548.5985	3.325835	0.00000
	Error	12	2.713556	0.271356			
	Total	20	747.9332				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	4.713644	2.356822	4.182949	4.102821	
	Treatment	6	709.1654	141.8331	251.729	3.325835	0.00000
	Error	12	5.634356	0.563436			
	Total	20	719.5134				
Pooled	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.374578	1.187289	5.962414	4.102821	
	Treatment	6	722.3984	144.4797	725.5587	3.325835	0.00000
	Error	12	1.991289	0.199129			

	Total	20	726.7643				

Plant height (cm) 90 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.414578	0.707289	2.917751	4.102821	
	Treatment	6	459.8769	91.97538	379.4225	3.325835	0.00000
	Error	12	2.424089	0.242409			
	Total	20	463.7156				
2023	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	5.793644	2.896822	10.343	4.102821	
	Treatment	6	515.2372	103.0474	367.9273	3.325835	0.00000
	Error	12	2.800756	0.280076			
	Total	20	523.8316				
Pooled	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.148678	1.574339	8.573015	4.102821	
	Treatment	6	485.9429	97.18858	529.2375	3.325835	0.00000
	Error	12	1.836389	0.183639			
	Total	20	490.928				

Petiole length (cm) 30 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.054878	0.527439	1.744798	4.102821	
	Treatment	6	59.34469	11.86894	39.26313	3.325835	0.00000
	Error	12	3.022922	0.302292			
	Total	20	63.42249				
2023	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.058978	0.529489	1.812766	4.102821	
	Treatment	6	77.99338	15.59868	53.40386	3.325835	0.00000
	Error	12	2.920889	0.292089			
	Total	20	81.97324				
Pooled	**Source**	df	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.231369	0.115685	1.026046	4.102821	
	Treatment	6	67.81451	13.5629	120.2939	3.325835	0.00000
	Error	12	1.127481	0.112748			
	Total	20	69.17336				

Petiole length (cm) 60 DAP

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	1.069378	0.534689	2.170395	4.102821	
	Treatment	6	676.5087	135.3017	549.2133	3.325835	0.00000
	Error	12	2.463556	0.246356			
	Total	20	680.0416				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.341878	1.170939	3.024544	4.102821	
	Treatment	6	632.0834	126.4167	326.5353	3.325835	0.00000
	Error	12	3.871456	0.387146			
	Total	20	638.2968				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.637908	0.818954	4.654802	4.102821	
	Treatment	6	650.7303	130.1461	739.729	3.325835	0.00000
	Error	12	1.759375	0.175937			
	Total	20	654.1276				

Petiole length (cm) 90 DAP

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	1.384211	0.692106	2.343481	4.102821	
	Treatment	6	422.1202	84.42405	285.8613	3.325835	0.00000
	Error	12	2.953322	0.295332			
	Total	20	426.4578				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	5.956311	2.978156	9.829906	4.102821	
	Treatment	6	472.7368	94.54737	312.0696	3.325835	0.0058
	Error	12	3.029689	0.302969			
	Total	20	481.7228				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.243753	1.621876	7.71576	4.102821	
	Treatment	6	445.6723	89.13445	424.0398	3.325835	0
	Error	12	2.102031	0.210203			
	Total	20	451.018				

Plant spread (E-W) (cm) 30 DAP

2022	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.271511	0.635756	2.413813	4.102821	
	Treatment	6	23.48678	4.697356	17.83475	3.325835	0.0001
	Error	12	2.633822	0.263382			
	Total	20	27.39211				
2023	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.283062	0.141531	1.111836	4.102821	
	Treatment	6	19.94439	3.988878	31.33573	3.325835	0.00000
	Error	12	1.272949	0.127295			
	Total	20	21.5004				
Pooled	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.098078	0.049039	0.434744	4.102821	
	Treatment	6	4.622203	0.924441	8.19539	3.325835	0.0026
	Error	12	1.128001	0.1128			
	Total	20	5.848282				

Plant spread (E-W) (cm) 60 DAP

2022	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.486978	0.743489	2.348882	4.102821	
	Treatment	6	168.0724	33.61448	106.1972	3.325835	0.00000
	Error	12	3.165289	0.316529			
	Total	20	172.7246				
2023	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.054533	0.027267	0.074943	4.102821	
	Treatment	6	303.0243	60.60487	166.5732	3.325835	0.00000
	Error	12	3.638333	0.363833			
	Total	20	306.7172				
Pooled	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.447778	0.223889	0.994691	4.102821	
	Treatment	6	227.5865	45.51731	202.2238	3.325835	0.00000
	Error	12	2.250839	0.225084			
	Total	20	230.2852				

Plant spread (E-W) (cm) 90 DAP

2022	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.402033	0.201017	1.005	4.102821	

	Treatment	6	303.5015	60.70029	303.4762	3.325835	0.00000
	Error	12	2.000167	0.200017			
	Total	20	305.9037				
2023	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.320678	0.160339	0.65315	4.102821	
	Treatment	6	305.1194	61.02387	248.5844	3.325835	0.00000
	Error	12	2.454856	0.245486			
	Total	20	307.8949				
Pooled	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.353636	0.176818	1.150313	4.102821	
	Treatment	6	303.5812	60.71624	394.9973	3.325835	0.00000
	Error	12	1.537131	0.153713			
	Total	20	305.4719				

Plant spread (N-S) (cm) 30 DAP

2022	**Source**	**Df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.376133	0.188067	0.701567	4.102821	
	Treatment	6	6.133	1.2266	4.575727	3.325835	0.0197
	Error	12	2.680667	0.268067			
	Total	20	9.1898				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.213733	0.106867	1.1544	4.102821	
	Treatment	6	11.13193	2.226387	24.04998	3.325835	0.00000
	Error	12	0.925733	0.092573			
	Total	20	12.2714				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.006533	0.003267	0.035525	4.102821	
	Treatment	6	1.848533	0.369707	4.02059	3.325835	0.0292
	Error	12	0.919533	0.091953			
	Total	20	2.7746				

Plant spread (N-S) (cm) 60 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.406044	0.203022	0.68847	4.102821	
	Treatment	6	226.3208	45.26417	153.4957	3.325835	0
	Error	12	2.948889	0.294889			

	Total	20	229.6758				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.4016	0.7008	2.65723	4.102821	
	Treatment	6	275.3803	55.07605	208.8324	3.325835	0
	Error	12	2.637333	0.263733			
	Total	20	279.4192				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.191111	0.095556	0.835284	4.102821	
	Treatment	6	248.5825	49.71651	434.5891	3.325835	0
	Error	12	1.143989	0.114399			
	Total	20	249.9176				

Plant spread (N-S) (cm) 90 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.426433	1.213217	4.2055	4.102821	
	Treatment	6	349.9968	69.99936	242.6461	3.325835	0.00000
	Error	12	2.884833	0.288483			
	Total	20	355.3081				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.112311	0.056156	0.242948	4.102821	
	Treatment	6	289.8796	57.97592	250.8236	3.325835	0.00000
	Error	12	2.311422	0.231142			
	Total	20	292.3033				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.882119	0.44106	3.010447	4.102821	
	Treatment	6	315.5263	63.10527	430.7241	3.325835	0.00000
	Error	12	1.465097	0.14651			
	Total	20	317.8736				

Number of leaves 30 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.454444	0.227222	0.365374	4.102821	
	Treatment	6	27.15778	5.431556	8.733965	3.325835	0.00205
	Error	12	6.218889	0.621889			
	Total	20	33.83111				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**

	Replication	2	0.963333	0.481667	1.568947	4.102821	
	Treatment	6	20.05167	4.010333	13.06298	3.325835	0.0004
	Error	12	3.07	0.307			
	Total	20	24.085				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.680278	0.340139	1.118367	4.102821	
	Treatment	6	17.56569	3.513139	11.5511	3.325835	0.00000
	Error	12	3.041389	0.304139			
	Total	20	21.28736				

Number of leaves 60 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.087778	0.043889	0.122405	4.102821	
	Treatment	6	302.5894	60.51789	168.7825	3.325835	0.00000
	Error	12	3.585556	0.358556			
	Total	20	306.2628				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.434444	0.717222	3.08409	4.102821	
	Treatment	6	300.8511	60.17022	258.7348	3.325835	0.00000
	Error	12	2.325556	0.232556			
	Total	20	304.6111				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.280833	0.140417	0.85144	4.102821	
	Treatment	6	297.8163	59.56325	361.1718	3.325835	0.00000
	Error	12	1.649167	0.164917			
	Total	20	299.7463				

Number of leaves 90 DAP

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.474444	0.237222	1.946217	4.102821	
	Treatment	6	292.0111	58.40222	479.1431	3.325835	0.00000
	Error	12	1.218889	0.121889			
	Total	20	293.7044				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.497778	0.248889	1.12	4.102821	
	Treatment	6	271.9844	54.39689	244.786	3.325835	0.00000

	Error	12	2.222222	0.222222			
	Total	20	274.7044				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.2275	0.11375	1.169666	4.102821	
	Treatment	6	277.5	55.5	570.6941	3.325835	0.00000
	Error	12	0.9725	0.09725			
	Total	20	278.7				

Leaf Area (sq cm)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.015352	0.007676	0.069497	3.885294	
	Treatment	6	80538.18	13423.03	121526	2.99612	0.0336
	Error	12	1.325448	0.110454			
	Total	20	80539.52				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.723543	0.361771	2.824028	3.885294	
	Treatment	6	80876.13	13479.35	105221.3	2.99612	0.2051
	Error	12	1.537257	0.128105			
	Total	20	80878.39				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.221111	0.110556	3.038168	4.102821	
	Treatment	6	1.104028	0.220806	6.067939	3.325835	0.0078
	Error	12	0.363889	0.036389			
	Total	20	1.689028				

Chlorophyll content index

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	17.09194	8.545972	4.712491	4.102821	
	Treatment	6	123.699	24.73981	13.64223	3.325835	0.0003
	Error	12	18.13472	1.813472			
	Total	20	158.9257				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.6075	0.30375	0.429379	4.102821	
	Treatment	6	106.6946	21.33892	30.16457	3.325835	0.00000
	Error	12	7.074167	0.707417			
	Total	20	114.3763				

Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	5.802986	2.901493	3.069303	4.102821	
	Treatment	6	68.85444	13.77089	14.56734	3.325835	0.0003
	Error	12	9.453264	0.945326			
	Total	20	84.11069				

Days to bud formation

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.083333	0.041667	0.2	4.102821	
	Treatment	6	11329.96	2265.992	10876.76	3.325835	0.00000
	Error	12	2.083333	0.208333			
	Total	20	11332.13				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.083333	0.041667	0.151515	4.102821	
	Treatment	6	11168.67	2233.733	8122.667	3.325835	0.00000
	Error	12	2.75	0.275			
	Total	20	11171.5				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.020833	0.010417	0.238095	4.102821	
	Treatment	6	11248.32	2249.665	51420.9	3.325835	0.00000
	Error	12	0.4375	0.04375			
	Total	20	11248.78				

Days to flowering

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.527778	0.263889	1.067416	4.102821	
	Treatment	6	14287.24	2857.447	11558.21	3.325835	0.00000
	Error	12	2.472222	0.247222			
	Total	20	14290.24				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.083333	0.041667	0.135135	4.102821	
	Treatment	6	14455.33	2891.067	9376.432	3.325835	0.00000
	Error	12	3.083333	0.308333			
	Total	20	14458.5				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**

	Replication	2	0.048611	0.024306	0.327103	4.102821	
	Treatment	6	14370.23	2874.045	38678.74	3.325835	0.00000
	Error	12	0.743056	0.074306			
	Total	20	14371.02				

Days to maturity

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.361111	0.180556	0.684211	4.102821	
	Treatment	6	19180.24	3836.047	14536.6	3.325835	0.00000
	Error	12	2.638889	0.263889			
	Total	20	19183.24				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.361111	0.180556	0.915493	4.102821	
	Treatment	6	19090.74	3818.147	19359.62	3.325835	0.00000
	Error	12	1.972222	0.197222			
	Total	20	19093.07				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.173611	0.086806	0.806452	4.102821	
	Treatment	6	19134.28	3826.856	35552.72	3.325835	0.00000
	Error	12	1.076389	0.107639			
	Total	20	19135.53				

Number of bud formation

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.81482	0.90741	1.033756	4.102821	
	Treatment	6	753.2407	150.6481	171.6242	3.325835	0.00000
	Error	12	8.777792	0.877779			
	Total	20	763.8333				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.049382	0.024691	0.062499	4.102821	
	Treatment	6	744.8457	148.9691	377.0787	3.325835	0.00000
	Error	12	3.950611	0.395061			
	Total	20	748.8457				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.614198	0.307099	1.220858	4.102821	
	Treatment	6	748.6975	149.7395	595.2825	3.325835	0.00000

	Error	12	2.515436	0.251544			
	Total	20	751.8271				

Number of flowers

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.861706	0.430853	1.340352	4.102821	
	Treatment	6	665.001	133.0002	413.7539	3.325835	0.00000
	Error	12	3.214476	0.321448			
	Total	20	669.0772				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.1605	0.08025	0.22185	4.102821	
	Treatment	6	663.512	132.7024	366.8548	3.325835	0.00000
	Error	12	3.6173	0.36173			
	Total	20	667.2898				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.40075	0.200375	1.543201	4.102821	
	Treatment	6	663.9998	132.8	1022.768	3.325835	0.00000
	Error	12	1.298437	0.129844			
	Total	20	665.699				

Number of fruits

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.333356	0.666678	2.307693	4.102821	
	Treatment	6	595.1669	119.0334	412.032	3.325835	0.00000
	Error	12	2.888936	0.288894			
	Total	20	599.3892				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.111111	0.055556	0.180723	4.102821	
	Treatment	6	590.8704	118.1741	384.4218	3.325835	0.00000
	Error	12	3.074073	0.307407			
	Total	20	594.0555				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.361115	0.180558	1.423358	4.102821	
	Treatment	6	592.8149	118.563	934.6466	3.325835	0.00000
	Error	12	1.268533	0.126853			
	Total	20	594.4446				

Fruit set (%)

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	17.41033	8.705164	4.690628	4.102821	
	Treatment	6	22250.77	4450.155	2397.89	3.325835	0.00000
	Error	12	18.55863	1.855863			
	Total	20	22286.74				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.368978	0.184489	0.149588	4.102821	
	Treatment	6	22074.26	4414.851	3579.669	3.325835	0.00000
	Error	12	12.33313	1.233313			
	Total	20	22086.96				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.766639	1.883319	3.981321	4.102821	
	Treatment	6	22161.43	4432.286	9369.815	3.325835	0.00000
	Error	12	4.730388	0.473039			
	Total	20	22169.93				

Fruit volume

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.551481	0.275741	1.373363	4.102821	
	Treatment	6	451.5407	90.30815	449.7916	3.325835	0.00000
	Error	12	2.007778	0.200778			
	Total	20	454.1				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.58679	0.293395	1.112333	4.102821	
	Treatment	6	439.424	87.8848	333.193	3.325835	0.00000
	Error	12	2.637654	0.263765			
	Total	20	442.6485				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.005309	0.002654	0.027771	4.102821	
	Treatment	6	445.1119	89.02239	931.3889	3.325835	0.00000
	Error	12	0.955802	0.09558			
	Total	20	446.073				

Average berry weight (g)

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	0.137431	0.068715	0.228791	4.102821	
	Treatment	6	504.621	100.9242	336.0316	3.325835	0.00000
	Error	12	3.003414	0.300341			
	Total	20	507.7618				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.226757	0.113378	0.638848	4.102821	
	Treatment	6	510.6598	102.132	575.4775	3.325835	0.00000
	Error	12	1.774734	0.177473			
	Total	20	512.6613				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.117065	0.058532	0.425761	4.102821	
	Treatment	6	507.507	101.5014	738.3144	3.325835	0.00000
	Error	12	1.374772	0.137477			
	Total	20	508.9988				

Average yield per plant (g)

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	150.2199	75.10994	0.7126147	4.102821	
	Treatment	6	124450.8	24890.15	236.14833	3.325835	0.00000
	Error	12	1054.005	105.4005			
	Total	20	125655				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	111.7355	55.86774	0.9607884	4.102821	
	Treatment	6	125465.8	25093.15	431.54077	3.325835	0.00000
	Error	12	581.4781	58.14781			
	Total	20	126159				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	11.14338	5.571691	0.2160775	4.102821	
	Treatment	6	124939.4	24987.88	969.06272	3.325835	0.00000
	Error	12	257.8562	25.78562			
	Total	20	125208.4				

Estimated yield (kg per 1000 sqm)

2022	Source	df	SS	MS	Cal.F	Table F	P value
	Replication	2	61225.5	30612.75	0.712615	4.102821	

	Treatment	6	50722708	10144542	236.1483	3.325835	0.00000
	Error	12	429583.5	42958.35			
	Total	20	51213517				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	45540.31	22770.16	0.960788	4.102821	
	Treatment	6	51136396	10227279	431.5408	3.325835	0.00000
	Error	12	236994.5	23699.45			
	Total	20	51418931				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	4541.736	2270.868	0.216077	4.102821	
	Treatment	6	50921869	10184374	969.0627	3.325835	0.00000
	Error	12	105095.1	10509.51			
	Total	20	51031506				

TSS (ºBrix)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000833	0.000417	0.514403	4.102821	
	Treatment	6	250.4431	50.08861	61837.79	3.325835	0.00000
	Error	12	0.0081	0.00081			
	Total	20	250.452				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.002744	0.001372	2.678959	4.102821	
	Treatment	6	251.586	50.31721	98233.16	3.325835	0.00000
	Error	12	0.005122	0.000512			
	Total	20	251.5939				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000603	0.000301	1.183206	4.102821	
	Treatment	6	251.012	50.2024	197086.9	3.325835	0.00000
	Error	12	0.002547	0.000255			
	Total	20	4.224331				

Titrable acidity (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000211	0.000106	0.612903	4.102821	
	Treatment	6	1.186228	0.237246	1377.555	3.325835	0.00000
	Error	12	0.001722	0.000172			

	Total	20	1.188161				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000478	0.000239	1.125654	4.102821	
	Treatment	6	1.170761	0.234152	1103.335	3.325835	0.00000
	Error	12	0.002122	0.000212			
	Total	20	1.173361				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000303	0.000151	1.282353	4.102821	
	Treatment	6	1.189128	0.237826	2014.522	3.325835	0.00000
	Error	12	0.001181	0.000118			
	Total	20	1.190611				

Vitamin C (mg per 100g)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.041944	0.020972	0.076717	4.102821	
	Treatment	6	6297.601	1259.52	4607.345	3.325835	0.00000
	Error	12	2.733722	0.273372			
	Total	20	6300.377				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.147144	0.573572	1.045192	4.102821	
	Treatment	6	6465.059	1293.012	2356.19	3.325835	0.00000
	Error	12	5.487722	0.548772			
	Total	20	6471.694				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.269536	0.134768	0.742573	4.102821	
	Treatment	6	6377.657	1275.531	7028.183	3.325835	0.00000
	Error	12	1.814881	0.181488			
	Total	20	6379.741				

Reducing sugar (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.004433	0.002217	4.18239	4.102821	
	Treatment	6	18.63672	3.727343	7032.723	3.325835	0.00000
	Error	12	0.0053	0.00053			
	Total	20	18.64645				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**

	Replication	2	0.000233	0.000117	1.129032	4.102821	
	Treatment	6	18.61113	3.722227	36021.55	3.325835	0.00000
	Error	12	0.001033	0.000103			
	Total	20	18.6124				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000711	0.000356	2.949309	4.102821	
	Treatment	6	18.61487	3.722975	30881.82	3.325835	0.00000
	Error	12	0.001206	0.000121			
	Total	20	18.61679				

Non-reducing sugar

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000678	0.000339	2.563025	4.102821	
	Treatment	6	103.1389	20.62778	156008.4	3.325835	0.00000
	Error	12	0.001322	0.000132			
	Total	20	103.1409				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000233	0.000117	0.555556	4.102821	
	Treatment	6	103.4405	20.68809	98514.73	3.325835	0.00000
	Error	12	0.0021	0.00021			
	Total	20	103.4428				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000411	0.000206	1.428571	4.102821	
	Treatment	6	103.2896	20.65792	143568.5	3.325835	0.00000
	Error	12	0.001439	0.000144			
	Total	20	103.2914				

Total sugars (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.002711	0.001356	2.202166	4.102821	
	Treatment	6	209.4595	41.8919	68055.43	3.325835	0.00000
	Error	12	0.006156	0.000616			
	Total	20	209.4684				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000533	0.000267	3.076923	4.102821	
	Treatment	6	209.7982	41.95964	484149.7	3.325835	0.00000

	Error	12	0.000867	8.67E-05			
	Total	20	209.7996				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000211	0.000106	0.535211	4.102821	
	Treatment	6	209.6281	41.92563	212580.6	3.325835	0.00000
	Error	12	0.001972	0.000197			
	Total	20	209.6303				

Antioxidants (%)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.084233	0.042117	1.361677	4.102821	
	Treatment	6	14892.93	2978.586	96300.88	3.325835	0.00000
	Error	12	0.3093	0.03093			
	Total	20	14893.32				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.005033	0.002517	0.1006	4.102821	
	Treatment	6	14861.53	2972.306	118813	3.325835	0.00000
	Error	12	0.250167	0.025017			
	Total	20	14861.78				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.030233	0.015117	0.835791	4.102821	
	Treatment	6	14876.82	2975.365	164506	3.325835	0.00000
	Error	12	0.180867	0.018087			
	Total	20	14877.04				

Flavonoids (mg QE per 100g of FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.300833	0.150417	1.772875	4.102821	
	Treatment	6	5330.386	1066.077	12565.24	3.325835	0.00000
	Error	12	0.848433	0.084843			
	Total	20	5331.535				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.052433	0.026217	0.309414	4.102821	
	Treatment	6	5408.8	1081.76	12767.14	3.325835	0.00000
	Error	12	0.8473	0.08473			
	Total	20	5409.699				

Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.0324	0.0162	0.304683	4.102821	
	Treatment	6	5369.243	1073.849	20196.51	3.325835	0.00000
	Error	12	0.5317	0.05317			
	Total	20	5369.807				

Total phenols (mg GAE per 100g of FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.7103	0.85515	4.61387	4.102821	
	Treatment	6	50968.07	10193.61	54998.54	3.325835	0.00000
	Error	12	1.853433	0.185343			
	Total	20	50971.63				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	3.4048	1.7024	7.276458	4.102821	
	Treatment	6	50862.3	10172.46	43479.49	3.325835	0.00000
	Error	12	2.3396	0.23396			
	Total	20	50868.05				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.359975	1.179988	8.238075	4.102821	
	Treatment	6	50914.84	10182.97	71092.33	3.325835	0.00000
	Error	12	1.432358	0.143236			
	Total	20	50918.64				

Chlorophyll a (mg per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000231	0.000115	0.676944	4.102821	
	Treatment	6	3.28703	0.657406	3856.759	3.325835	0.00000
	Error	12	0.001705	0.00017			
	Total	20	3.288965				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000456	0.000228	2.00039	4.102821	
	Treatment	6	3.271981	0.654396	5735.845	3.325835	0.00000
	Error	12	0.001141	0.000114			
	Total	20	3.273578				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000293	0.000146	1.349332	4.102821	

	Treatment	6	3.278878	0.655776	6049.746	3.325835	0.00000
	Error	12	0.001084	0.000108			
	Total	20	3.280255				

Chlorophyll b (mg per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000311	0.000156	0.15625	4.102821	
	Treatment	6	10.35098	2.070196	2079.437	3.325835	0.00000
	Error	12	0.009956	0.000996			
	Total	20	10.36124				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.001233	0.000617	0.622896	4.102821	
	Treatment	6	10.42087	2.084173	2105.226	3.325835	0.00000
	Error	12	0.0099	0.00099			
	Total	20	10.432				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000353	0.000176	0.883171	4.102821	
	Treatment	6	10.38481	2.076962	10399.25	3.325835	0.00000
	Error	12	0.001997	0.0002			
	Total	20	10.38716				

Total chlorophyll (mg per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000211	0.000106	0.76	4.102821	
	Treatment	6	42.92876	8.585752	61817.42	3.325835	0.00000
	Error	12	0.001389	0.000139			
	Total	20	42.93036				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000844	0.000422	2.5	4.102821	
	Treatment	6	42.89244	8.578489	50793.68	3.325835	0.00000
	Error	12	0.001689	0.000169			
	Total	20	42.89498				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000203	0.000101	0.802198	4.102821	
	Treatment	6	42.90999	8.581998	67901.52	3.325835	0.00000
	Error	12	0.001264	0.000126			

	Total	20	42.91146				

Total anthocyanins (mg per g)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	1.181111	0.590556	2.080919	4.102821	
	Treatment	6	6930.02	1386.004	4883.811	3.325835	0.00000
	Error	12	2.837956	0.283796			
	Total	20	6934.039				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	2.729478	1.364739	2.073592	4.102821	
	Treatment	6	6866.584	1373.317	2086.625	3.325835	0.00000
	Error	12	6.581522	0.658152			
	Total	20	6875.895				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.194786	0.097393	0.629291	4.102821	
	Treatment	6	6897.583	1379.517	8913.541	3.325835	0
	Error	12	1.547664	0.154766			
	Total	20	6899.325				

Total carotenoids (mg per g FW)

2022	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000278	0.000139	1.168224	4.102821	
	Treatment	6	2.108578	0.421716	3547.14	3.325835	0.00000
	Error	12	0.001189	0.000119			
	Total	20	2.110044				
2023	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000633	0.000317	1.17284	4.102821	
	Treatment	6	2.128717	0.425743	1576.827	3.325835	0.00000
	Error	12	0.0027	0.00027			
	Total	20	2.13205				
Pooled	**Source**	**df**	**SS**	**MS**	**Cal.F**	**Table F**	**P value**
	Replication	2	0.000353	0.000176	1.178108	4.102821	
	Treatment	6	2.11784	0.423568	2829.026	3.325835	0.00000
	Error	12	0.001497	0.00015			
	Total	20	2.11969				

APPENDIX-II

LUX INTENSITY

Experiment 1: Outdoor conditions Year: 2022

	December			January			February			March		
Treatment	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**
T1	4321.36	4667.67	4200.42	4808.67	5305.5	4910.15	4867.19	5654.33	5218.56	9595.43	10000	9893.25
T2	4111.57	4493.11	4237.48	4784.89	5186.42	4811.38	4724.04	5470.33	5128.01	9494.35	9678.27	9514.33
T3	4032.58	4221.88	4078.36	4692.15	4916.47	4754.15	4410.58	5269.16	4914.26	8617.5	8820.04	8572.89
T4	3868.18	4072.91	3899.03	4279.23	4882.57	4550.4	4247.23	4780.15	4650.11	8357.93	8532.17	8318.62
T5	4440.43	4607.39	3116.64	4790.65	5103.59	4982.44	4932.73	5641.84	5207.51	9758.47	9943.18	9668.68
T6	4159.41	4324.47	4150.56	4756.33	5084.31	4913.67	4720.33	5370.18	5132.74	9050.27	9400.4	9268.34
T7	3828.34	4145.15	4072.78	4671.34	4994.33	4825.67	4707.58	5130.12	4989.5	8620.15	9150.28	9094.33

Year: 2023

	December			January			February			March		
Treatment	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**
T1	5634.23	5946.39	5790.18	4084.41	4479.19	4219.25	5673.36	6830.67	6159.34	9482.84	10000	9693.42

T2	5589.65	5706.47	5592.12	3976.34	4195.04	4189.33	5210.15	6537.63	6091.33	9379.03	9602.58	9431.48
T3	5218.18	5483.47	5377.33	3891.67	4046.58	4096.89	5088.38	6159.51	5785.81	8453.17	8794.18	8492.36
T4	5056.4	5294.04	5197.26	3652.11	3863.56	3705.33	4765.74	5580.74	5128.48	8269.25	8510.23	8290.15
T5	5723.73	5879.17	5782.95	3979.88	4298.78	4086.34	5536.67	6754.5	6420.89	9353.42	9875.43	9420.5
T6	5419.33	5668.18	5540.59	3689.44	4010.33	3971.56	5329.76	6436.33	6043.15	8950.47	9341.35	9122.93
T7	5174.58	5327.4	5216.31	3619.67	3998.33	3799.01	5108.92	5984.27	5658.91	8500.03	9208.64	8993.47

Experiment 2: Indoor conditions Year: 2022

	December			**January**			**February**			**March**		
Treatment	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**
T1	3010.33	3200.23	3068.04	2595.17	2878.18	2662.44	2758.33	3089.12	2830.34	4192.35	4558.67	4424.27
T2	3118.89	3337.23	3257.17	2856.56	3026.78	2974.4	2745.85	3249.04	3112.33	4353.74	4531.23	4601.6
T3	3108.33	3568.43	3277.06	2803.15	3169.33	3012.73	2911.25	3205.58	3078.5	5189.5	5670.65	5426.38
T4	3287.34	3447.67	3243.34	2995.5	3216.26	3178.33	2978.42	3418.56	3256.39	5777.46	6083.15	5932.74
T5	3442.11	3630.63	3513.33	3178.84	3306.95	3219.08	3037.76	3547.33	3364.47	5278.58	5548.33	5320.67
T6	3350.88	3515.51	4500.81	3069.03	3358.41	3125.19	3129.34	3469.67	3270.64	5765.32	6082.58	5896.48

Year: 2023

	December			**January**			**February**			**March**		
Treatment	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**	**Morning**	**Afternoon**	**Evening**
T1	3568.23	3679.33	3518.26	2678.88	2982.33	2786.67	3564.23	3931.38	3746.33	4237.56	4657.47	4578.33
T2	3423.73	3598.89	3460.11	2718.42	2985.28	2886.11	3587.65	3995.15	3753.67	4483.01	4609.15	4517.18
T3	3536.33	3884.5	3756.74	2837.47	3080.16	2914.25	3993.58	4348.4	4010.89	5456.17	5893.18	5571.4
T4	3895.84	4061.03	3967.43	2934.57	3126.19	3061.36	3922.93	4300.68	4217.15	5882.42	6188.27	5982.39
T5	3950.43	4196.64	4058.41	3117.51	3388.04	3200.57	4228.95	4450.34	4290.27	5383.48	5640.59	5420.44
T6	3683.09	4097.56	3940.18	2954.91	3347.58	3069.58	4089.15	4328.5	4118.04	5939.36	6346.31	6097.67

Appendix-III: Images of plants during experiment:

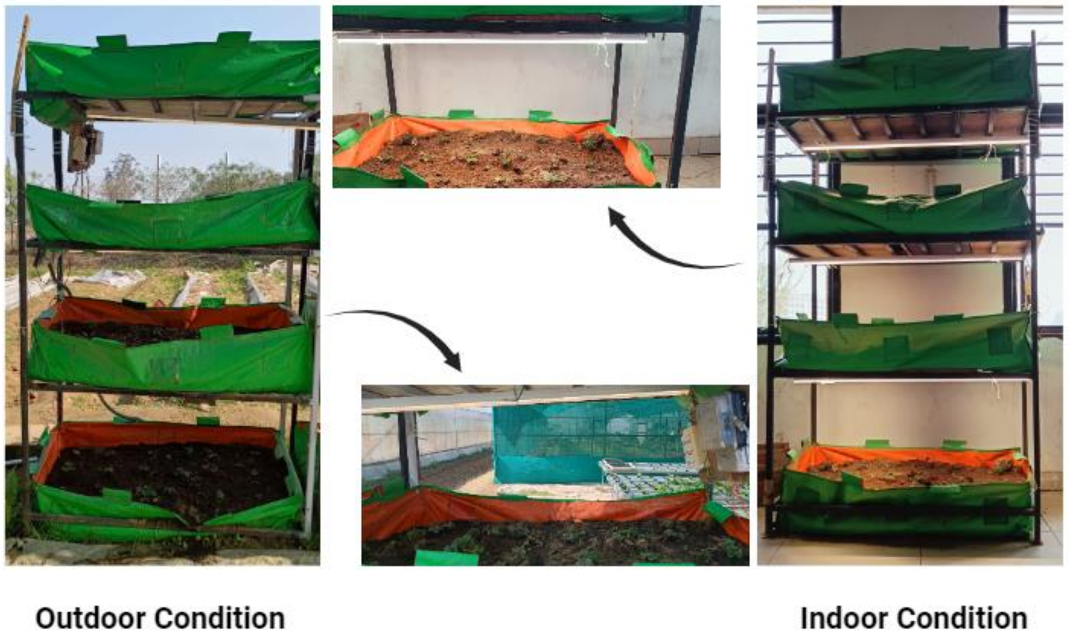


Fig. 1: Vertical farming structure with full spectrum in outdoor and indoor condition.

Fig. 2: Plants in different level of vertical farming. Outdoor Condition: A) T5 (Natural light+Full spectrum light+ Third Level + 2hours), B) T3 (Natural light+ Second Level), Indoor Condition: C)T5 (Natural light+Full spectrum light+ Third Level+ 6hours) D) T6 (Natural light+Full spectrum light+ Second Level+ 8hours)

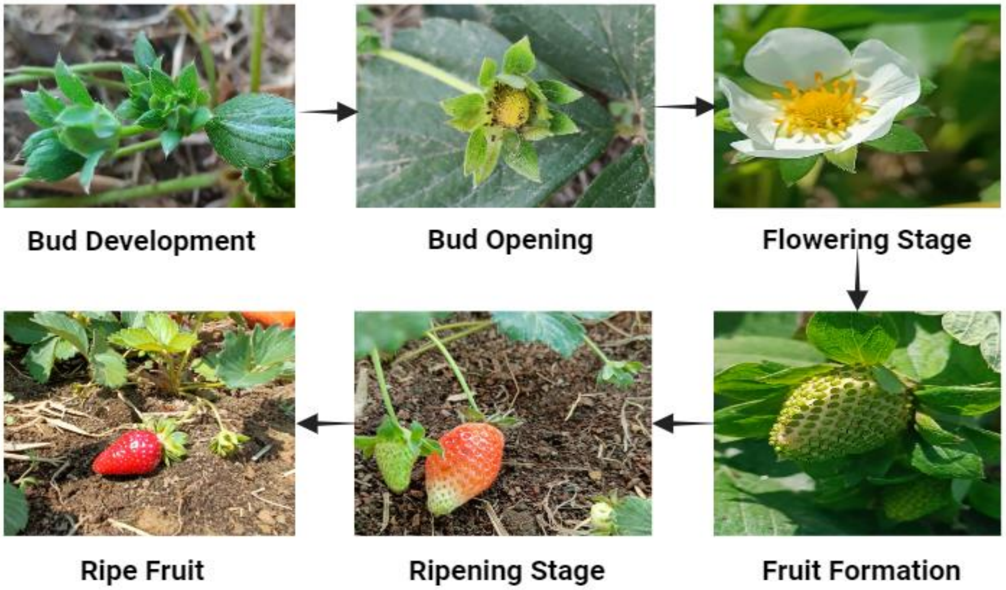


Fig. 3: Growth stages of strawberry in Outdoor Condition.

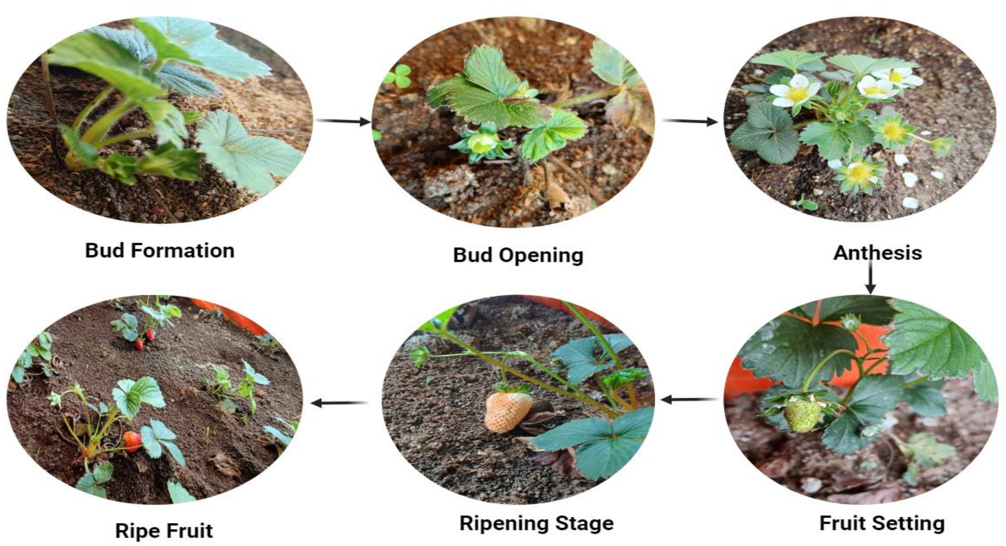


Fig. 4: Growth stages of strawberry in Indoor Condition.

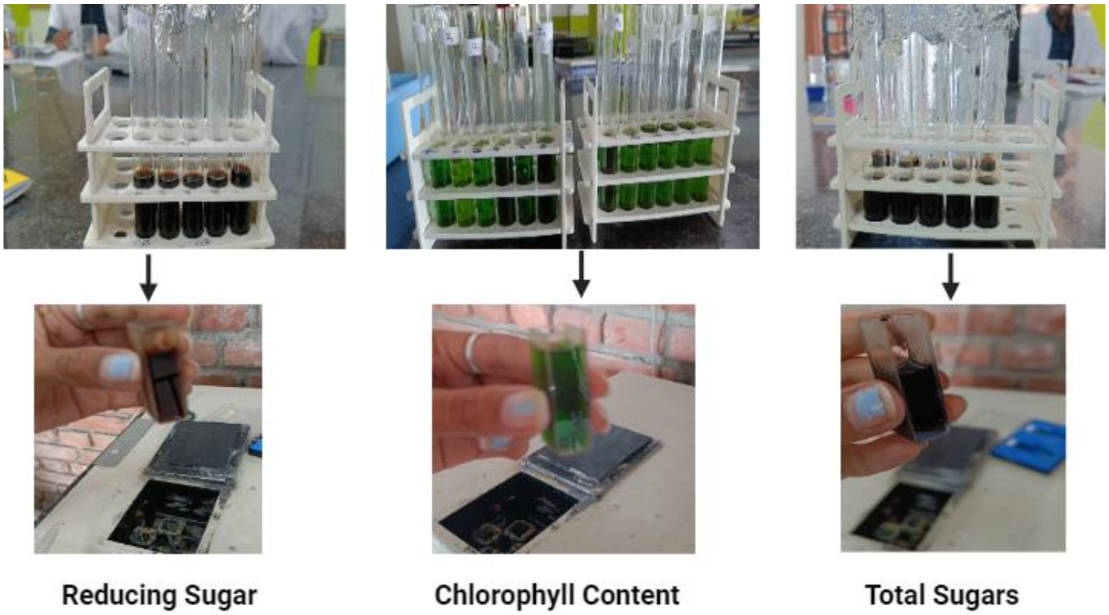
Fruit Weighing

Leaf Area

Fruit Volume

Lux Meter

Fig. 5: Observation of different parameters.



Reducing Sugar

Chlorophyll Content

Total Sugars

Fig. 6: Biochemical analysis of strawberry.