MORPHO-PHYSIOLOGY AND YIELD OF TOMATO (*Solanum lycopersicum* L.) VARIETIES AFFECTED BY DIFFERENT LEVELS OF LIGHT INTENSITY

SUMIT MANDAL

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE

SHER-E-BANGLA AGRICULURAL UNIVERSITY

DHAKA-1207

DECEMBER, 2021

MORPHO-PHYSIOLOGY AND YIELD OF TOMATO (*Solanum lycopersicum* L.) VARIETIES AFFECTED BY DIFFERENT LEVELS OF LIGHT INTENSITY

BY

SUMIT MANDAL

REGISTRATION NO.: 19-10316

A Thesis
Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

IN

AGROFORESTRY AND ENVIRONMENTAL SCIENCE

SEMESTER: JULY-DECEMBER, 2021

Approved by:

Dr. Jubayer-Al-Mahmud
Professor
Supervisor

Dr. Nazmun Naher
Professor
Co-supervisor

Dr. Nasrin Sultana
Chairman
Examination committee

Dr. Jubayer-Al-Mahmud
Professor
Department of Agroforestry and Environmental Science
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh
Mobile: +8801771-606735
E-mail: jamahmud_bd@yahoo.com

CERTIFICATE

This is to certify that thesis entitled, ***"MORPHO-PHYSIOLOGY AND YIELD OF TOMATO (Solanum lycopersicum L.)VARIETIES AFFECTED BY DIFFERENT LEVELS OF LIGHT INTENSITY"*** *submitted to the faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE*** *in* ***AGROFORESTRY AND ENVIRRONMENTAL SCIENCE****, embodies the result of a piece of bona fide research work carried out by* ***Sumit Mandal****, Registration No.:* **19-10316** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has been fully acknowledged by him.

Dated: December, 2021
Place: Dhaka, Bangladesh

(Dr. Jubayer-Al-Mahmud)
Professor
Supervisor

Dedicated To

My Beloved Parents
and
Respected Research Supervisor

ACKNOWLEDGEMENT

All praises to the Almighty and kind full trust on "God" for his never-ending blessing, it is a great pleasure to express profound thankfulness to my respected father and mother, who entitled much hardship inspiring for prosecuting my studies, thereby receiving proper education.

I would like to express my deepest, and sincerest gratitude, heartfelt respect, profound regards, and indebtedness to my respected teacher, and research Supervisor ***Dr. Jubayer-Al-Mahmud****, Professor, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka.* ***Dr. Jubayer-Al-Mahmud*** *being a great mentor, taught me every detail of experimentation, and data analysis. His door was always open for me to knock at, and start discussing any issues. Thanks to* ***Dr.Jubayer-Al-Mahmud*** *for his kind cooperation, excellent advice, valuable suggestions, and encouragement throughout the research work, and this thesis.*

I would also like to express my heartiest respect and profound appreciation to my Co-Supervisor ***Dr. Nazmun Naher,*** *Professor, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka, for his efficient supervision, invaluable advice, and excellent support, scholastic guidance, untiring assistance, valuable suggestions, and continuous encouragement in every aspect from the very beginning to the completion of this research work, and meticulous review of this thesis.*

I sincerely express the heartiest respect, and deepest gratitude to all the respected teachers, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka, for providing the facilities to conduct the experiment and for their valuable advice and sympatheticconsideration in connection with the study.

I express my deepest, and boundless gratitude, and a deep sense of pride to express my sincere appreciation, and indebtedness to my beloved parents ***Santosh Chandra Mandal*** *and* ***Biplobi Howlader*** *whose affections, inspiration, sacrifice, encouragement, and continuous blessing paved the way to higher education, and brought me to this position, and who always rolled as a constant, source of energy, happiness, and encouragement in my life.*

Lastly, I would be grateful to the official staff of the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka. I would also like to thank my friend ***Niloy Gain*** *for his support throughout my MS journey.*

Date: December 2021

Place: Dhaka, Bangladesh

- The Author

MORPHO-PHYSIOLOGY AND YIELD OF TOMATO (*Solanum lycopersicum* L.) VARIETIES AFFECTED BY DIFFERENT LEVELS OF LIGHT INTENSITY

ABSTRACT

Light stress is a limiting factor for crop production, especially in agroforestry system. A pot experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka-1207, during the months of October 2019 to mid-April 2020 in a completely randomized design (CRD) to determine the effect of low light on morpho-physiology and yield of tomato. Three tomato varieties viz. BARI Tomato-2, BARI Tomato-15, BARI Tomato-16 were exposed to four light intensities including 100% (S_0, control), 75% (S_1) , 50% (S_2), and 25% (S_3) to evaluate their performances. Light stress (mainly S_2 and S_3) substantially hampered the plant growth, development as well as yield. Low light stress primarily reduced the photosynthetic performance of plants which contributes in reduction of plant height, number of primary branches, and leaves of all tomato plants. Moreover, low light intensity negatively affected the fresh and dry weight of tomato. It also decreased the number of fruits, fruit length, fruit diameter, and individual fruit weight in all varieties. As a result, plant wise tomato production was hampered seriously with low yield. In comparison with control, S_1 condition decreased tomato yield per plant by 22.5, 16.9 and 15.3% in BARI Tomato-2, BARI Tomato-15 and BARI Tomato-16, respectively. Under S_2 condition, tomato yield per plant decreased by 38.7, 37.4, and 32.7% in BARI Tomato-2, BARI Tomato-15 and BARI Tomato-16, respectively, in contrast to control. Lastly, S_3 condition decreased tomato yield per plant by 73.1, 67.0 and 62.1% in BARI Tomato-2, BARI Tomato-15, and BARI Tomato-16, respectively, compared with control. From this result, it was clear that BARI Tomato-16 was more tolerant to low light stress than BARI Tomato-2 and BARI Tomato-15.

Keywords: Low light intensity, Morpho-physiology, Agroforestry, Tomato, Production system

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

Full Word	Abbreviation	Full Word	Abbreviation
Agro-Ecological Zone	AEZ	Milligram	mg
Bangladesh Agricultural Research Institute	BARI	Millimeter	mm
Centimeter	cm	Milliliter	mL
Completely Randomized Design	CRD	Muriate of Potash	MoP
Days after transplanting	DAT	Negative logarithm of hydrogen ion concentration (-log[H+])	p^H
Degree Celsius	°C	North	N
East	E	Percentage	%
Ecology	Ecol.	Photosynthetically Active Radiation	PAR
Environment	Environ.	Plant Genetic Resource Centre	PGRC
Experiment	Exp.	Review	Rev.
Gram	g	Science	Sci.
Hectare	ha	Soil Plant Analysis Development	SPAD
Journal	J	Specific Leaf Area	SLA
Kilogram	kg	Triple Super Phosphate	TSP
Microgram	µ	“which is” or “as follows”	viz.

CHAPTER 1

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) which belongs to the family Solanaceae is one of the most important vegetable species, produced and consumed worldwide, grown in both open-field and protected conditions, in soil or soil-less media (Milenkovic *et al.* 2018), concerning both economic and health aspects. Tomato originally came from American Southwest namely Peru and Mexico (Peralta and Spooner, 2007). It is the fourth largest vegetable in respect of production and third in respect of area in Bangladesh. Its uses in various forms both fresh and processed played a major role in its widespread adoption. In Bangladesh, the area of tomato cultivation is about 13,066 ha with the production of about 74,000 m tons (BBS, 2020).

Tomato is a tender perennial crop and one of the horticultural commodities which have high economic value. Tomatoes can be consumed fresh or processed into a variety of foods, including sauce, juice, ketchup, chutney, salad, pickles, and many other dishes. The acidity of tomatoes makes them simple to preserve as tomato paste or sauce in home canning. Additionally, unripe green tomatoes can be pickled or breaded and fried (Okunlola *et al.*, 2012).

Most tomato seeds are sown between October and November, and they are ready for harvest between December and April. Although tomato may grow in a range of climates, from temperate to hot and humid tropical areas, it needs a cool and dry temperature for its high quality and productivity (Nicola *et al.*, 2009).The optimal temperature range for tomato growth is 20–27°C.Fruit does not set well at average temperatures of more than 30°C or less than 10°C.Tomatoes prefer soil that has good drainage since they are sensitive to water logging.The pH of the soil should be between 6.0 and 7.0 for tomatoes; if it is below 5.5, issues like blossom end rot are frequently observed (Bibi *et. al.*, 2012).

The environment has a significant impact on the growth, morphology, physiology, and biochemistry of plants, in addition to being a key source of energy (Kwon and Woo, 2016).Changes in the light spectrum have had a substantial impact on the anatomy, morphology, and physiology of leaves (Macedo *et al.,* 2011).

In order to adapt to changing environmental light regimes, plants have developed a variety of mechanisms, such as morphological and physiological alterations at different levels (Zhang *et al.,* 2003; Fan *et al.,* 2013).According to Manurung*et al.* (2008), the metabolism of tomato plants grown in an agroforestry system or through any type of interculture (multiple cropping) is disrupted, which is thought to be the cause of the drop in the photosynthesis rate and carbohydrate synthesis.

Climate change and rising temperatures in recent years have had a detrimental impact on all vegetable crops, including tomato plants (El-Bassiony*et al.,* 2012).High temperatures can be harmful to tomatoes, reducing fruit yield and increasing the prevalence of fruit diseases like Sunscald and Blossom-end rot(Adegoroye and Jolliffe, 1987).Disorders in tomato fruits are caused by high light intensity (Dorais*et al.,* 2001).

With the population growth and changes in the environment, the arable land available percapita has gradually reduced and the adverse environmental factors that affect plant growth haveincreased, challenging food security (Rozendaal*et al*. 2006, Pires *et al*. 2011). So, it is now a prime need to improve system-based productivity and emphasis should be given to homestead vegetable production.Among the different traditional agroforestry systems, homestead agroforestry system is one of the oldest and potential systems because of its diversified role in homestead economy. Traditionally farmers grow different types of vegetables in association with tree in homesteads, where productivity of vegetables is low due to lack of appropriate combination and management as well.

Bangladesh Agricultural Research Institute (BARI) has developed several tomato varieties Moreover, it was noted that different cultivars have varying production potential and degrees of stress tolerance. The three most well-known BARI tomato types that are now on the market are BARI tomato 2, BARI tomato 15, and BARI tomato 16. According to Miah (2001), tomatoes can be successfully grown under artificial shade conditions up to a 25% shade level without yield loss. However, there is no information on how other well-known tomato types perform in different levels of light intensity conditions. It would therefore be more effective to screen out the various tomato varieties under different light levels of shaded conditions before suggesting the farmers to cultivate tomato varieties under various trees at the farm level. The growers might then choose the optimal tree-tomato combination in an agroforestry system if it were possible to determine the maximum levels of shade tolerance for the selected tomato varieties in terms of growth and productivity. Therefore, the objectives of the present study were as follows.

i. To characterize the morphological and physiological changes of three tomato varieties under reduced light condition;
ii. To evaluate the yield and yield contributing characteristics of different tomato varieties under low light stress and
iii. To identify the most suitable and adaptive variety under a partial shaded environment

CHAPTER 2

REVIEW OF LITERATURE

A large number of researchers gave their attention for the improvement of *Solanum lycopersicum* L. species on the various aspects of its production and utilization in consideration of its adaptability to the shaded condition. Tomato is one of the top most vegetables around the world as well as Bangladesh. Several studies on morphology, physiology, growth and yield of tomato and other crops under different levels of light intensity have been carried out in many countries of world. The review of literature concerning the studies represented under the following head:

2.1 Light

Light constitutes one of the most important environmental factors for plant growth and development. It determines the photosynthetic rate and accumulate-assimilation besides its regulatory roles in plant growth and productivity. However, plants are frequently exposed to excessive or inadequate light intensities and these fluctuations, collectively known as light stress, affect the agronomic traits in plants via inhibiting their physiological metabolic processes including photosynthesis, antioxidant machinery, and their abilities to fix atmospheric carbon and nitrogen.

2.2 Effect of light stress on germination

Seed germination is the growth of an embryonic plant contained within a seed resulting in the formation of a seedling. Germination of seeds may be affected by several environmental factors. It is a complex process that is controlled by several biological (species, seed viability, seed dormancy, seed size) and environmental (moisture availability, temperature, relative humidity, light intensity, and duration) factors. The most important external factors include temperature, water, oxygen, and sometimes light or dark (Araus*et al*., 2002).

A study on the germination of *Phalaris arundinacea*, reported that there was a high germination percentage under dark conditions (38%) and it was stated that "germination is not accelerated by light as in many other grass seeds, and may be even light inhibited in some cases" (Cisneros and Zedler, 2001).

Ologundudu *et al.* (2013)reported that seeds of *Abelmoschus esculentus,Amaranthus cruentus, Celosia argentea, Corchorus olitorius,*and *Delonix regia* were germinatedunder light and dark conditions. The germination parameters revealed that germination was higher in seeds of *A. cruentus*and *C. olitorus*under the light while the seeds of *D. regia* germinated more in the dark.

Veloso *et al.*(2017) obtained that seeds exposedto the high light intensity required more time to germinate while studying the *Copaiferaoblongifolia.* Seeds sown under high light had a lower germination percentage than seeds sown under low light.

Akinyemi and Sakpere (2015) found that there were no significant differences ingermination percentage in light and dark condition while studying the *Moringa oleifera.*

Thanos and Skordilis (1987) observed seeds of the Mediterranean pines, *Pinus halepensis* and *P. brutia*. germinate optimally at 20°C in dark conditions. Uninterrupted red light or diurnal white light always increases germination rate and sometimes give maximum germination percentage, as well. Irregular far-red light not only decreases germination in both species but also encourages secondary dormancy.

Kulkarni *et al.* (2005) observed the effects of temperature and light on seed germination of two medicinal plant species *Albucapachychlamys* and *Drimiarobusta*. At 25/20°C showed a significant ($P < 0.05$) effect on seed germination of *A. pachychlamys*, and resulted in 100% germination under 16:8h light/dark conditions. For *D. robusta*, the germination percentage was found at a constant temperature of 20°C (87%) and alternating temperatures of 25/20°C (90%).

Jha *et al.* (2016) conducted a study to investigate the effects of shading and location of the mother plant on germination and hormone content ofPalmer amaranth seed and found that the germination of fresh viable seed decreased from 25 to 12% with the increase of shade from 0% to 87%.

An experiment was carried out by Marca *et al.* (2021) with *Acacia feddeana*, *Prosopis ferox*, *Cercidiumandico*la (woody species), *Parodiamaassii*, and *Oreocereus celsianus* (cactus species) at an experimental garden considering shaded and unshaded pots. *A. feddeana* did better in the shade than *P. feroxand* and *C. andicola* did in the absence of shade.Shade had a greater impact on *Cercidium andicola* than *P. ferox*.

Cacti showed poor germination rates, although both species did well in the shade.

2.3 Effect of light stress on growth

As a primary source of energy, light is one of the most important environmental factors for plant growth (Naoya *et al.*, 2008), promotes plant photosynthesis in the form of energy, and regulates morphogenesis in the form of signals (Smith, 2000). The growth environments of plants vary because of different light intensities (Shi *et al.*, 2013), which exert varying influences on the shape, structure, photosynthetic characteristics, growth, anddevelopment of plants (Xie, 2013; Liu *et al.*, 2015). For example, shading increases plant height but decreases stem diameter, leaf area index, and leaf thickness (Shi *et al.*, 2006).

Light intensity is also an important factor for plant growth. Low-light grown plants have frequently been shown to be more susceptible to photoinhibition than those plants grown under high light intensity (Long *et al.*, 1994).The intensity and quality of light are essential for the growth, morphogenesis, and other physiological responses of plants (Rajapakse *et al*., 1992; Fukuda *et al.*, 2008; Li and Kubota, 2009).

Low light intensity affects plant growth and flowering (Zhao *et al.* 2012; Miller *et al.* 2015), changes in agronomic and morpho-physiological characters (Chairudin *et al.*, 2015), and also affect the production and quality of fruit (Ilic *et al*., 2012). Flower formation in most tomato cultivars is reduced dramatically, and formed flowers are often undeveloped and fail to reach the stage of fruit set under high temperature (Ohkawa *et al.*, 2007).

The photo-selective responses include fruitset, harvesting time and fruit yield, size, color, as well as internal and external quality (Shahak *et al.*, 2008, Rajapakse and Shahak, 2007).

Flowering, pollination, and fruit set of tomato are often adversely affected by extremely high temperatures. The optimum temperatures for tomato fruit setting are from 18.5 to 26.5°C (LeBoeuf, 2004).

The composition of the fruit is markedly affected by light levels, which also affects the fruit ripening characteristics including harvest time and storage life (Tombesi *et al.*, 1993; Zoran *et al.*, 2012).

Baharudin *et al.* (2014) found that under a shade level of 50%, 20 tomato genotypes cultivated in polybags showed high variances in plant growth, yield, and quality as responses to low light intensity.

Diversified light intensity could have different effects on the development of leaf area, growth, and yield (Vyas *et al*., 1996; Martin *et al*., 2011).

Sulistyowati *et al*.(2016) experimented on several tomato traits and evaluated their morphological and physiological characteristics responses to low light intensity. The study was conducted on 50 tomato genotypes cultivated under 50% and 100% light intensity and thevariables observed were: leaf number and area, flower number, fruit number, fruit weight and production, flowering and harvesting time. The tolerance levels of tested genotypes were classified based on plant relative productivity rate. The 50 genotypes under shading conditions were classified into 5 shade-loving genotypes, 16 shade-tolerant genotypes, 15 shade- moderately-tolerant genotypes, and 14 shade-sensitive genotypes. The first two principal components explained 57.19% variation. The first principal component was plant production and reproduction with a value of 37.69%; and the second one was planted morphological characters with the value of 19.50%. The dendrogram from cluster analysis separated 50 genotypes to 3 clusters with a distance of 20. There were 7 genotypes in the first cluster, 11 genotypes in the second cluster; and 32 genotypes in the third cluster.

Venkateswarlu *et al*. (2011) carried out an experiment to examine effects of low light intensity on different growth phases in rice (*Oryza sativa* L.). They reported that low light intensity negatively affect plant growth and development which ultimately decreased rice production.

Chouhan *et al.* (2018) experimented with a green colour shade net having 50% shade and found increased plant height and harvest duration by 40.03% and 60% respectively in comparison to open field.

Abdel-Mawgoud *et al.* (1996) found that shade (using a shade screen at 1.5 m above the plants 10 days after transplanting to provide 30% shade) has a significant effect on mainstem length and leaf area but not on leaf number or interceptedPhotosynthetically Active Radiation (PAR) of Tomato seedlings *(Lycopersicon esculentum* Mill.) cv. Prigade. The results showed that shade also reduced total dry matter production significantly as well as air and leaf temperatures under shade conditions were lower than that of the open field during daytime but it was higher under shade during the night. The results of this work and other works showed that shade didn't affect tomato fruit yield consistently and its use is not justified. Meanwhile, Shade can be used to improve fruit quality such as by reducing sunburn.

Kumar *et al.* (2013) experimented with clary sage (*Salvia sclarea* L.) under four levels of shade (0%, 25%, 50% and 75%) to investigate the effect of shading and plant density on plant growth as well as yield and found that root length, number of rootsplant^{-1}, flower weight/plant, total biomass/plant significantly reduced with increase in shade levels.

Argade *et al.* (2018) experimented to study the effect of different (35, 50, and 75 percent) shading intensities on the growth of cherry tomato. Maximum plant height was observed in 75 percent shading intensity and genotype KSP-113 at 30 days intervals (74.70 and 60.95 cm respectively).50 % flowering of cherry tomato required minimum days were observed in cherry tomatoes grown under 35 percent shading intensity (45.00 days) and genotype KSP-113 (44.00 days) and the maximum cluster length found (9.58 cm) also found under 35 percent shading and genotype KSP-113. The cultivation of KSP-113 genotype under 35 percent shading intensity was found to be most sustainable for improving the growth and yield of cherry tomato during the summer season.

Bibi *et al.* (2012) studied partial shade effects on various growth parameters of tomato varieties. The experiment consisted of providing shades (55 percent) and two tomato cultivars (Roma, Rio Grande).A maximum increase in plant height (101cm) was recorded in partial shade applied from April. Meanwhile, plant height in control (74.5cm), partial shade (74.1cm) in May, and partial shade in June (75.4cm) were almost the same.The maximum number of branches per plant was recorded in the controlled shade from May (4.1) and s June (4.2) while the minimum number of branches per plant (3.2) was observed in April. The maximum number of flower clusters and flowers per cluster were recorded in control plots (12.6, 5.1) whereas the minimum number was recorded in partial shade from April (5, 4.2) respectively.Fruit size was not affected significantly by shade. Partial shade applied in April and May significantly reduced the yield compared to that applied in June and full sun. Based on the results, it is concluded that shading tomato during summer is not recommended.

An experiment was conducted by Masabni *et al.* (2016) to observe the effects of two shade nets difference in shading intensity on growth of ‘Celebrity’ tomato and ‘Sweet Banana’ chili pepper was investigated from May to Aug. 2014.Plants were grown in 50% shade, 70% shade, orfull sun. Tomato grown in 50% shade hadsimilar yield and shoot fresh and dry weight and less photochemical stress compared to unshaded condition. The number and weight of unmarketable tomato decreased under 50% shade andsimilar resultswere obtained with chili pepper except for lower numbers of marketable fruit.Yield parameters of both tomato and chili pepper reduced significantly under 70% shade. Moreover, 50% and 70% shadecloth reduced leaf temperatures of tomato and chili pepperwith variable results in June and July.This study indicated that shading at 50% benefitstomato and chili pepper production in west Texas by reducing heat stress.

Okunlola *et al*. (2012) reported that tomato seedlings were subjected to light and nutrient stress to determine the effects of each of these stress factors as well as their combined effects on some morphological parameters of the plant. A two-way Analysis of Variance (ANOVA) carried out on the data obtained showed that light produced a significant effect on all the parameters measured except the shoot height. Nutrients however did not produce any significant effect on any of the morphological parameters measured. There was also no significant interactive effect of light and nutrients on the morphological parameters measured.

Haque *et al*. (2009) investigated the morpho-physiological changes and yield performance under four different levels of light (100, 75, 50, and 25% PAR) and observed that stem length, internode length, and individual leaf area increased, on the other hand, main stem diameter and numbers of leaves per plant decreased due to the reduced light levels.At 50% PAR number of leaves per plant did not decrease significantly in bottle gourd.Bottle gourd produced the highest yield (41.53 t ha) at 75% PAR level and at 25% PAR, it did not show significant fruit yield reduction level compared to full sunlight. However, considering TDM and fruit yield bottle gourd and cucumber were found suitable for reduced light condition (up to 50% PAR).

Wang and Zhu (2012) conducted a pot experiment to evaluate the effect of different light intensities and nitrogen supply levels with different soil water content on the production of tomatoes and found that the production of fruits under the same nitrogen treatment became higher with the higher light intensity. The best result was found on 60% of the traditional nitrogen application, high light intensity, and 70-75% soil water content.

Zhao *et al.* (2012)investigated the effects of different light intensities on the growth and leaf development of young tomato plants by using red light-emitting diodes (LEDs, R) and blue light-emitting diodes (LEDs, B) and found that fresh weight, dry weight, stem diameter and health index were superior in plants grown under 300, 450 and 550 μmolm^{-2} s^{-1}. The highest energy efficiency was found under 300 μmolm^{-2} s^{-1}. When photosynthetic photon flux density (PPFD) increased from 50 to 550 μmolm^{-2} s^{-1}, a decrease in the specific leaf area (SLA) was observed. The thickness of leaves, palisade parenchyma, and spongy parenchyma was the bigger, so the stomatal frequency and stomatal area per unit leaf area under 300 and 450 μmol m^{-2} s^{-1}.

Nguyen *et al.*(2019) investigated the effect of four different light intensities (90, 140, 190, and 240 µmol/m2/s) on the growth of hydroponic cultivated spinach under a combination of red and blue LEDs (R660/B450 = 80/20) in house and found that plant height, leaf number, leaf areaincreased with increasing intensity. He observed that differences in leaf thickness, palisade tissue length, and spongy tissue length was statistically significant between the 4 treatments.

2.4 Effect of light stress on physiology

Light plays a critical role in plant growth and development. The effects of shade on plant leaves have been extensively investigated. The quantity and quality, as well as direction of light, are perceived by photosensory systems which, collectively, regulate plant development, presumably to maintain photosynthetic efficiency (Hangarter, 1997). Shade affects photosynthesis parameters, decreasing the maximum net photosynthetic rate, light-compensation point, and dark respiration rate (Feng *et al*. 2004, Craine and Reich 2005, Joesting*et al*. 2009, Du *et al*. 2011, Wang *et al*. 2012).

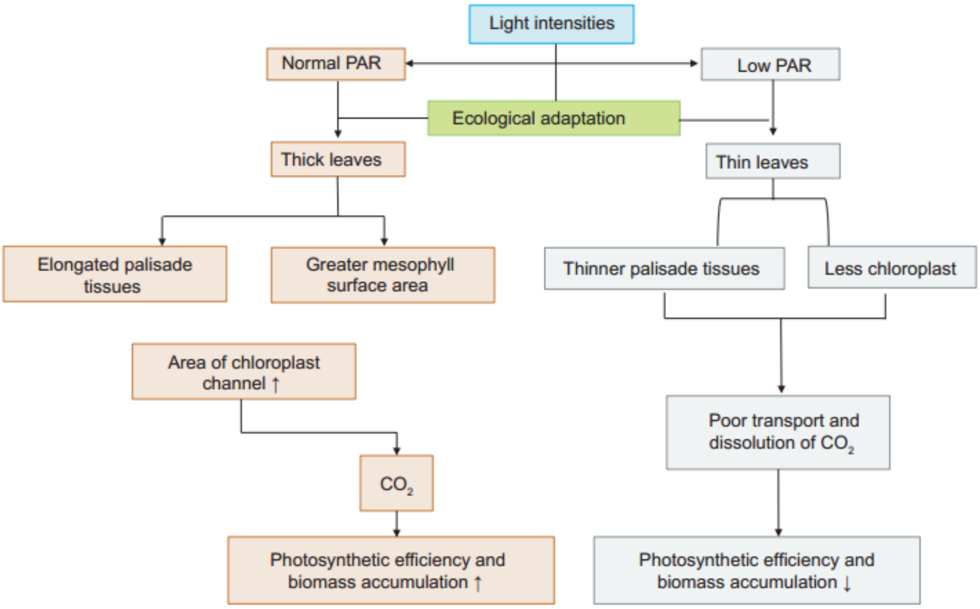


Figure 1: Effect of light intensity on leaf anatomy. The upward and downward arrows in the box represent increase and decrease, respectively PAR, photosynthetically active radiation (Shafiq *et al*., 2021)

Low radiation intensity can lead to an increase in specific leaf area (SLA) and plant height. These adaptations aimed to maximize available light absorption for photosynthesis (Steinger *et al.,* 2003). Meanwhile, the high radiation intensity is associated with many physiological and morphological characteristics that are appropriate to environmental conditions, such as reduced SLA to protect plants from high radiation exposure; increase leaf thickness by increasing the number of cell layers, or increasing the development of palisade and spongy tissue. This modification helps to prevent or mitigate the damage caused by excessive illumination by light energy, ensuring good photosynthesis (Matos *et al.*, 2009). In plant tissues such as stems and leaves, the synthesis of secondary metabolites may change due to physiological,biochemical, and genetic factors in whichlight is one of the photoreceptors (Lefsrud *et al.*, 2008).

On the other hand, according to Terashima *et al.* (2009), the light in the red and blue regions of the spectrum is mainly absorbed by photosynthetic pigments. About 90% of absorption by plant leaves is blue or red light (Terashima *et al.*, 2009). Thus, photosynthetic rate, physiology, plant growth, and development are significantly influenced by blue or red light (Chen *et al.*, 2014).

Light is the most important factor affecting stomatal conductance and leaf chlorophyll content (Christie, 2007; Kilinç and Kutbay, 2008; Taiz and Zeiger, 2008).

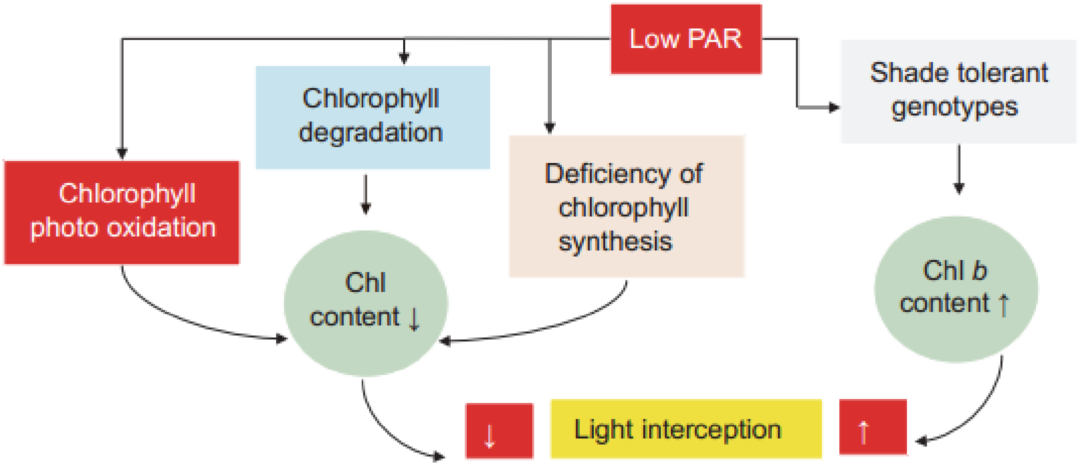


Figure 2: Contrasting effect of low irradiance on chlorophyll content. Upward and downward arrows refer to increase and decrease respectively while the red color shows the importance of the parameters with respect to its function. PAR, photosynthetically active radiations (Shafiq *et al*., 2021)

Fluctuation in light intensity can lead to stress in plants. Light as an energy source for plant life is known to affect plants dually. It affects photosynthetic rate and assimilates accumulation, thereby playing a substrate role; it also controls growth and development, in that way, it plays a regulatory role (Sysoeva *et al.*, 2010).

The cultivation of tomatoes with multiple cropping systems is constrained by low light intensity due to shade from other higher plants. The lack of light intensity causes physiological changes in plants, especially in photosynthetic activity (Susanto and Sundari 2011). Photosynthesis disturbances due to lack of light cause low carbohydrate (sucrose and starch) synthesis and a decrease in photosynthetic enzyme activity (Rubisco) which will impact on low production of plants (Jian-lei *et al*., 2014).

Photo oxidative damage, i.e. light-dependent generation of reactive oxygen species (ROS) in chloroplasts, is the key process involved in cell damage and cell death in plants exposed to environmental stress factors (Foyer *et al*., 1997; Asada 2000; Foyer and Noctor, 2005).

In general, plant leaves developed under shade conditions are thinner, have a low net CO_2 assimilation rate (An) (Tateno and Taneda 2007), CO_2 assimilation rate saturated at lower photosynthetic photon flux density (PPFD) (Zhang *et al.* 2004), and lower amounts of electron transfer carriers than unshaded leaves (Jiang *et al.*, 2011).

In addition, shading can regulate the carbon and nitrogen metabolism of plants (Evans and Poorter, 2001; Zhi *et al.*, 2001; Song *et al.*, 2010; Zhao (2012); Chen *et al.*, (2016).

Gregoriou *et al*. (2007) experimented with olive (*Olea europaea* L.) plant to observe the effects of reduced irradiance on leaf morphology, photosynthetic capacity, and fruit yield and concluded that reduced level of light intensity contributes in significant changes on different plant activities including growth, photosynthesis and total yield.

Sunaryanti *et al.* (2018) used two shade-sensitive, two shade-tolerant, and two shade-loving genotypes of tomato to evaluate the differences in adaptation mechanisms between shade-sensitive, shade-tolerant, and shade-loving tomato genotypes, based on their growth response and physiological characters and observed that low light intensity significantly decreased the Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) of tomato plants and also affected physiological characters, i.e., the rate of photosynthesis, stomatal conductance, pigment content, sucrose and starch in leaves, and NPK nutrient status. Moreover, the yield of shade-sensitive genotype was lower than the yield of both shade-tolerant and shade-loving genotypes because it has different physiological response to low light intensity.

Shao *et al*. (2014) used different shade treatments–50%, 30%, 20%, and 5% of natural irradiance for growing *Anoectochilus roxburghii* to evaluate its photosynthetic characteristics, chloroplast ultra structure, and physiology.At 30% shade, it showed the highest net photosynthetic ratesand stomatal conductance, followed in descending order by 20%, 5%, and 50% shade treatments. With the decrease of shade from 50% to 30%, electron transport rate and photochemical quenching increasedwhile non-photochemical quenching indexes decreased. Decreasing shade effect significantly increased *chl a* and *chl b* contents and decreased *chl a/b* ratios.

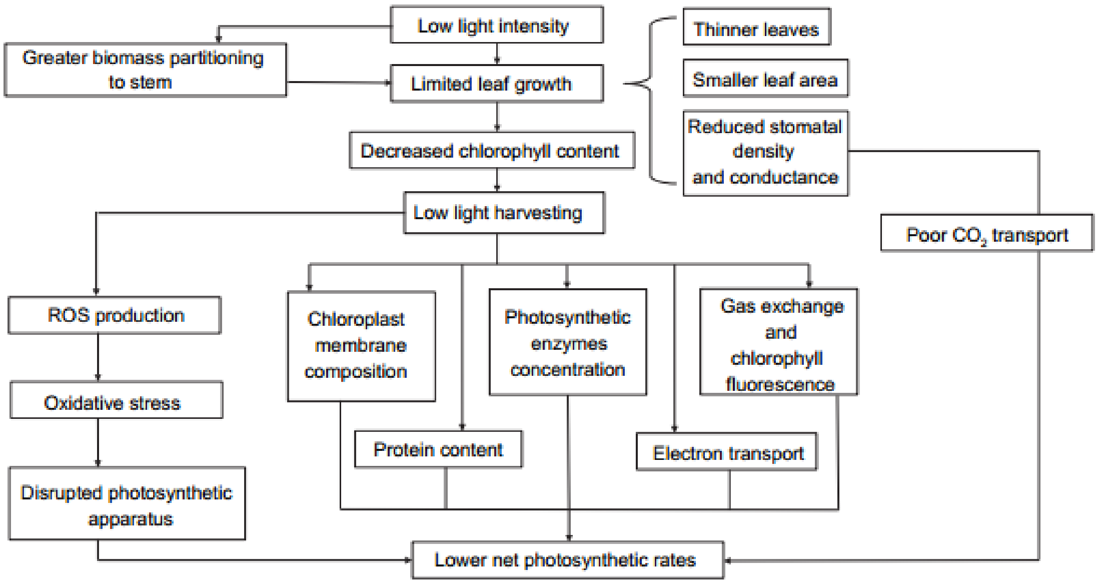


Figure 3: A proposed pathway for how low light intensity results in lower net photosynthetic rates. ROS, reactive oxygen species (Shafiq *et al.*, 2021)

At 50% shade effect, the highest peroxidases (POD) and superoxide dismutase (SOD) levels, and the lowest catalase activities, were observed.

Masabni *et al.* (2016) experimented to observe the effects of two shade nets difference in shading intensity on chlorophyll fluorescence, andphotosynthesis of ‘Celebrity’ tomato and ‘Sweet Banana’ chili pepper. Less photochemical stress was found in 50% shade.

Hang *et al.* (2019) analyzed photosynthetic characteristics and chlorophyll fluorescenceparameters of two maize cultivars under three light treatments: natural light (control), 44% shading, and 66% shading additionally observed the reduction of light-saturation point and light-compensation point of both the maize cultivars and improvement of theapparent quantum efficiencyduring the shaded period.

Studies were carried out by Yang *et al.* (2020) to observe the physiological changes and the mechanism of stress tolerance in tomato under low temperature and low light conditions and found that the activity of SOD and POD in tomato seedlings decreased under low temperature regime and it showed its greatest effect on the increase in enzyme activity. He also observed that the concentration ofmalondialdehyde (MDA) in plant tissue also decreased under low temperature (20˚C/10˚C day/night) compared to the standard temperature control (25˚C/16˚C day/night), but increased at 15˚C/5˚C day/night temperatures.But the content of soluble sugar decreasedunder only low temperature stress but increased under double stresses.

Lu *et al*. (2019)investigated theeffects of foliage spray of GR24, a synthesized SLs, on tomato seedlings grown under low light conditions and found that application of GR24 effectively mitigatedthe inhibition of plant growth and increased the fresh and dry weight under low light condition. Besides application of GR24 to low light condition, tomato leaves increased the electron transport rateof PSII and PSI [ETR(II) and ETR(I)], the ratio of the quantum yield of cyclic electronflow (CEF) to Y(II) [Y(CEF)/Y(II)], the oxidized plastoquinone (PQ) pool size and the nonphotochemical quenching. Moreover, GR24 application increased the activity and geneexpression of antioxidant enzymes, but it reduced malonaldehyde (MDA) and hydrogenperoxide (H_2O_2) content in low light conditions.

Purple pakchoi seedlings were exposed to low light by shading with white gauze and black shading in a phytotron by Zhu *et al*. (2017) and measured the responses in terms of photosynthetic properties, carbohydrate metabolism, antioxidant enzyme activity,anthocyanin biosynthetic enzyme activity, and the relative chlorophyll and anthocyanin content of leaves. They found that chlorophyll b, intra-cellular CO_2 content, stomatal conductance, and antioxidant activities of guaiacol peroxidase, catalase, and superoxide dismutase transiently increased in the shade treatments at 5 d.This experiment provides valuable information for further deciphering genetic mechanisms and improving agronomic traits in purple pakchoi under optimal light requirements.

Nguyen *et al.* (2019) investigated the effect of four different light intensities (90, 140, 190 and 240 µmol/m^2/s) onphotosynthesis, and leaf microstructure of hydroponic cultivated spinach under a combination of red and blue LEDs (R660/B450 = 80/20) in house and found that NGR, NAR, *chl a*, *chl* (*a* +*b*), photosynthetic capacity increased with increasing intensity.

Zhang *et al.* (2018) exposed potted *Begonia semperflorens*to different levels of shading (25%, 50%, 75%, 87%, and 93%) toinvestigate the response of thephysiological characteristics and found that with the increase of shading level, water content, superoxide anion ($O_2^{\cdot -}$) production rate, malondialdehyde (MDA)content and plasma membrane permeability exhibited increasing trends when compared with natural light but the relative contents of anthocyanin, soluble sugar, starch and the SOD activity displayed decreasing trends. Further analysis indicated that chlorophyll content, nitrate reductase (NR), and POD activities initially increased but subsequently decreased. The final result showed that plant can adapt from full light to 87% shading, and the number of flowers increased under 25–75% shading, at which the best ornamental quality was also observed.

Wijeratne *et al.* (2008) examined the physiological, anatomical, and biochemical changes of mature tea when subject to long-term exposure to three different levels of shade, i.e. NS (receiving 100% incident photosynthetically active radiation [PAR]), MS (receiving 65% incident PAR) and HS (receiving 35% incident PAR). On bright, clear days, NS leaves at the top of the canopy received PAR over the requirement and hence showed signs of photoinhibition. MS leaves received desirable levels of PAR, therefore had the highest rates of photosynthesis (A) (12.2% higher than NS). HS leaves received much less PAR than the requirement, hence had the lowest rates of A.HS leaves received much less PAR than the requirement, hence had the lowest rates of A.Radiation use efficiency was lowest in NS, which increased with shade, showing flexibility in adaptation to different light environments.

Rezai *et al*. (2018) conducted an experiment with sage (*Salvia officinalis* L.). plants under different light intensity. They reported that different level of light intensity contributes in significant changes on diverse plant parameters including on leaf morphology, photosynthetic capacity, and chlorophyll content.

Yao *et al.* (2017) carried out a study to understand the light acclimation of different soybean cultivars grown under different shade treatments and why the photosynthetic capacity of soybean decreased in shade. The chlorophyll content [*chl a,* chl b and *chl* (*a* +*b*)], apparent quantum efficiency (AQE), the value of electrons produced per photon (α), the maximal quantum yield of primary photochemistry (φPo), quantum yield for electron transport (φEo), efficiency/probability that an electron moves further than QA− (ψEo), andperformance index on the absorption basis (PIABS) of shade treatment increased significantly.On the other hand, efficiency/probability with which an electron from the intersystem electron carriers is transferred to reduce end electron acceptors at the PSI acceptor side (δRo), quantum yield for the reduction in end electron acceptors at the PSI acceptor side (φRo), total PI, measuring the performance up to the PSI end electron acceptors (PItotal) dropped significantly.The results showed that shade increased the light-intercepting and utilization ratio to low light and the activity of PSII of soybean plants, but the energy transport from PSII to PSI was blocked, which was the reason why the photosynthetic capacity was inhibited.Shade-tolerant cultivar L32 had higher PSII activity and energy transport from PSII to PSI than L29 in shade, so the shade-tolerant cultivar exhibited higher photosynthetic capacity and yield than shade-sensitive in shade.

2.5 Effect of light stress on yield

High temperature and light intensity during the summer have a negative effect on plant growth and yield (Lopez-Marin *et al*., 2012). Excessive light and heat load on leaves is a result of high solarradiation (Lopez-Marin *et al.,* 2011) which severely limits the productivity of a crop. Shading is a popular method to improve plant microclimate in the summer by decreasing leaf temperature and leaf transpiration rate, thus alleviating heat stress (Aberkani*et al*., 2008).

The growth,yield, and fruit quality of tomatoes can be influenced by their geneticpotential and environmental factors, such as temperature, radiation, etc. (Milenkovic L *et al*., 2018)**.**

Shade can increase the total and marketable yield of tomato grown in the open field in hot climates, whereas a 30-40% reduction in sunlight intensity seems to be optimum (Abdel-Mawgoud *et al,* 1996).

To produce a good yield, it is important that all the environmental factors should be at optimal levels. Under natural conditions, plants frequently encounter combinations of stress factors (Bazzaz, 1996; Sultan *et al*., 1998). Consequently, the individual ability to tolerate multiple stresses through morphological adjustments is a major feature that determines species survival andcolonization, and hence the ecological breadth of the species (Chapin *et al*., 1987; Bazzaz, 1996; Sultan *et al*., 1998).

Argade *et al.* (2018) conducted an experiment to study the effect of different (35, 50, and 75 percent)shading intensities on the yield of cherry tomato. The maximum weight of cluster (27.67 g), number of fruits per cluster (9.42), and number of pickings (11.67) were observed in 35 percent shading intensities and genotype KSP-113. The cultivation of KSP-113 genotype under 35 percent shading intensity was found to be most sustainable for improving the growth and yield of cherry tomato during the summer season.

Nangare *et al.* (2015) conducted a field trial to determine the effect of three green shade nets (35,50 and 75%) along with three height (2, 2.5, and 3.5 meters) bamboo framed structures on the yield and quality of tomato.There was no significant difference found in average monthly temperature and humidity inside shade net house and open field (control) but a significant difference was found in yield. The highest average plant yield (3.49 kg/plant) was found in 35% shading net followed by open field (2.27). The lowest yield was observed (1.07 kg/plant) in 75 % shading net.The tomatoes grown under shade net structures were glossy in appearance with good colour development as compared to an open field (control).

Nguyen *et al.*(2019) investigated the effect of four different light intensities (90, 140, 190, and 240 µmol/m2/s) on the yield of hydroponic cultivated spinach under a combination of red and blue LEDs (R660/B450 = 80/20) in house. The final results showed that fresh weight and dry weight of stem and leaf, theoretical yield, and final harvest yield were not highest in 240 µmol/m2/s treatment but in 190 µmol/m2/s treatment.

An experiment was conducted by Chouhan*et al.* (2018) to evaluate the performance of a green shade net on the yield and quality of tomato at farmers' field in the Shahdol district. A similar crop along with similar cultural practices in the open field and shade net cultivation was selected for performance evaluation. A green colour shade net having 50% shade factor was used in the experiment. The study resulted that under shade net condition performance of tomato the crop yield, number of fruit per plant, fruit weight,and harvest number increased by 75.32 percent, 61 percent, 76.3 percent,and 50 percent respectively over open field cultivation.

Shehata *et al.* (2013)carried out an experiment to improve fruit set and plant performance to increase tomato productivity under high temperature during the late summer season. Four tomato cultivars, i.e., Castlerock (as control), G.S.12, Alissa and Fayrouz were tested by using some shading treatments of 65% by agryl, 35% by ceran, and untreated control. The results showed that Alissa hybrid had the highest significant number of flowers and fruits during the two seasons.The interaction of Alissa hybrid and ceran had the highest significant stem diameter in the second season, the number of flowers in the first season.The interaction of G.S.12 hybrid and ceran had the highest significant firmness and Vitamin C. Alissa hybrid had the highest significant number of flowers, fruits,and yield per plant in the first season only. Fayrouze hybrid had the highest significant marketable yield in the second season.

Milenkovic *et al.* (2018)experimented on tomato (grafted and nongrafted) growing in the soil under net-house cover by pearl and red nets (50% shade index) or under unshaded condition (open field-control).Commercial tomato cultivars ('Optima F' and 'Big Beef F') were used todetermine whether grafting (Maxifort rootstock) could prevent the decrease in fruit weight and quality under light stress conditions.Shading maintained 30-40% highermarketable yield (reduced the amount of physiological disorders) than plants from non-shaded conditions in both cultivars.Fruits from shading plants under red nets obtained the highest lycopene content in both grafted and non-grafted plants.

Gent (2019) experimented to produce high-quality tomatoes in a greenhouse during summer under shade condition in the northeast United States. Marketable fruit was greatest for plants grown under 50%shade. This fraction was 9%greater than in a greenhouse with no shade in 2003 and 7% greater in 2004 and 2005. Cracked skin was the defect most affected by shade. Among sensitive cultivars, up to 35% of the fruit produced in greenhouses with no shade had cracked skin, whereas in greenhouses covered with 50% shade, only 24% to 26% of the tomatoes had cracked skin. The effect of shade increased with the duration of shading. There was no effect of 50% shade compared with no shade on total yield within 20 days, but yield decreased by 20% in the interval from 25 to 45 days after shading and by 30% after 50 or more days ofshading in 2005. Marketable yield only decreased after more than 45 days of shading for cultivars that were not sensitive to cracked skin or uneven ripening. Shade decreased fruit size over the entire season only in 2003. In general, shading increased the fraction of marketable tomato fruit without affecting fruit size.

El-Bassiony *et al.*(2014)used three shading levels (0%, 25%, and 50%) and two tomato plant cultivars (GS 12 and Marwa) to investigatethe effect of shading on fruit yield and quality of two tomato cultivars. He found that shading of tomato plants significantly enhanced the vegetative growth of tomato plants as plant length, number of leaves and shoots per plant as well as plant fresh and dry weight. The best results were obtained by shading net with 50% density followed by 25% density as compared with control.While shading increased the number of fruits per plant and total fruit yield. The maximum fruit yield was obtained by plants grown under 50% shading in both cultivars. Tomato plants grown under shading gave the best physical characteristics of tomato fruits (fruit length and diameter) and TSS%. Leaf concentrations of N, K, and Ca were significantly increased with the increased shading levels. The highest content of N, K and Ca was observed with shading with black net at 50% density. On the other hand, Plants grown without shading had the highest content of P.

Anusiya and Sivachandiran (2019) conducted an experiment to find out the performance of lettuce under different shade conditions using three different shade levels (0%, 50%, and 75%). The experiment was done based on the parameters of growth such as the number of leaves and leaf area, yield, and sensory attributes such as Color, Leaves stem appearances, and Overall appearance of the crop and found that the growth and yield of lettuce were greatly influenced by 50 % shade level.

Noertjahyani *et al.* (2020) carried out a pot experiment to study the effect of different shade levels of three peanut cultivars on the growth and seed yield as well as to determine the shade-tolerant cultivar using 50%, 65%, and 75% artificial shade levels during the lifetime of Tuban, Jepara, and Bima cultivars.The shade significantly affected the number of trifoliate leaves, number of branches, plant dry weight, yield components (number of pods, number of filled pods, and number of seeds), dry weight of pod, and seed weight per plant.The cultivar gave the same effect on the growth and seed yield per plant. Only Tuban cultivar showed great tolerance of 65% shade of natural light based on Stress Tolerance Index (STI) analysis on the seed dry weight per plant. The final result showed that cultivars tested sensitive at 75% shade level.

Pathiratna and Perera (2005) conducted an study to find the possibility of intercropping cinnamon (*C. verum*) with rubber (*H. brasiliensis* clone RRIC 100) planted with the normal inter-row spacing of 8.1 m.PAR from the rubber canopy into the center of the inter-row was reduced to 20.6% by the period of eight years. Cinnamon length per stick, weight, and bark yield have also reduced. The bark yield of cinnamon per bush was reduced to 70.5 %. The dry matter content of bark was highest (9.36 %) at 60% light level. Adverse effects of low light availability and rubber competition at this spacing on cinnamon were quite clear after five years.

Abubaker (2015) aimed to evaluate and determine the potential effects of threeseasonal regimes of drip irrigation (400, 600 and 800 mm) in a greenhouse with 30% shade and without shade on fresh market tomatoes (*Lycopersicon esculentum* Mill.). He used indeterminate transplants of tomato cultivar `Neuton`. Under shaded plastic cover, dry matter content of plants (leaves and stems) and stem diameter (mm) was higher compared to non-shaded plants. Days required for 50% flowering were statistically lowered under the non-shaded condition. The shaded treatments produced significantly higher yields (196.3 t/ha) compared to the non-shaded treatments (177.2 t/ha). Tomato yields were the highest under 800 mm irrigation water regimes in shaded and non-shaded conditions.

Özer (2017) conducted a study to determine the effects of 50% shading and three different organic fertilizers [ricehusk compost (RHC), broad bean green manure (B), and turnip residues (T)] on the yield and quality parameters of tomatoes cv. Sumela F1grown in the field. Higher yield was found in 50% shade compared to the unshaded condition and also the highest leaf photosynthetic rate (88.31µmol O2 m-2 s-1), fruit firmness (19.62 N) and fruit vitamin C content (38.44mg 100 g-1) were obtained from turnip residues (T) treatment under shading.The highest values for SSC (5.6%), yield (3.97 kgper plant), and leaf chlorophyll content (46.68 CCI) were obtained fromshaded and broad bean green manure treatment.

A field experiment consisted of three levels of light intensity (viz. L1: Full sunlight, L2: 20 % reduced sunlight, and L3: 40% reduced sunlight was conducted by Amin *et al.* (2014) to evaluate the influence of light intensity on tomato yield and found that the highest plant height (26.2 cm at 60 DAT), leaf number (49.6 at 60 DAT), branch number (5.5/plant at 60 DAT), number of flowers (58.4/plant), number of fruit (39.5), length of fruit (4.8 cm), diameter of fruit (4.5 cm), weight of individual fruit (40.9 g) and yield (22.32 t/ha) of tomato was found from L2 which was statistically similar to those of L3 the corresponding values were observed in L1 treatment.

CHAPTER 3

MATERIALS AND METHODS

This chapter deals with the information on the subject of materials and methods that were used in the experiment. It consists of a short explanation of the location of the experimental site, soil characteristics, climate, materials used in the experiment, layout, and design of the experiment, land preparation, manuring and fertilizing, seed sowing, intercultural practices, harvesting, data recording procedure, and statistical analysis, etc. which are presented as follows:

3.1 Experimental site

This experiment was conducted in the field laboratory of the Agroforestry and Environmental Science Department, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period from October 2019 to Mid-April 2020. The location of the site is 23°74' N latitude and 90°35'E longitude with an elevation of 8 meters from sea level (Islam, 2014; Laylin, 2014). The experimental site is shown in the map of AEZ of Bangladesh in Appendix I.

3.2 Soil Characteristics

The soil of the experimental site lies in Agro-ecological region of Madhupur Tract. Soil of the experimental site belongs to the general soil type, shallow red brown terrace soils under Tejgaon Series. The soil was loam in texture. The experimental site was medium high land and the pH was 5.6 to 5.8 and organic carbon content was 0.82%. Physiochemical properties of the soil used in plastic pot experiment are listed in Appendix III.

3.3 Climate

The climate of experimental site was located under a subtropical climatic zone. The experimental phase [during October to Mid-April (Rabi season)] showed plenty of sunshine and moderately low temperature shown in Appendix IIwhich was highly suitable for tomato production in Bangladesh.

3.4 Planting materials

Three popular varieties of tomato were collected from PGRC, BARI, Gazipur on September 2020. The three selected tomato genotypes are BARI Tomato-2 (V_1), BARI Tomato-15 (V_2), and BARI Tomato-16 (V_3).

3.5Treatments of the experiment

The experiment was conducted to evaluate the performance of 3tomato varieties; BARI Tomato-2 (V_1), BARI Tomato-15 (V_2), and BARI Tomato-16 (V_3) under 4 different levels of light intensity treatment.These treatments are (1) S_0-Control, 100% light intensity /full sunlight, (2) S_1-75% light intensity, (3) S_2-50% light intensity, (4) S_3-25% light intensity. The light intensity was measured by lux meter in an open field condition which was considered as 100% light intensity. One layer of nylon net was used and it gave approximately 75% light intensity. Likewise, two layers of nylon net gave 50% light intensity and three layers of nylon net gave about 25% of light intensity. These four light intensity levels were maintained in this study for each variety to create low light stress by using white nylon nets.

So, The total number of treatment was 12. The treatment combinations are listed below:

1. V_1S_0
2. V_1S_1
3. V_1S_2
4. V_1S_3
5. V_2S_0
6. V_2S_1
7. V_2S_2
8. V_2S_3
9. V_3S_0
10. V_3S_1
11. V_3S_2 and
12. V_3S_3

3.6 Design and layout of the experiment

The experiment was set up and evaluated in completely randomized design (CRD) using two factors; Factor A comprises 3 tomato varieties and Factor B included 4 light intensity treatments. The experiment was conducted with 3 replications. So, total 36 plastic pots were used in the experiment.

3.7 Pot preparation

Pots were filled with soil after mixing appropriate doses of cowdung on October, 2019. Weeds and stubbles were completely removed from the soil before pot filling to ensure proper plant growth. Formaldehyde (45%) was used for soil treatment for 48 hours to keep the soil free from pathogens before filling the plastic pots. Each plastic pot was filled with 10 kg of soil. The height of the pot was 35 cm, the top diameter was 30 cm and the bottom diameter was 20 cm.

3.8 Raising of seedlings and crop establishment

Seed sowing was done in separate plastic pots on October 29. Before sowing, seeds were treated with 70% ethanol for five minutes. Seedlings were raised in the pots using regular nursery practices. Recommended cultural practices were undertaken before and after seed sowing. When the seedlings become 25 days old (on November 23, 2019), two homogenous seedlings were transferred to each main plastic pot. Furthermore, after establishment, one plant was removed and one was allowed to grow for the experiment.

3.9 Manure and fertilizers application

The requiredamount of fertilizers (N, P, K, and S kg ha^{-1}) and manure were estimated on the basis of the initial soil test result according to the Fertilizer Recommendation Guide (BARC, 2012). Urea 7.0g, triple super phosphate (TSP) 7.0g, muriate of potash (MoP) 3.0g, gypsum 2.0g, and 100.0g of cow dung per pot were applied in the plastic pot as per recommendation. One-third of urea and the entire amount of cow dung, TSP, and MoP were mixed with the soil in each pot before sowing. The rest of the urea was applied as a side dressing at 25 and 45 days after transplanting.

3.10 Establishment of shading treatments

Nylon nets of different sieve size hanged after transplantation to the main pot with the help of bamboo sticks at a height of 2.3meters to create lowlight treatments. 75% light intensity, 50% light intensity, and 25% light intensity indicated the low light treatments. The control treatment consisted of full sunlight or 100% light intensity (Plate 1).

3.11 Intercultural operations

Irrigation and different intercultural operations were appliedas per requirement. Weeding was performed in all pots at regular intervals to keep plants free from weeds. Diseases and pest attack is limiting factors to tomato growth and yield which later hamper the overall production. Tomato plants were treated with Bavistin DF and Cupravit 50WP to prevent undesired diseases @1g/L and 2g/L respectively. Malathion 250EC @ 0.5ml/l is used for controlling leaf miner and aphid. Those fungicides and pesticides were sprayed in two intervals, the first dose at the vegetative growth stage and another one during the early flowering stage to manage pests and diseases. Stakingwas done to each plant by bamboo stick between 25-30 days after transplanting when plants were well established to keep the plants straight and to avoid breakage of plants due to heavy fruit weights during the fruiting stage. Proper tagging and labeling were done for each plant using thin sticks. Intercultural operation is presented on Plate 4.

3.12 Harvesting

Harvesting was done at the edible stage of all three varieties when they turned into a medium to deep red at regular intervals from last week of January to end of March, 2020.

3.13 Parameter Studied

Data were recorded from each pot based on physiology, growth, and yield parameters. Data on the following parameters were recorded throughout the experiment:

3.13.1 Measurement of growth and morpho-physiological characters

1) Plant height (cm)

2) Number branch Plant^{-1}

3) Number of leaves Plant^{-1}

4) Plant fresh weight (gm)

5) Plant dry weight (gm)

6) SPAD unit

3.13.2 Measurement of yield and yield contributing characters

1) Number of fruits cluster^{-1}

2) Number of fruits plant^{-1}

3) Fruit length (cm)

4) Fruit diameter (cm)

5) Individual fruit weight (g)

6) Fruit weight Plant^{-1}

7) Yield (ton ha^{-1})

3.14 Detailed Procedures for Recording Data

The data collection (Plate 2) and recording procedure are briefly given below:

3.14.1 Measurement of morpho-physiological characters (Plate 3)

3.14.1.1 Plant height (cm)

Plant heights were measured in centimeters (cm) from the ground level to the tip of the longest stem after 30 DAT and 60 DAT.

3.14.1.2 Number of leaves per plant

The leaf of the individual plant was recorded at 10 days interval from 30 DAT to 60 DAT and the average number of leaves per plantwas calculated.

3.14.1.3 Number of branchesper plant

The branch number of the individual plant was recorded at 20 days intervals from 50 DAT and70 DAT in addition the average number of branchesper plant was calculated.

3.14.1.4 Plant fresh weight

Plant fresh weight excluding fruits was counted after uprooting the plant using an electrical balance machine and the mean was calculated.

3.14.1.5 Plant dry weight

Plant dry weight (DW) excluding fruits was counted after oven drying at 70° C temperature. Then the uprooted plant samples were weighed using an electrical balance machine and the mean was calculated.

3.14.1.6 SPAD unit

Chlorophyll (Chl) content in terms of SPAD (soil plant analysis development) unit was recorded using a portable SPAD 502 Plus meter (Konica-Minolta, Tokyo, Japan).

In each measurement, the SPAD reading was repeated 5 times from the leaf tip to the base, and the average was used for analysis.

3.14.2 Measurement of yield and yield contributing characters

3.14.2.1 Number of fruits cluster per plant

The number of fruit clusters of the individual plants was counted and the average number of a cluster was recorded (Plate 5).

3.14.2.2 Number of fruits per plant

The number of fruits of the individual plants was counted and the average number of fruits was recorded.

3.14.2.3 Individual fruits weight (g)

The fresh weight of individual fruits was recorded by an electric balance (Plate 6) and the average fruit weight of an individual plant was also recorded. In addition,the mean value was calculated.

3.14.2.4 Fruit length (cm)

The length of fruit was measured with slide calipers from the neck of the fruit to the bottom of 10 fruits from each plant and their average was taken and expressed in cm.

3.14.2.5 Fruit diameter (cm)

Fruit diameter was measured at the middle portion of 10 fruits from each plant with slide calipers. Their average was taken and expressed in cm.

3.14.2.6 Fruit weight per plant

Fruits were harvested many times. Fruit weight per plant was recorded from all harvests of each plant and expressed as kilogram (kg) per plant.

3.14.2.7 Yield per plant (ton/ha)

Fruits were harvested many times. Yield per plant was recorded from all harvests of each plant and expressed as kilogram (kg) per plant. It was also calculated from the total number of tomatoes by multiplying individual fruit weight.

3.15 Statistical analysis

Statistix 10 software was used to statistically evaluate the collected data. The mean for each treatment was calculated and Least Significant Difference (LSD) test was used to evaluate the analysis of variance and treatment differences at a 5% level of significance (Gomez and Gomez,1984).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Growth and physiological parameters

4.1.1 Plant height

The plant height of BARI Tomato-2 (V_1) was 40.5, 33.33, 31.0 and 26.0 cm under 100% (control), 75%, 50% and 25% light intensity, respectively, at 30 DAT. For BARI Tomato-15 (V_2), plant height was 41.83, 33.17, 30.67 and 27.33 cm under 100%, 75%, 50%, 25% light intensity, respectively and the plant height for BARI Tomato-16 (V_3) under 100%, 75%, 50% and 25% was 39.83, 34.5, 32.67 and 28.83 cm, respectively.

In comparison with 100% (control) light intensity, the plant height of all three tomato varieties decreased gradually. At 75% light intensity, plant height was decreased by 17.7, 20.7, and 13.3% in V_1, V_2, and V_3, respectively. For 50% light intensity, more reduction percentage was noticed compared to 25% light intensity. At 25% light intensity, plant height of all the three varieties decreased drastically which was 35.8, 34.6, and 27.6% in V_1, V_2, and V_3, respectively.

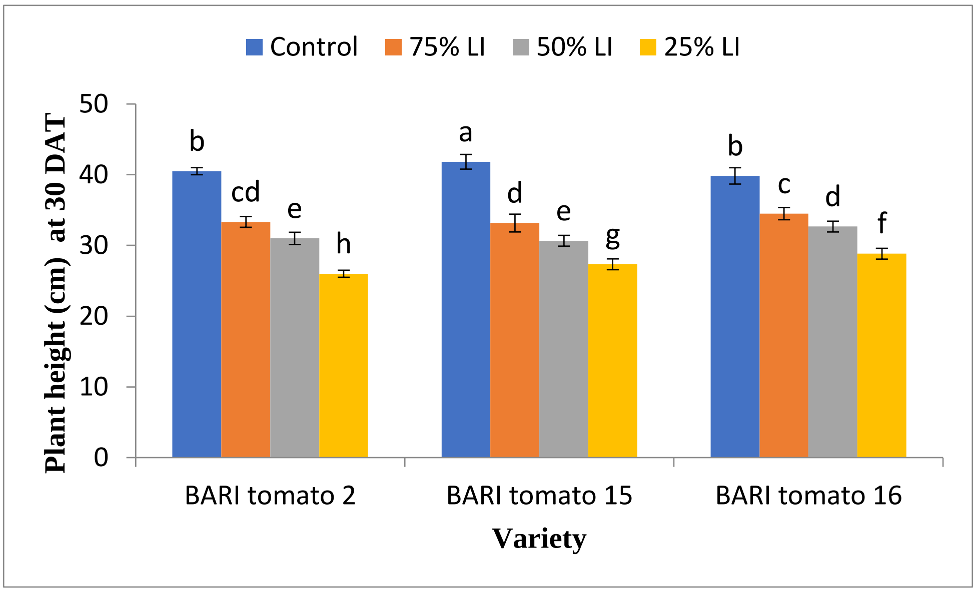


Figure 4. Effect of different light intensity on plant height of different tomato varieties at 30 DAT (days after transplanting). LI indicates Light Intensity. Bars (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

At 60 DAT, under 100% (control), 75%, 50% and 25% light intensity, the plant height of BARI Tomato-2 (V_1) was 83.83, 70.5, 60.67 and 53.17 cm, respectively. For BARI Tomato-15 (V_2), plant height was 92.17, 77, 70.83 and 57.67 cm under 100%, 75%, 50%, 25% light intensity, respectively and the plant height for BARI Tomato-16 (V_3) under 100%, 75%, 50% and 25% was recorded 85.33, 82.40, 74.83 and 62.67 cm, respectively.

In contrast with 100% light intensity, the plant height was decreased gradually in all varieties at 75%, 50% and 25% light intensity as before. The lower reduction in plant height was recorded in 75%, which was 15.9, 16.4, and 3.43% in V_1, V_2, and V_3, respectively, and the higher reduction was observed under 25% light intensity. In contrast to control, the reduction was 36.5, 37.4, and 26.5% in V_1, V_2, and V_3, respectively.

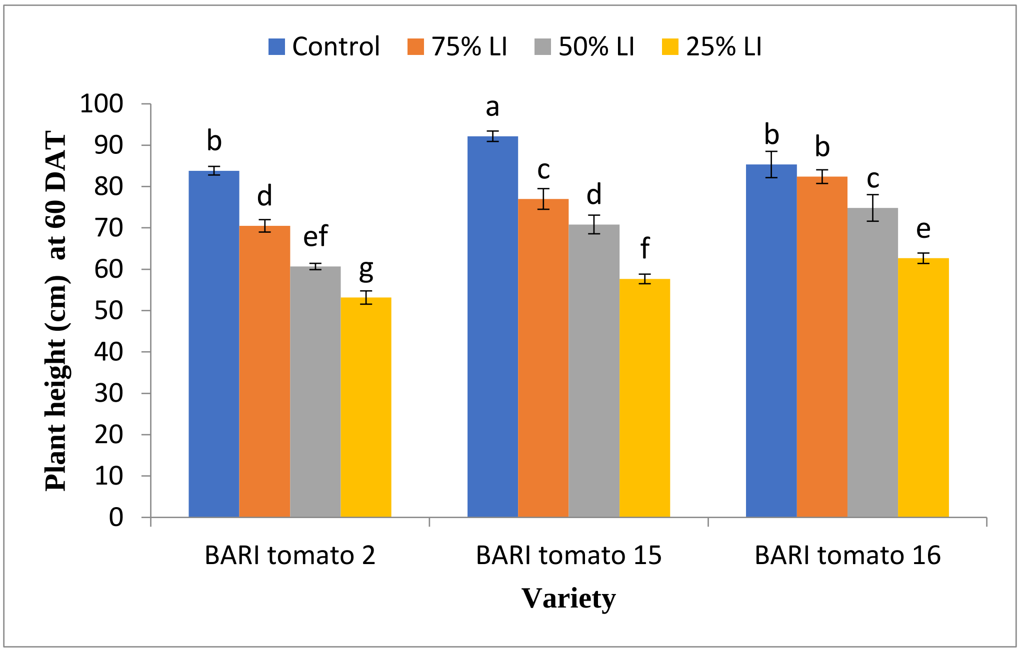


Figure 5. Effect of different light intensity on plant height of different tomato varieties at 60 DAT (days after transplanting). LI indicates Light Intensity. Bars (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

So, it is very clear that maximum reduction was observed under 25% light intensity (S_3 treatment) and minimum reduction was found under 75% light intensity (S_1) in all three varieties. Furthermore, BARI Tomato-16 showed the best result in plant height and BARI Tomato-2 (V_1) showed the lowest result.

Low light stress may decrease the cell division of the plant. The findings of the present study are supported by Dong *et al*. (2014) who confirmed that low light intensity affects the growth especially decreased the straw length of wheat (*Triticum aestivum* L.) at different growth stages. Similar results were also obtained by Thakur *et al*. (2019) in damask rose (*Rosa damascena* Mill.). Haque *et al*. (2009) also observed low light intensity severely hampered the plant height of bottle gourd. Interestingly Steinger *et al.* (2003) found the reverse result that shows low radiation intensity can lead to an increase in plant height.

4.1.2 Leaf number

Leaf number was counted two times at 30 and 60 DAT. Leaf number at 30 DAT was found 13.5, 11.83, 11.17, and 8.17 under 100%, 75%, 50%, and 25% light intensity, respectively for BARI Tomato-2 (V_1). Again, under 100%, 75%, 50%, and 25% light intensity condition, the leaf number was found 12.83, 10.5, 10.17, and 9.17, respectively, for BARI Tomato-15 (V_2). On the other hand, 14.17, 12.67, 12, and 10.17 leaves were recorded under 100%, 75%, 50%, and 25% light intensity, respectively, in BARI Tomato-16 (V_3).

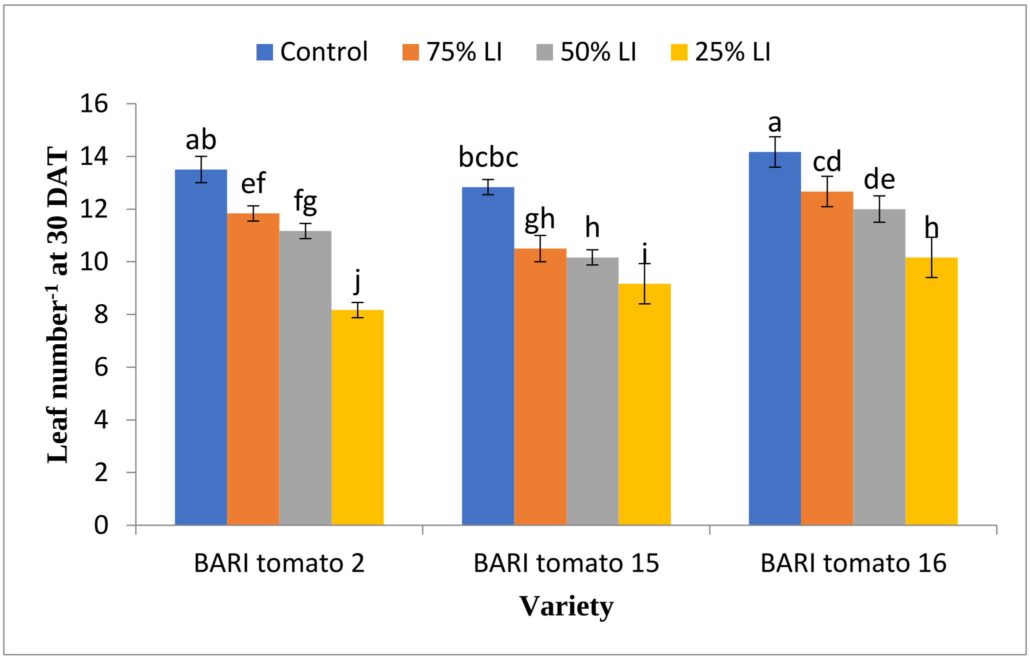


Figure 6. Effect of different light intensity on leaf number of different tomato varieties at 30 DAT (days after transplanting). LI indicates Light Intensity. Bars (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

These data showed a gradual reduction of leaf number under 75, 50, and 25% light intensity in contrast to 100% light intensity. The highest reduction was found at 25% light intensity which was 12.3%, 18.1%, and 10.5% for V_1, V_2, and V_3, respectively. At 50%, we found a moderate reduction, and at 75% light intensity, the lowest reduction was found which was 39.4, 28.5, and 28.2% for V_1, V_2, and V_3, respectively.

Almost similar results were found at 60 DAT. The leaf number was recorded as 29.67, 26.0, 23.67, and 16.33 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively, for BARI Tomato-2. For BARI Tomato-15, the leaf number was 25.67, 22, 19, and 15.33 under S_0, S_1, S_2, and S_3, respectively. In addition, the number of leaves for BARI Tomato-16 was found 30.33, 27.33, 24.67, and 22.33 under S_0, S_1, S_2, and S_3, respectively.

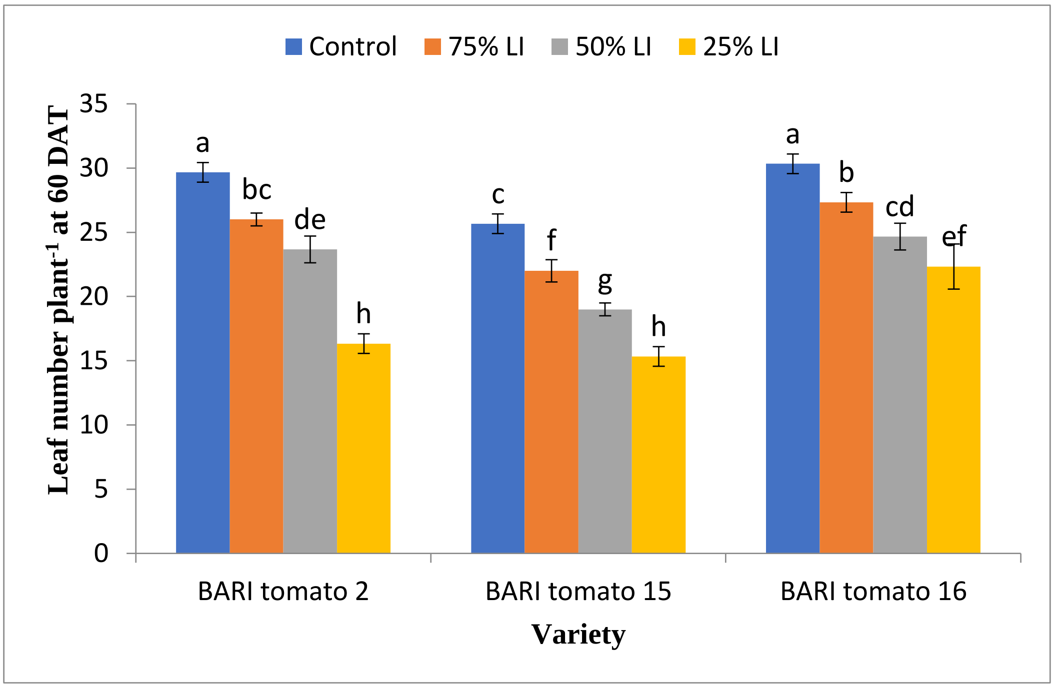


Figure 7. Effect of different light intensity on leaf number of different tomato varieties at 60 DAT (days after transplanting).LI indicates Light Intensity. Bars (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test

In comparison with 100% light intensity, the leaf number gradually decreased in all three varieties. The reductions in leaf numbers of V_1, V_2, and V_3 were 12.3, 14.2, and 9.8%, respectively, at 75% light intensity (S_1). At 50% light intensity (S_2) the reductions were 20.2, 25.9, and 18.6%, respectively. The highest reduction in leaf number was found under the 25% light intensity level which were 44.9, 40.2, and 26.3% in V_1, V_2, and V_3, respectively.

It is evident from the result that all the varieties under 75% light intensity expressed the lowest reduction in leaf number per plant whereas 25% light intensity condition decreased the highest. Furthermore, among the tested variety BARI Tomato-16 showed the lowest reduction and BARI Tomato-2 showed the highest reduction in plant leaf number.

Anusiya and Sivachandiran (2019) found that the number of lettuce leaves was greatly influenced by the 50% shade level. Haque *et al.* (2009) and Pathiratna and Perera (2005) also found that the number of leaves per plant decreased due to the reduced light levels in different plants. However, Kubota and Hamid (1992) reportedthat under low light conditions, plants expense more energy on structural development compared to a plant grown under full sunlight.

4.1.3 Number of branches

The number of branches of BARI Tomato-2 at 50 DAT was 4.7, 4.5, 4.2, and 3.7 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For BARI Tomato-15, branch no. was recorded 4.8, 4.7, 4.3, and 3.8 under S_0, S_1, S_2, and S_3, respectively.

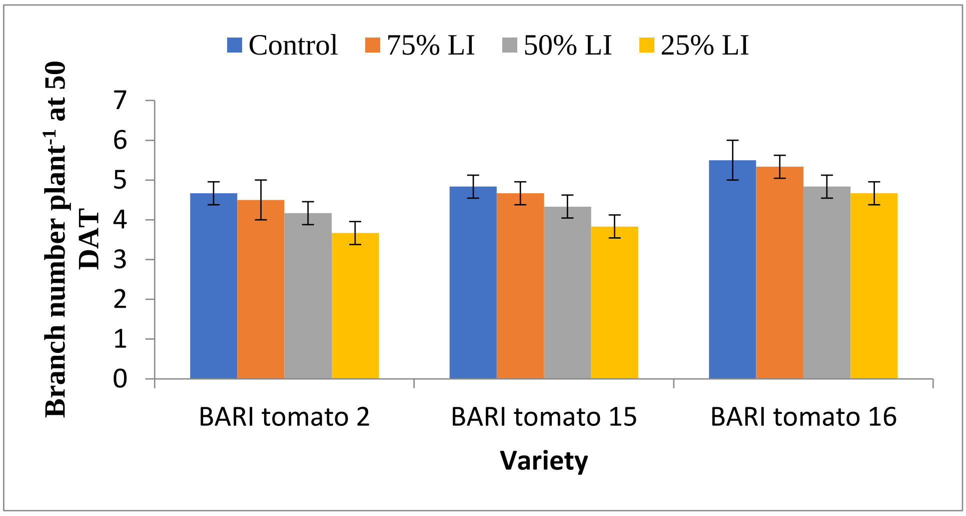


Figure 8. Effect of different light intensity on branch number of different tomato varieties at 50DAT (days after transplanting). LI indicates Light Intensity.

Moreover, the number of branches for BARI Tomato-16 was 5.5, 5.3, 4.8, and 4.7 under S_0, S_1, S_2, and S_3, respectively. The reduction of branch number in V_1, V_2, and V_3 under 75%, 50%, and 25% light intensity level was not significant.

At 70 DAT, the number of branches was 6.5, 6.3, 6, and 5.5 in BARI Tomato-2; 6.7, 6.5, 6.2, and 5.7 in BARI Tomato-15; 7.3, 7.2, 6.7, and 6.5 in BARI Tomato-16 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. The successive decrease was observed in all three varieties due to increase of low light stress but they were non-significant.

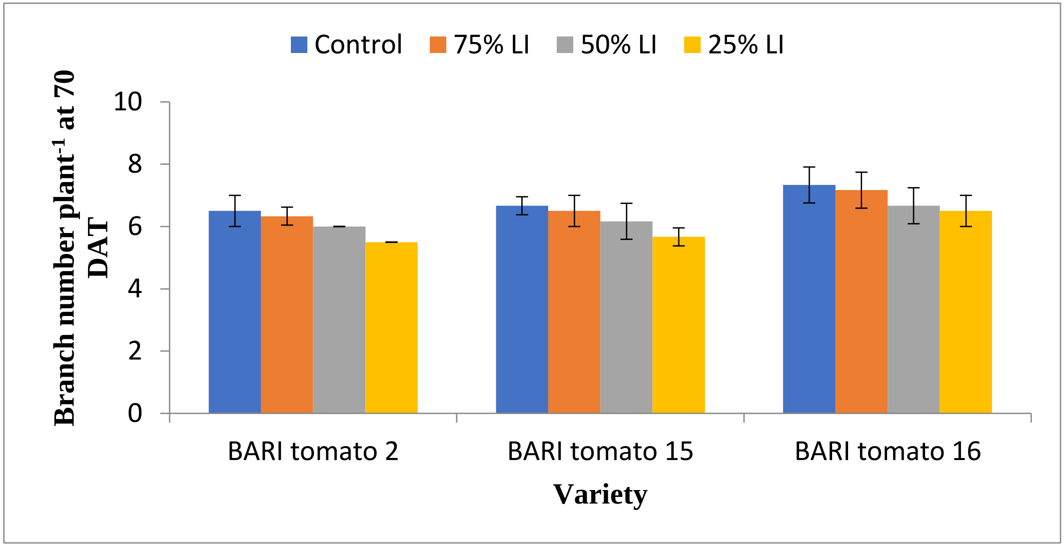


Figure 9. Effect of different light intensity on branch number of different tomato varieties at 70DAT (days after transplanting). LI indicates Light Intensity.

It is obvious that 25% light intensity showed the highest reduction while 75% showed the lowest in all varieties compared to 100% light intensity. BARI Tomato-2 expressed the highest reduction and BARI Tomato-16 showed lowest reduction.

Noertjahyani *et al.* (2020) found almost the same result with three peanut cultivars but all the cultivars are sensitive to 75% shade level. Bibi et al. (2012) found that tomato plants grown under controlled conditions gave the best result than shaded conditions (55% partial shade). Thakur *et al.* (2019) demonstrated that 25 and 50% shading significantly decreased the number of branches in damask rose (*Rosa damascena*).

4.1.4 Fresh weight

The fresh weight of BARI Tomato-2 was 129.8, 123.7, 89.6, and 63.3g under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For BARI

Tomato-15, the fresh weight was found 159.7, 159.5, 112.2, and 81.7g under S_0, S_1, S_2, and S_3, respectively. Moreover, the fresh weight for BARI Tomato-16 was 171, 169.2, 121.8, and 91.1 (gm) under S_0, S_1, S_2, and S_3, respectively.

In comparison with the control (100% light intensity) treatment, 75% light intensity condition (S_1) decreased the fresh weight by 4.6, 0.12, and 1.05% in BARI Tomato-2, BARI Tomato-15, BARI Tomato-16, respectively. At 50% light intensity condition, fresh weight decreased by 30.9, 29.7, and 28.7% in BARI Tomato-2, BARI Tomato-15, and BARI Tomato-16, respectively, in contrast to the control treatment. Lastly, under severe stress (S_3) the fresh weight reduction in the tomato plant was 51.2, 48.8, and 46.7% in BARI Tomato-2, BARI Tomato-15, and BARI Tomato-16, respectively. So, it is clear that maximum fresh weight reduction was recorded under 25% light intensity and minimum reduction was documented under 75% light intensity. Also, BARI Tomato-16 is more tolerant to low light stress and gives maximum fresh weight than the BARI Tomato-2 and BARI Tomato-15.

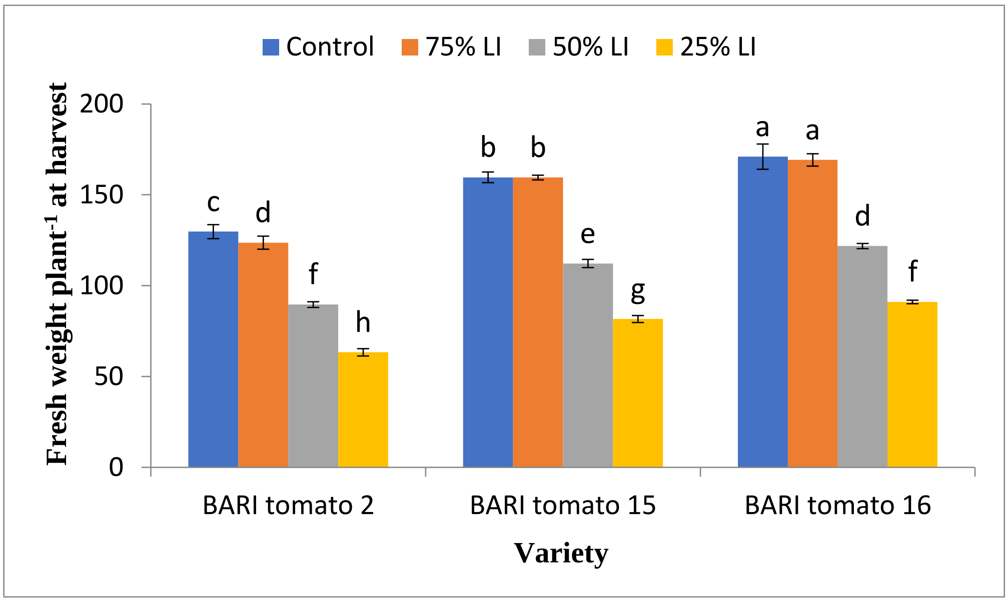


Figure 10. Effect of different light intensity on fresh weight per plant of different tomato varieties at harvest. LI indicates Light Intensity.Bars (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test

The reduction of plant weight under stress conditions indicates the damage to the growth of the tomato plant which corroborates other findings reported by Haque *et al*. 2009 and Dong *et al*. 2014 in different plants. Nguyen *et al*. (2019) demonstrated that fresh weight increases with the increase of light intensity which support the findings of the present study.

4.1.5 Dry weight

For BARI Tomato-2, the dry weight was 21.5, 20.9, 14.7, and 9.3 g under 100% (S0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. The dry weight of BARI Tomato-15 was 29.8, 27.3, 17.5, and 13.8 under S_0, S_1, S_2, and S_3, respectively. Furthermore, under same condition the dry weight of BARI Tomato-16 was 35.9, 33.4, 20.4, and 16.7, respectively.

In comparison with 100% light intensity (S_0), a gradual reduction was observed in 75%, 50%, and 25% light intensity in terms of dry weight of all three tested varieties. Though dry weight was reduced by 2.7, 8.3, and 6.9% at 75% light intensity; 31.6, 41.2, and 43.1% at 75% light intensity in V_1, V_2 and V_3, respectively, but 56.7, 53.7 and 53.4% reduction was observed at 25% light intensity level in V_1, V_2 and V_3, respectively.

From this result, it is clear that in all varieties the lowest reduction occurred under 75% light intensity and the highest reduction under 25% light intensity. So, we can conclude that BARI Tomato-16 showed the best result under severe low light intensity in comparison with BARI Tomato-2 and BARI Tomato-15.

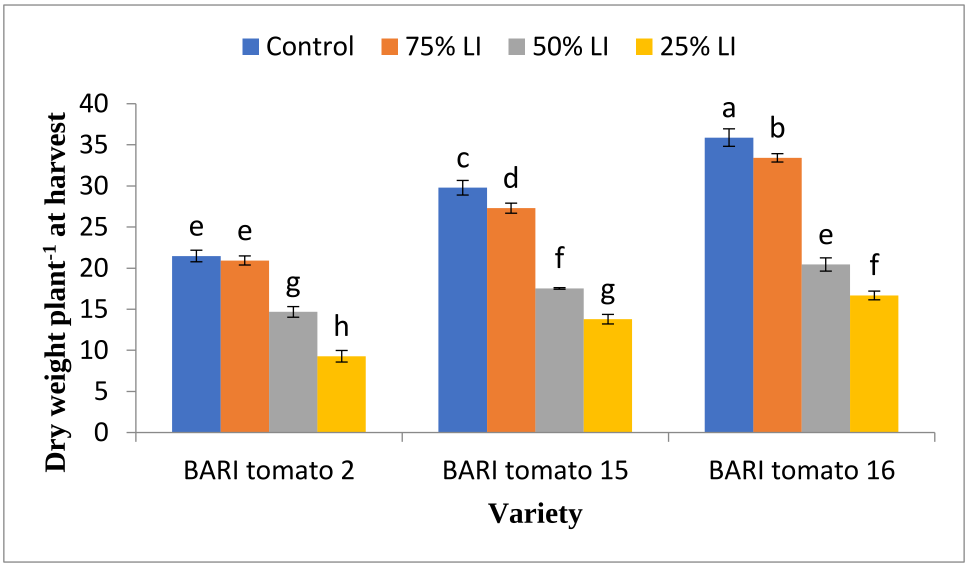


Figure 11. Effect of different light intensity on dry weight per plant of different tomato varieties at harvest. LI indicates Light Intensity.Bars (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

Thakur *et al*. (2019) also found a similar growth reduction in damask rose (*Rosa damascena* Mill.). Dong *et al*. (2014) found a similar result in the wheat plant. Nguyen et al. (2019) demonstrated that fresh weight increases with a high light intensity which increase the dry weight of the plant and corroborate our findings.

4.1.5 SPAD unit

SPAD unit gives an idea about the photosynthetic performance of a plant. The SPAD unit of BARI Tomato-2 was recorded at 63, 54, 51.33, and 43.0 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For BARI Tomato-15, the SPAD unit was 61.0, 54.33, 51.0, and 43.33 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. In addition, the SPAD unit of BARI Tomato-16 leaf was 60.0, 54.33, 51.0, and 45.33 under S_0, S_1, S_2, and S_3, respectively.

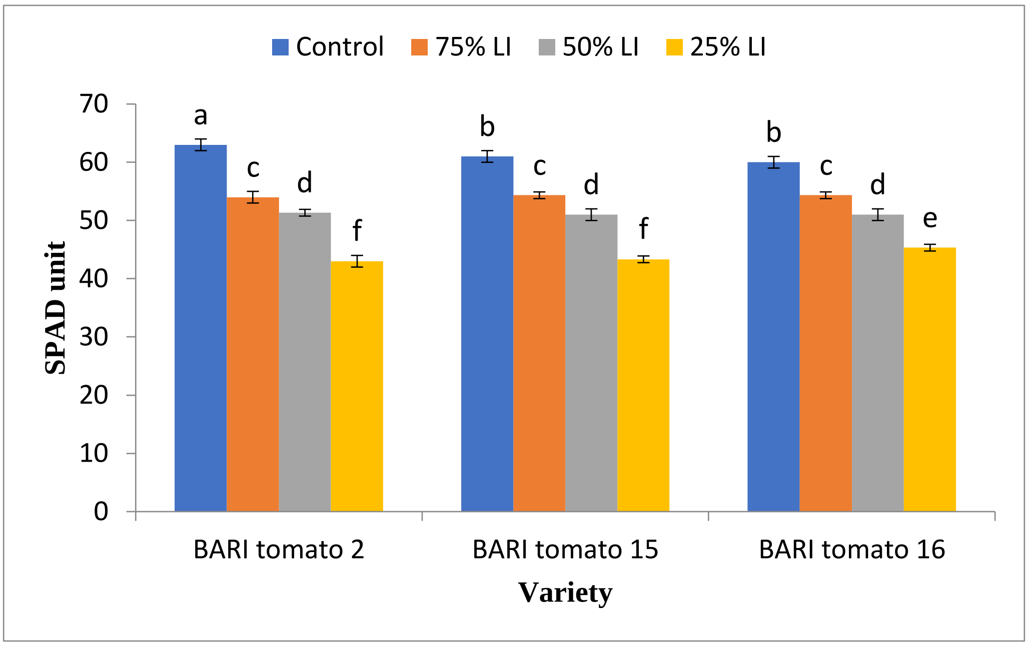


Figure 12. Effect of different light intensity on SPAD unit of different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

In contrast to 100% light intensity, the SPAD unit of leaf was decreased by 14.2, 10.9, and 9.4% of V_1, V_2, and V_3 respectively under 75% light intensity. 18.5, 16.3, and 15% SPAD unit reduction were estimated in V_1, V_2, and V_3, respectively under 50% light intensity. Lastly, the SPAD unit of tested varieties was decreased by 31.7, 28.9, and 24.45% under severe low light stress condition (S_3).

In this experiment, low light stress significantly decreases the SPAD unit of leaves. We observe that the lowest reduction occurred under 75% light intensity, the moderated reduction was for 50% light intensity and the highest reduction occurred under 25% light intensity. We can say from the result that BARI Tomato-16 shows the best result in terms of SPAD unit of leaf than BARI Tomato-2 and BARI Tomato-15.

So, it is clear that light stress in this study significantly decreased the photosynthetic activity of tomato as SPAD value indicates the concentration of chlorophyll content of leaves. Light is the most important factor affecting stomatal conductance and leaf chlorophyllcontent (Christie, 2007; Taiz and Zeiger, 2008). Sysoeva *et al.* (2010) stated that fluctuations of light affect the photosynthetic rate. Gregoriou *et al*. (2017) reported that reduced irradiance on olive (*Olea europaea* L.) notably decreased SPAD value. Rezai *et al*. (2018) found a similar result in sage (*Salvia officinalis* L.) under low light condition. Shao *et al.* (2014)found that *Anoectochilusroxburghii* showed the highest net photosynthetic rates at 30% shade treatment, followed in descending order by 20%, 5%, and 50% shade treatments. My experiment is supported by Susanto and Sundari (2011) who observed that the lack of light intensity causes physiological changes in plants, especially in photosynthetic activity. Jian-lei *et al.* (2014) also stated that photosynthesis disturbances due to lack of light cause low carbohydrate (sucrose and starch) synthesis and a decrease in photosynthetic enzyme activity (Rubisco) which will impact on low production of plants.

4.2 Yield and yield contributing components

4.2.1 Fruits number per cluster

Fruits numbers per cluster were 6.67, 5.67, 5.33, and 3.67 for BARI Tomato-2 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For BARI Tomato-15, we got 6.33, 5.67, 5.33, and 4.33 respectively, under the same treatments Furthermore, the fruits number per cluster was 6.33, 5.33, 5.00, and 4.67 in BARI Tomato-16 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively.

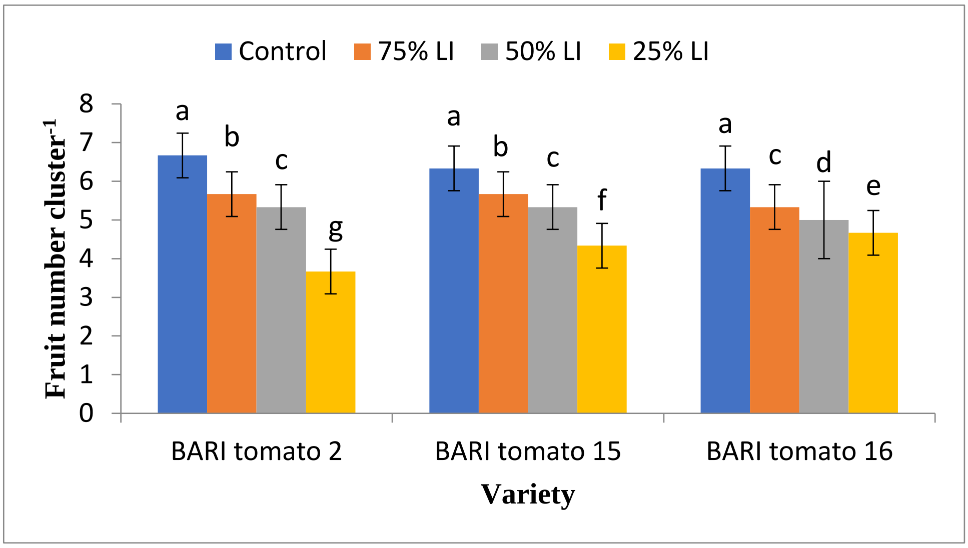


Figure 13. Effect of different light intensity on fruit number per clusterof different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test

At 100% light intensity, the fruits per cluster were 6.67, 6.33, and 6.33 in BARI Tomato-2, BARI Tomato-15, and BARI Tomato-16, respectively, which were successively decreased for all three varieties with the application of low light stresses. At 75% light intensity, fruits per cluster reduced by 14.9, 10.4, and 15.7% in V_1, V_2, and V_3, respectively, in contrast to 100% light intensity. It was further reduced by 20.0, 15.7, and 21.01% at 50% light intensity for V_1, V_2, and V_3, respectively. Moreover, there was a drastic reduction occurred in BARI Tomato-2, BARI Tomato-15, and BARI Tomato-16 by 44.9, 31.5, and 26.2% respectively, at 25% light intensity.

So, it is clear that the results of the present study showed a gradual reduction in fruit number per cluster with an increase in low light stress. Under severe stress, in terms of fruit number per cluster, BARI Tomato-16 performs well than the BARI Tomato-2 and BARI Tomato-15.

Under low light conditions, plants expense more energy on structural development (Kubota and Hamid, 1992). As a result, fruit per cluster decreases with the increase of stress. The findings of the current experiment is supported by Argade *et al.* (2018) who demonstrated the number of cherry tomato per cluster gave the highest result in the lowest shading treatment. Bibi *et al.* (2012) also found negative results under low light stress compared with controlled (full sunlight) condition.

4.2.2 Fruits per plant

The number of fruits per plant was 20.97, 18.67, 16.87, and 10.67 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively for BARI Tomato-2. In addition, For BARI Tomato-15, the number of fruits per plant was 20.67, 19.4, 17, and 11.53 under S_0, S_1, S_2, and S_3 treatment, respectively. We also got 19.6, 18.7, 16.67, and 12.1 fruits per plant for BARI Tomato-16 under the same treatment.

Fruits from all the varieties showed negative results with low light stress. In comparison with 100% light intensity, fruits number per plant was reduced by 10.9, 6.1, and 4.5% at 75% light intensity in BARI Tomato-2 (V_1), BARI Tomato-15 (V_2), and BARI Tomato-16 (V_3), respectively. At 50% light intensity, it was decreased by 19.5, 17.7, and 14.9% in V_1, V_2, and V_3, respectively.

Moreover, we got a reduction of 49.1, 44.2, and 38.2% in V_1, V_2, and V_3, respectively at 25% light intensity which was the highest.

It is obvious that the number of fruits per plant decreased gradually and under 75% light intensity, it showed less reduction in contrast to 100% light intensity while the highest reduction was observed under 25% light intensity. In this situation, BARI Tomato-16is better than BARI Tomato-2 and BARI Tomato-15 as the lowest reduction occurred in BARI Tomato-16, in terms of fruit number.

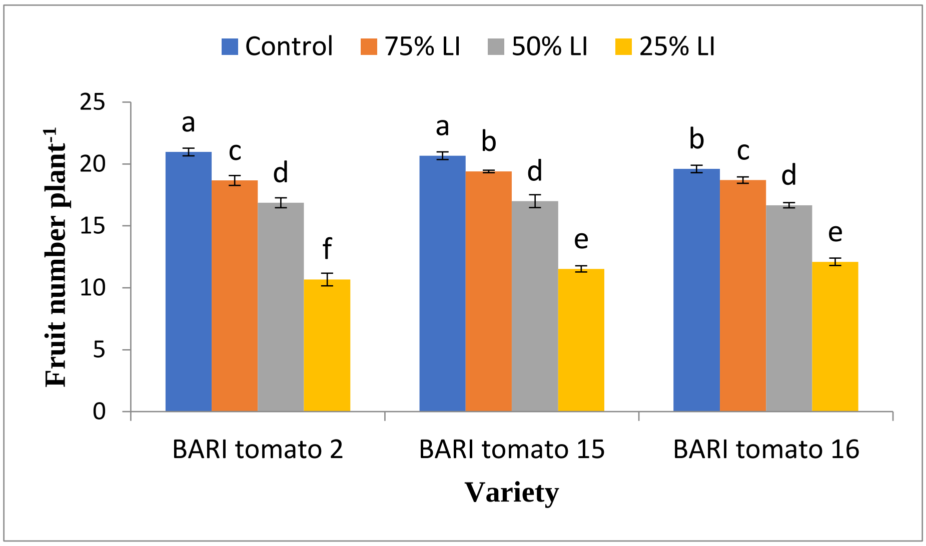


Figure 14. Effect of different light intensity on fruit number per plant of different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

El-Bassiony *et al*. (2014) found a reverse result with tomato which is shading increased the number of fruits per plant. However, Kumar *et al*. (2013) and Gregoriou*et al*. (2017) reported that in shaded condition fruit numbers decreased at clary sage and olive. Both research findings support the present experimental findings. Wang and Zhu (2012) also found the same results in tomato fruit production while experimenting with different levels of light intensities.

4.2.3 Fruit diameter

Fruit diameter is directly dependenton individual fruit weight. In this experiment, the fruit diameter of BARI Tomato-2 was 5.4, 5.1, 4.87, and 4 cm under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For BARI Tomato-15, the fruit diameter was 5.17, 4.9, 4.73, and 4.1 cm under S_0, S_1, S_2, and S_3, respectively. On the other hand, for BARI Tomato-16 the fruit diameter was 5.1, 4.8, 4.6, and 4.2 cm under the same treatments, respectively.

Fruit diameter was successively decreased in low light intensities compared to 100% light intensity and it was decreased by 5.5, 5.2, and 5.8% in BARI Tomato-2 (V_1), BARI Tomato-15 (V_2), and BARI Tomato-16 (V_3), respectively under 75% light intensity. In case of 50% light intensity, fruit diameter was reduced by 9.8, 8.5, and 9.8% in V_1, V_2, and V_3, respectively. Lastly, the highest reduction percentage was estimated at 25% light intensity which was 25.9, 20.6, and 17.6% in V_1, V_2, and V_3, respectively.

The fruit diameter of all three varieties showed a gradual decreasing pattern. It is observed that the reduction percentage was highest for 25% light intensity and lowest for 75% light intensity condition. Moreover, it is clear from the results that reduction of fruit diameter is less in BARITomato-16 under severe low light (25% light intensity) stress than in BARI Tomato-2 and BARI Tomato-15.

In collaboration withthe findings of the present study Hoque *et al.* (2009) got the reverse result under similar stress treatment with bottle gourd.

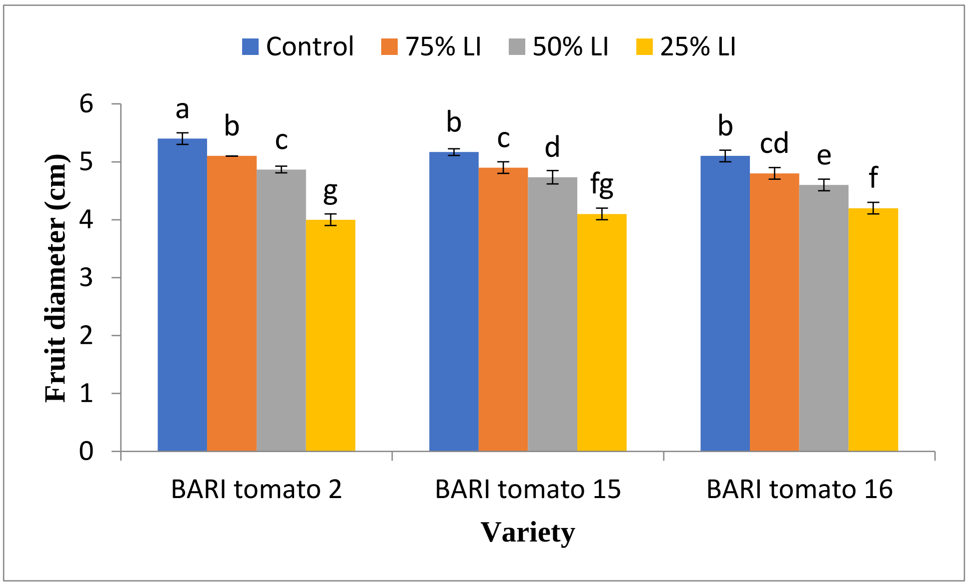


Figure 15. Effect of different light intensity on fruit diameter of different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

4.2.4 Fruit length

Fruit length can also directly affect the individual fruit weight as well as total production. In this study, the fruit length was 4.87, 4.7, 4.57, and 3.9 in BARI Tomato-2 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For BARI Tomato-15, the fruit length was 5.23, 4.77, 4.53, and 4.1 under S_0, S_1, S_2, and S_3, respectively. Furthermore, the fruit length was 5.3, 4.87, 4.67, and 4.3 in BARI Tomato-16 under S_0, S_1, S_2, and S_3 treatment, respectively.

In contrast to 100% light intensity, the fruit length was decreased by 3.4, 8.7, and 8.1% in BARI Tomato-2 (V_1), BARI Tomato-15 (V_2), and BARI Tomato-16 (V_3), respectively at 75% light intensity. Under 50% light intensity, 6.1, 13.3, and 11.8% reduction was observed in V_1, V_2, and V_3, respectively. However, the highest reduction was found under 25% light intensity which was 20, 21.6, and 18.8% in V_1, V_2, and V_3, respectively.

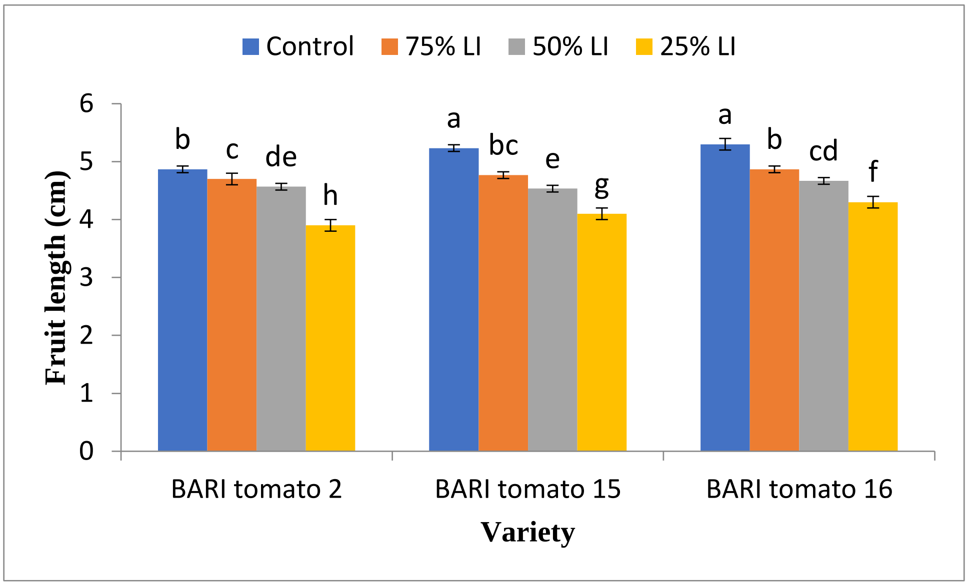


Figure 16. Effect of different light intensity on fruit length of different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test

It is evident from the results that 75% light intensity showed the minimum fruit length reduction in all tested varieties whilst 25% light intensity showed the maximum reduction. In comparison with the three varieties, fruit length reduction under 25% light intensity condition was lowest in BARI Tomato-16 than in the other varieties.

Haque *et al*. (2009) found the reverse result with bottle gourd. They confirmed that under 50% and 75%light intensitycondition fruit length increased and no significant variation was observed under 25% light intensity, compared to the control treatment. Kabir (2020) examined brinjal and found that fruit size decrease with the increase of shading intensity.

4.2.5 Individual fruit weight (g)

The individual fruit for BARI Tomato-2 was 86.75, 75.48, 66.09, and 45.87 g under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For BARI Tomato-15 the individual fruit weight was 92.95, 82.27, 70.79, and 55.07 g under S_0, S_1, S_2, and S_3, respectively. However, in BARI Tomato-16, the individual fruit weight was 98.97, 87.84, 78.3, and 60.7 g under S_0, S_1, S_2, and S_3, respectively.

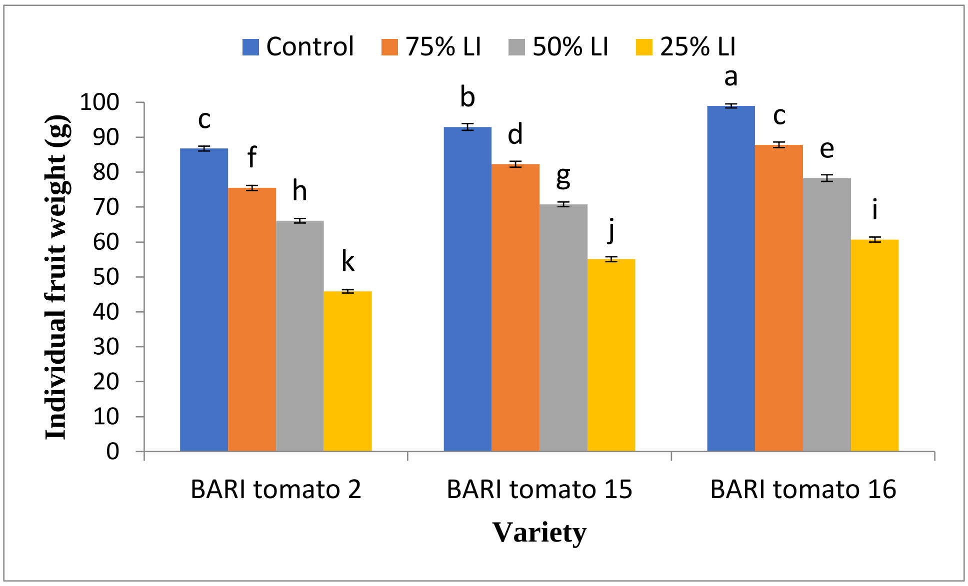


Figure 17. Effect of different light intensity on individual fruit weight of different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

Individual fruit weight depends on fruit length, diameter, and internal fluid density. As it was found that fruit length and diameter decreased with the increase of low light stress, individual fruit weight also decreased substantially. In comparison with the control (100% light intensity) treatment, 75% light intensity condition (S_1) decreased individual fruit weight by 13, 11.4, and 11.2% in BARI tomato-2, BARI tomato-15, BARI tomato-16, respectively. In the 50% light intensity condition, individual fruit weight decreased by 23.8, 23.8, and 20.8% in BARI tomato-2, BARI tomato-15, and BARI tomato-16, respectively, in contrast to control. Lastly, under severe stress (25% light intensity) individual fruit weight decreased by 47.1, 40.7, and 38.6% in BARI tomato-2, BARI tomato-15, and BARI tomato-16, respectively.

From this result, it is clear that the reduction of individual fruit weight was lowest in BARI tomato-16.

Low light stress decreased the individual fruit weight and ultimately decreases the overall production (Kumar *et al.* 2013;Gregoriou*et al*. 2017). Kabir(2020) experimented with brinjal and found that individual fruit weight decreased with the increase of shading intensity.

4.2.6 Fruit weight (kg) per plant

Fruit weight per plant was 1.819, 1.409, 1.115, and 0.489 kg under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively for BARI Tomato-2. Similarly in BARI Tomato-15, the fruit weight per plant was 1.921, 1.596, 1.203, and 0.635 kg under S_0, S_1, S_2, and S_3 treatment, respectively. The yield per plant for BARI Tomato-16 was 1.94, 1.643, 1.305, and 0.735 kg for BARI Tomato-16.

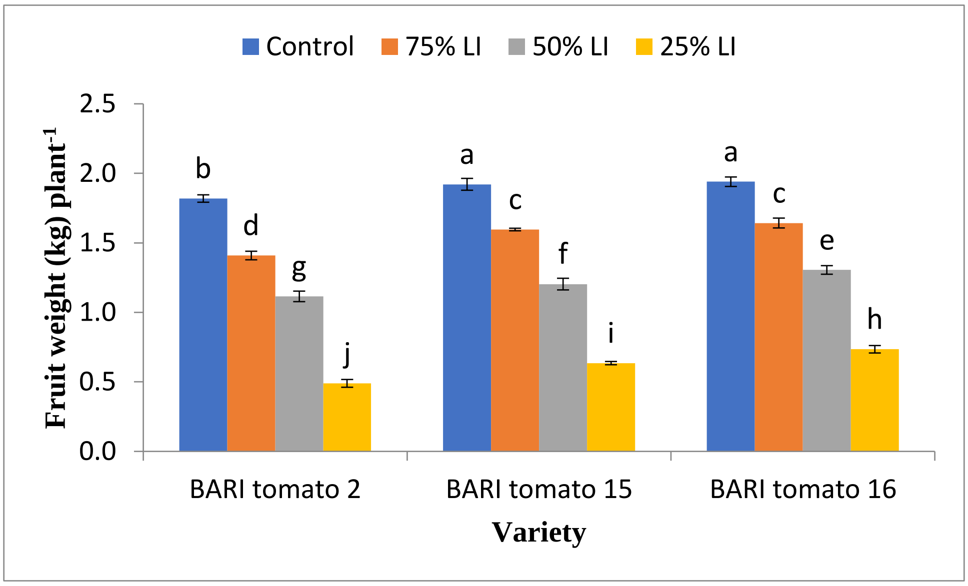


Figure 18. Effect of different light intensity on fruit weight per plant of different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test

In comparison with the control (100% light intensity) treatment, 75% light intensity condition (S_1) decreased tomato yield per plant by 22.5, 16.9, and 15.3% in BARI Tomato-2, BARI Tomato-15, BARI Tomato-16, respectively. In the 50% light intensity condition, tomato yield per plant decreased by 38.7, 37.4, and 32.7% in BARI tomato-2, BARI Tomato-15, BARI Tomato-16, respectively, in contrast to control. Severe stress (25%) condition drastically decreased the tomato yield per plant by 73.1, 67, and 62.1% in BARI Tomato-2, BARI Tomato-15, BARI Tomato-16, respectively.

So, it is very clear that maximum yield reduction was observed under 25% light intensity (S_3 treatment) and minimum under 75% light intensity (S_1) in all three varieties. Furthermore, BARI Tomato-16 showed the lowest yield reduction and BARI Tomato-2 (V_1) showed the highest yield reduction.

Diversified light intensity could have different effects on the growth and yield of plant (Vyas *et al.*, 1996; Martin et al., 2011). In the present experiment, low light stress decreased the growth and yield of plants with the increase in stress intensity. Similarly, Nangare *et al.* (2015) found that tomato yield decreased under different levels of low light intensity.

Masabni *et al.* (2016) demonstrated that the yield parameter of both tomato and chili pepper reduced significantly under 70% shade compared to full sunlight. Gent (2019) reported that yield decreased by 20% in the interval from 25 to 45 days after shading and by 30% after 50 or more days of shading. Haque *et al.* (2009), Dong *et al.* (2014) and Thakur *et al.* (2019) confirmed similar yield reductions in different plants. However, Argade et al. (2018) found the opposite result in the yield of cherry tomato during the summer season.

4.2.6 Yield (ton ha^{-1})

The yield was 43.29, 33.53, 26.53, and 11.65ton ha^{-1}under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S3) light intensity, respectively for BARI Tomato-2. Similarly in BARI Tomato-15, the yield was 45.72, 37.98, 28.64, and 15.11ton ha-1 under S0, S1, S2, and S3 treatment, respectively. The yield for BARI Tomato-16 was 46.17, 39.1, 31.06, and 17.48 ton ha^{-1} for BARI Tomato-16.

In comparison with the control (100% light intensity) treatment, 75% light intensity condition (S_1) decreased tomato yield per plant by 22.5, 16.9, and 15.3% in BARI Tomato-2, BARI Tomato-15, BARI Tomato-16, respectively. In the 50% light intensity condition, tomato yield per plant decreased by 38.7, 37.4, and 32.7% in BARI tomato-2, BARI Tomato-15, BARI Tomato-16, respectively, in contrast to control. Severe stress (25%) condition drastically decreased the tomato yield per plant by 73.1, 67, and 62.1% in BARI Tomato-2, BARI Tomato-15, BARI Tomato-16, respectively.

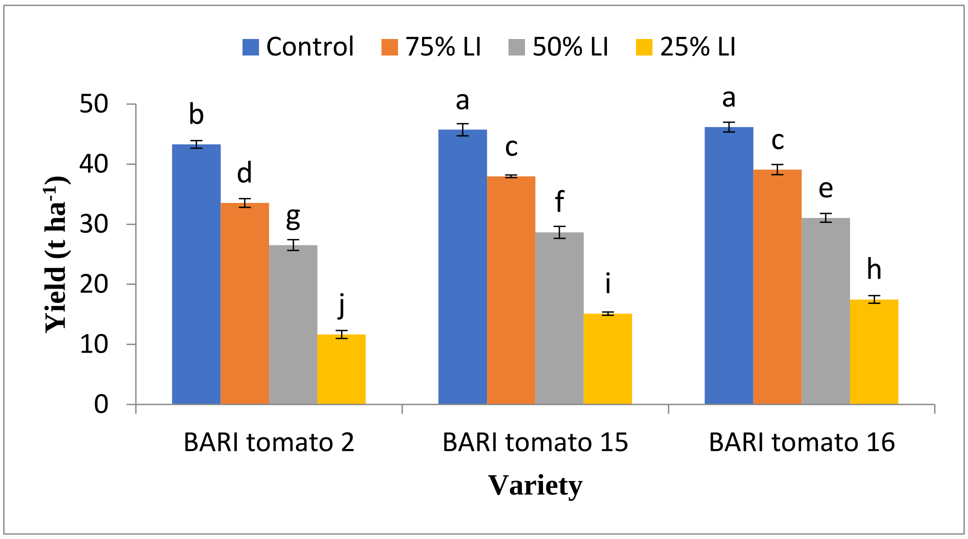


Figure 19. Effect of different light intensity on yield of different tomato varieties. LI indicates Light Intensity. (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test

So, it is very clear that maximum yield reduction was observed under 25% light intensity (S_3 treatment) and minimum under 75% light intensity (S_1) in all three varieties. Furthermore, BARI Tomato-16 showed the lowest yield reduction and BARI Tomato-2 (V_1) showed the highest yield reduction.

Diversified light intensity could have different effects on the growth and yield of plant (Vyas *et al.*, 1996; Martin et al., 2011). In the present experiment, low light stress decreased the growth and yield of plants with the increase in stress intensity. Similarly, Nangare *et al.* (2015) found that tomato yield decreased under different levels of low light intensity.

Masabni *et al.* (2016) demonstrated that the yield parameter of both tomato and chili pepper reduced significantly under 70% shade compared to full sunlight. Gent (2019) reported that yield decreased by 20% in the interval from 25 to 45 days after shading and by 30% after 50 or more days of shading. Haque *et al.* (2009), Dong *et al.* (2014) and Thakur *et al.* (2019) confirmed similar yield reductions in different plants. However, Argade et al. (2018) found the opposite result in the yield of cherry tomato during the summer season.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

A pot experiment was carried out to evaluate the performances of three Tomato genotypes under four different light intensity treatments. The experiment was conducted at the Field Laboratory of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, during October 2019 to mid-April 2020. Two factorial experiments includingthree varieties viz. BARI Tomato-2 (V_1), BARI Tomato-15 (V_2), BARI Tomato-16 (V_3), and 4 levels of light intensity viz. S_0-100% light intensity/ full sunlight as control, S_1-75% light intensity, S_2-50% light intensity, and S_3-25% light intensitywere outlined in completely randomized design (CRD) with replications.

The result showed that the growth, development, yield, and yield attributing characteristics of tomato varied with different genotypes.

The plant height at 30 DAT was decreased maximum (35.8%) for V_1 (BARI Tomato-2) under S_3 (25% light intensity) and showed a minimum decrease (13.3%) for V_3 (BARI Tomato-16) under S_1 (75% light intensity). V_3. In case of 60 DAT, the highest reduction (37.4%) showed by V_2 (BARI Tomato-15) under the treatment S_3 and the lowest reduction (3.43%) showed by V_3 under S_1 treatment. The least reduction (10.5%) of leaf number at 30 DAT was shown by V_3 under S_1 treatment and the maximum reduction (39.4%) was observed for V_1 under S_3 treatment. After 60 DAT, the leaf number decreased most (44.9%) for V_1 under S_3 treatment and the least reduction (9.8%) occurred for V_3 under S_1 treatment. In case of branch number at 50 DAT, the maximum reduction (21.2%) occurred in V_1 under S_3 treatment and the least reduction (3.6%) occurred in V_3 under S_1 treatment. If we looked at branch number at 70 DAT, we found the least decrease (1.3%) in V_3 under S_1 treatment and the highest decrease (15.3%) under S_3 treatment in V_1. In comparison with control, the SPAD decreased the most (31.7%) in V_1 under S_3 treatment and the lowest reduction (9.4%) was observed under S_1 treatment in V_3 variety.

The fruit weight showed the maximum reduction (51.2%) under S_3 treatment in V_1 and the minimum reduction (0.12%) occurred under S_1 treatment in V_2. We found totally different results compare to the previous parameter while estimating the dry weight. Both the highest and the lowest reductions found in V_1 variety under S_3 and S_1 treatment, respectively. The maximum reduction (45%) while observing fruit per cluster found in V_1 under S_3 treatment and the least reduction (10.4%) occurred for V_2 under S_1 treatment. Fruits per plant decreased the most (49%) for V_1 variety under S_3 treatment and least reduction observed for V_3 under S_1 treatment. The fruit diameter also decreased the maximum (25.9%) for V_1 under S_3 and least reduction occurred for V_2 under S_1 treatment. The highest reduction (21.6%) was observed under S_3 treatment in V_2 variety and lowest reduction (3.4%) observed in V_1 under S_1 treatment. In terms of individual fruit weight, the maximum reduction (47.1%) was shown by V_1 under S_3 treatment and the minimum reduction (11.2%) was shown by V_3 under S_1 treatment. In case of fruit weight per plant and yield (ton/ha), the result showed the least reduction (15.3%) for V_3 (BARI Tomato-16) under S_1 (75% light intensity) treatment and the maximum reduction (73%) observed under S_3 (25% light intensity) for V_1 (BARI Tomato-2).

5.2 CONCLUSION

A large number of vegetables produced and consumed in this country are coming from homesteads. So, shade tolerant tomato varieties must be chosen to overcome the low light intensity problem as low light interrupts the physiological activities of a plant which have negative effects on the growth and yield of tomato. Screening method can be easier to determine to partial shade tolerant varieties. It is clear from the experiment that BARI Tomato-16 is the best variety under 75% light intensity, 50% light intensity, and 25% light intensity as it had the least amount of yield reduction (62%) compared to BARI Tomato-2 (73%) and BARI Tomato-15 (67%), respectively, under severe light stress.

RECOMMENDATIONS

- To obtain more precise findings under field conditions, future growth and yield-based research on this topic should be carried out.
- More research should be done on the morphological and physiological bases of shade tolerance.
- Future studies should be conducted on the other two abiotic resource pools (nutrient stress and drought stress).

REFERENCES

Abdel-Mawgoud, A. M. R., El-Abd, S. O., Singer, S. M., Abou-Hadid, A. F., and Hsiao, T. C. (1996). Effect of shade on the growth and yield of tomato plants. *ActaHortic.* **434**: 313–319.

Aberkani, K., Hao, X., Gosselin, A. and Halleux.D. (2008). Responses of leaf gas exchanges, chlorophyll a fluorescence, and fruit yield and quality of greenhouse tomato to shading with retractable liquid foam. *Acta Hortic.* **797**:235–240.

Abubaker, S. (2015). Impact of Shade and Water Regimes on Yield and Quality of Tomato Grown in a Plastic House in Jordan. *Jordan J. Agric. Sci*. **11**(4): 1119–1126.

Adegoroye, A.S., Jolliffe, P.A. (1987). Some inhibitory effects of radiation stress on tomato fruit ripening. *J. Sci. Food Agric.* **39**:297–302.

Aditya, T. L., Rahman, L., Alam, M. S. and Ghoseh, A.K. (1997). Correlation and path co-efficientanalysis in tomato. *Bangladesh J. Agric. Sci*. **26**(1):119-122.

Akinyemi, T. E., and Sakpere, A. M. A. (2015). Effect of light regime and water stress on germination and seedling growth of *Moringa oleifera* Lam. *FUTA J. Res. Sci.* **2015**(2): 369–377.

Amin, M.R., Shemu, S.A., Shiam, I.H., Mehraj, H.and Jamal Uddin, A.F.M. (2014). Growth and yield of summer tomato as influenced by reduced light intensity. *J. Exp. Biosci.* **5**(2): 31–34.

Anusiya, M.S. (2019). Effect of Different shade levels on growth and yield performance of lettuce. *Int. J. Hortic. Sci.* **5**(3): 1–4.

Argade, M. B., Kadam, J. H., Garande, V. K., Patgaonkar, D. R., Patil, V. S., and Sonawane, P. N. (2018). Effect of different shading intensities on growth and yield of cherry tomato. *J. Appl. Nat. Sci.***10**(1): 352–357.

Araus, J.L., Slafer, G.A., Reynolds, M.P. and Royo,C.(2002) Plant breeding and droughtin C3 cereals: What should we breed for? *Ann. Bot.(London)*. **89**: 925-940.

Asada, K. (2000). The water-water cycle asalternative photon and electron sinks. *Philos. Trans. R. Soc.B.* **335**: 1419- 1430.

Baharuddin, R., Chozin, M.A. and Syukur, M. (2014). Shade tolerance of 20 genotypes of tomato(*Lycopersicon esculentum* Mill.). *J. Agron. Indones.* **42**(2): 130-135.

Bazzaz, F.A. (1996). Plants in changing environments:linking physiological, population and communityecology.Cambridge: Cambridge UniversityPress.

BBS. 2020. Statistical Year Book of Bangladesh. Bangladesh Bureau of Statistics. Ministry of Planing, Government of the Peoples Republic of Bangladesh, Dhaka, Bangladesh.

Bibi, B., Sajid, M., Rab, A., Shah, S.T., Ali, N., Jan, I., Ali, I. (2012). Effect of Partial Shade on Growth and Yield of Tomato Cultivars. *Glob. J. Biol. Agric. Health*

Sci. **1**(1): 22–26.

Chairudin, E. and Sabarudin (2015). Impact of shades to changes of characters of agronomy and morpho-physiology leaves in soybean (*Glycine max (L.) Merrill*). *J. Floratek.* **10**: 26-35.

Chapin, F.S., Bloom, A.J., Field C.B. and Waring,R.H. 1987. Plant responses to multipleenvironmental factors. *Biol. Sci.* **37**:49-57.

Chen, X. L., Guo, W. Z., Xue, X. Z., Wang, L. C. and Qiao, X. J. (2014). Growth and quality responses of 'Green Oak Leaf'lettuce as affected by monochromic or mixed radiation provided by fluorescent lamp (FL) and light-emitting diode (LED). *Sci.Hortic.* **172**:168-175.

Chen, Q., Yu, S.W., Jiang, X.M., Zhao, Y., Meng, X.Y. and Wan, X.C. (2016). Effect of shade treatment in summer on the expression of genes related to theanine biosynthesis in tea plants (*Camellia sinensis*). *Bull. Bot. Res.* **36**(2): 216-223.

Chouhan, D., Singh, M., Tripathi, P. N., and Sharma, A. (2018). Effect of Green Shade Net on Yield and Quality of Tomato.*Indian J. Agric. Sci.* **7**(9): 2148–2150.

Christie, J.M. (2007). Phototropin blue-light receptors. *Annu. Rev. Plant Biol.* **58**: 21-45.

Cisneros, R.L., Zedler, J. (2001). Effect of light on seed germination in *Phalaris arundinacea*L. (red canary grass). *Plant Ecol.* **155**: 75-78.

Craine, J.M. and Reich, P.B.(2005). Leaf-level light compensation points in shade-tolerant woody seedlings. *New Phytol.* **166**(3): 710-713.

Dong, C., Fu, Y., Liu, G., and Liu, H. (2014). Low light intensity effects on the growth, photosynthetic characteristics, antioxidant capacity, yield and quality of wheat (*Triticum aestivum* L.) at different growth stages in BLSS. *Adv. Space Res.* **53**(11): 1557–1566.

Dorais, M., Papadopoulos, A. P., Gosselin, A. (2001). Greenhouse tomato fruit quality. *Hortic. Rev.* **26**: 239-319.

Du, C.F., Li, C.H., Liu, T. and Zhao, Y.L. (2011). Response of anatomical structure and photosynthetic characteristics to low light stress in leaves of different maize genotypes. *Acta Ecol. Sin.* **31**(21): 6633-6640.

El-Bassiony, A., Fawzy, Z., Riad, G., and Ghoname, A. (2014). Mitigation of high temperature stress on growth, yield and fruit quality of tomato plants by different shading level. *Curr. Sci. Intl.* **4**(4): 1034–1040.

Evans, J.R. and Poorter, H. (2001). Photosynthetic acclimation of plants to growth irradiance: The relative importance of specific leaf area and nitrogen partitioning in maximizing carbon gain. *Plant Cell Environ.* **24**(8): 755-767.

Fan, X. X., Xu, Z. G., Liu, X. Y., Tang, C. M., Wang, L. W., and Han, X. lin. (2013). Effects of light intensity on the growth and leaf development of young tomato plants grown under a combination of red and blue light. *Sci. Hort.* **153**: 50–55.

Feng, Y.L., Cao, K.F. and Zhang, J.L.(2004). Photosynthetic characteristics, dark respiration, and leaf mass per unit area in seedlings of four tropical tree species grown under three irradiances. *Photosynthetica.* **42**(3): 431-437.

Foyer, C.H.andNoctor(2005). Oxidant andantioxidant signaling in plants: areevaluation of the concept of oxidativestress in a physiological context. *Plant Cell Environ.* **28**:1056-1071.

Foyer, C.H., Lopez-Delgado, H., Dat, J.F. and Scot, I.M. (1997). Hydrogen peroxide andglutathione associated mechanisms ofacclamatory stress tolerance and signaling.*Plant Physiol.* **100**: 241 254.

Fukuda, N., Fujitan, M., Ohta, Y., Sase, S., Nishimura, S., Ezura, H. (2008). Directional blue light irradiation triggers epidermal cell elongation of abaxial side resulting in inhibition of leaf epinasty in geranium under red light condition. *J. Hortic. Sci.* **115**: 176–182.

Gent, M. (2019). Effect of Shade on Quality of Greenhouse Tomato. *Hortic. Sci.* **39**(4): 759A – 759.

Gomez, K.A. and Gomez, A.A (1984). Comparison between treatment means. **In**: Statistical Procedures for Agricultural Research. Gomez, K.A. and Gomez, A.A., (eds.). 2nd Edition. John Wiley and Sons, NY, USA. pp. 187-240.

Gregoriou, K., Pontikis, K., Vemmos, S.N. (2007). Effects of reduced irradiance on leaf morphology, photosynthetic capacity, and fruit yield in olive (*Olea europaea* L.). *Photosynthetica*. **45**(2):172–181.

Hang, H., Ian, P., Ei, N., Ui, P., Hang, W. and Ua, H. (2019). *Asian J. Adv. Basic Appl. Sci*. **48**(3): 513–520.

Hangarter (1997). Gravity, light and plant form.*PlantCellEnviron.* **20**: 796-800.

Haque, M. M., Hasanuzzaman, M., and Rahman, M. L. (2009). Effect of light intensity on the morpho-physiology and yield of bottle gourd (*Lagenaria vulgaris*). *J. Plant Sci.* **2**(3): 158–161.

Ilic, Z.S., Milenkovic, L.,Stanojevic, L., Cvetkovic, D. and Fallik,E. (2012). Effect of the modification on light intensity by color shade nets on yield and quality of tomato fruits. *Sci.Hortic.***139**:90-95.

Islam, M.R. (2014). The effect of salinity on growth and accumulation of proline in calli of *Capsicum spp*. grown in vitro. M.S. thesis, SAU, Dhaka, Bangladesh.

Jian-lei, S., Xiao-lei, S., Hong-yu, H., Shao-hui, W., Yu-xia, W. and Zhen-xian, Z. (2014). Low light stress down-regulated rubisco gene expression and photosynthetic capacity during cucumber(*Cucumis sativus* L.) leaf development. *J. Integr. Agric.***13**(5): 997-1007.

Jha, P., Norsworthy, J. K., Riley, M. B., Bridges, W., Riley, M. B., Bridges, W., and Norsworthy, J. K. (2016). *Weed Sci*. **58(**1): 16–21.

Jiang, C.D., Wang X, Gao, H.Y., Shi, L. and Chow, W.S. (2011). Systemic regulation of leaf anatomical structure, photosynthetic performance, and high-light tolerance in sorghum. *Plant Physiol*.**155**(3):1416–1424.

Joesting, H.M., Mccarthy, B.C. and Brown, K.J. (2009). Determining the shade tolerance of American chestnut using morphological and physiological leaf parameters. *For. Ecol. Manag.* **257**(1): 280-286.

Kabir, Mahmudul (2020). Effect of different levels of light intensity on morphophysiology and yield of brinjal *(Solanum melongena* L). M.S. thesis, SAU, Dhaka, Bangladesh.

Kılınç, M. and Kutbay, G.H. (2008).Photosynthetic characteristics, dark respiration, and leaf mass per unit area in seedlings of four tropical tree species grown under three irradiances. *Plant Ecol.* **51**(2): 129-136.

Kulkarni, M. G., Sparg, S. G., and Van Staden, J. (2005). Temperature and light requirements for seed germination and seedling growth of two medicinal Hyacinthaceae species. *S. Afr. J. Bot.* **71**(3): 349–353.

Kumar R, Sharma S, Pathania V. (2013). Effect of shading and plant density on growth, yield and oil composition of clary sage (*Salvia sclarea* L.) in North Western Himalaya. *J. Essent. Oil Res.* **25**(1): 23–32.

Kwon, M. Y. and Young, S. (2016).Plants responses to drought and shadeenvironments. *Afr. J. Biotechnol.* **15**(2): 29-31.

Laylin, M.M.A. (2014). In vitro selection of water stressed tolerant callus lines using polyethylene glycol of *Capsicum spp*. M.S. thesis, SAU, Dhaka, Bangladesh.

LeBoeuf, J. (2004). Effects of high and low temperatures on tomato and pepper crop. *J. Plant Sci.***2**(3): 158–161.

Lefsrud, M. G., Kopsell, D. A. and Sams, C. E. (2008). Irradiance from distinct wavelength light-emitting diodes affect secondary metabolites in kale. *Hortic. Sci*. **43**: 2243-2244.

Li,Q. and Kubota, C. (2009). Effects of supplemental light quality on growth and phytochemicals of baby leaf lettuce. *J. Environ. Exp. Bot.***67**: 59–64.

Liu, Z.B., Cheng, R.M., Xiao, W.F., Guo, Q.S. and Wang, N. (2015). Effects of shading on growth and photosynthetic characteristics of distyliumchinense seedlings. *Sci. Sil. Sin.* **51**(2): 129-136.

Long, S.P., Humphries, S., Falkowski, P.G. (1994). Photoinhibition of photosynthesis in nature. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* **45**: 633–662.

Lopez-Marin, J., Galvez, A. and Gonzalez, A. (2011). Effect of shade on quality of greenhouse peppers. *Acta Hortic.* **893**:895–900.

Lopez-Marin, J., Galvez, A., Gonzalez, A., Egea-Gilabert, C. and Fernandez, J.A. (2012). Effect of shade on yield, quality, and photosynthesis-related parameters of sweet pepper plants. *Acta Hortic.* **956:**545– 552.

Lu, T., Yu, H., Li, Q., Chai, L., and Jiang, W. (2019). Improving plant growth and alleviating photosynthetic inhibition and oxidative stress from low-light stress with exogenous GR24 in tomato (Solanum lycopersicum l.) seedlings. *Front. Plant Sci.***10**(April): 1–13.

Macedo, A.F., Leal-Costa, M.V.T, Eliana, S.L., Celso, L.S. and Esquibel, M.A.

(2011). The effect of light on leaf quality on leaf production and development of invitro-cultured plants of *Alternanthera brasiliana*Kuntze. *Environ. Exp. Bot.* **70**: 43-50

Manurung, G.E.S., Roshetko, J.M., Budidarsono,S. and Kurniawan, I. (2008). Dudukuhan tree farming systems in West Java: how to mobilize self-strengthening of community-based forest management? **In:** *Smallholder Tree Growing for Rural Development and Environ. Services, Snelder, D.J. and R. Lasco, (Eds.).* World Agroforestry Centre (ICRAF) ICRAF-Bogor, Indonesia.

Marca, N. R., López, R. P., and Naoki, K. (2021). Effect of shade and precipitation on germination and seedling establishment of dominant plant species in an Andean arid region, the Bolivian Prepuna. *PLoS ONE*. **16**(2021): 1–16.

Martin, A., Matthew, R., Michael, E. and Christine, R. (2011). Raising yield potential of wheat. II. increasing photosynthetic capacity and efficiency. *J. Exp. Bot.* **62**:453-467.

Masabni, J., Sun, Y., Niu, G., and Del Valle, P. (2016). Shade effect on growth and productivity of tomato and chili pepper. *Hortic. Technol.* **26**(3): 344–350.

Matos, F. S., Wolfgramm, R., Gonçalves, F. V., Cavatte, P. C., Ventrella, M. C. and DaMatta, F. M. (2009). Phenotypic plasticity in response to light in the coffee tree. *Environ. Exp. Bot*. **67**:421-427.

Miah, M.M. 2001. Performance of five winter vegetables underdifferent light conditions for Agroforestry systems. M.S. thesis, BSMRAU, Gazipur, Bangladesh.

Milenkovic L , Mastilovic J , Kevresan Z , Jaksic A, G. A., and Sunic LJ, S. L. and I. S. (2018). Tomato Fruit Yield and Quality as Affected by Grafting and Shading. *Food Sci. Nutr*. **4**(3): 1–9.

Miller, S.S., Hott, C. and Tworkoski, T.(2015). Shade effect on growth, flowering, and fruit of apple. *J. Appl. Hortic.***17** (2): 101-105.

Nangare, D.D., Singh, J., Meena, V.S., and Bhushan, B. (2015). Effect of green shade nets on yield and quality of tomato (Lycopersicon esculentum Mill) in semi-arid region of Punjab. *Asian J. Adv. Basic Appl. Sci.***1**(1): 1–8.

Naoya, F., Mitsuko, F., Yoshitaka, O., Sadanori, S., Shigeo, N., Hiroshi, E. (2008). Directional blue light irradiation triggers epidermal cell elongation of abaxial side resulting in inhibition of leaf epinastyin geranium under red light condition. *J.Hortic. Sci.* **115**: 176–182.

Nguyen, T. P. D., Tran, T. T. H., and Nguyen, Q. T. (2019). Effects of light intensity on the growth, photosynthesis and leaf microstructure of hydroponic cultivated spinach (Spinacia oleracea L.) under a combination of red and blue LEDs in house. *Int. J. Agric. Technol*. **15**(1): 75–90.

Nicola, S., Tibaldi, G. and Fontana, E.(2009). Tomato production systems and their application to the tropics. *Acta Hortic.* **821**: 27-33.

Noertjahyani, N., Akbar, C., Komariah, A., and Mulyana, H. (2020). Shade effect on growth, yield, and shade tolerance of three peanut cultivars. *J. Agron*. **7**(1): 102–111.

Ohkawa, H., Sugahara, S., Takaichi, M. and Yabe, K. (2007). Effects of high and low temperature conditions on thefruit setting and growth of the parthenocarpic tomato Renaissance.*J. Jpn. Soc.Hortic. Sci.* **3:** 449-454.

Okunlola, G.O. and Adelusi, A. A. (2012). Effects of nutrient and light stress on some morphological parameters of tomato (*Lycopersicum esculentum* Mill.). *Ife J. Sci.* **14**(2): 289-295.

Ologundudu, A. F., Adelusi, A. A., and Adekoya, K. P. (2013). Effect of Light Stress on Germination and Growth Parameters of *Corchorus olitorius*, *Celosia argentea*,*Amaranthus cruentus*, *Abelmoschus esculentus*, and *Delonix regia*. *Not. Sci. Biol*. **5**(4): 468–475.

Özer, H. (2017). Effects of shading and organic fertilizers on tomato yield and quality. *Pak. J. Bot*. **49(**5): 1849–1855.

Pathiratna, L.S.S. and Perera, M.K.P. (2005). Rubber (*Hevea brasiliensis*) cinnamon (*Cinnamomum verum*) intercropping system: performance under standard inter row spacings of rubber. *J. Rubber Res*.**18**(2): 105-112.

Peralta, I.E. and Spooner, D.M. (2007). History, origin and early cultivation of tomato (Solanaceae). **In:** *Genetic improvement of Solanaceous Crops.* Razdan M.K. and Mattoo A.K. (eds.). Enfield, USA, Sci. Publishers. **2**:1-27.

Pires, M., Almeida, A., Figueiredo, A., Gomes, E. and Souza, M.(2011). Photosynthetic characteristics of ornamental passion flowers grown under different light intensities. *Photosynthetica.* **49**: 593-602.

Rajapakse, N.C., Pollock, R.K. and McMahon, M.J. (1992). Interpretation of light quality measurements and plant response in spectral filter research. *J. Hortic. Sci.* **27**: 1208–1211.

Rajapakse, N.C. andShahak, Y. (2007). Light quality manipulation by horticulture industry. **In:** Whitelam, G., Halliday, K. (Eds.), Light and Plant Development. Blackwell Publishing, UK. pp. 290–312.

Rezai, S., Etemadi, N., Nikbakht, A., Yousefi, M., Majidi, M.M. (2018). Effect of light intensity on leaf morphology, photosynthetic capacity, and chlorophyll content in sage (*Salvia officinalis* L.). *Hortic. Sci. Technol*. **36**(1): 46–57.

Rozendaal, D., Hurtado, V. and Poorter, L.(2006). Plasticity in leaf traits of 38 tropical tree species in response to light; relationships with light demand and adult stature. *Funct. Ecol.* **20**: 207-216.

Shafiq, I., Hussain, S., Raza, M. A., Iqbal, N., Asghar, M. A., Yang, F. (2021). Crop photosynthetic response to light quality and light intensity. *J. Integr. Agric.* **20**(1): 4–23.

Shahak, Y., Gal, E.,Offir, Y. and Ben-Yakir, D. (2008). Photo selective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. *Acta Hortic.***797**: 75–80.

Shao, Q., Wang, H., Guo, H., Zhou, A., Huang, Y., Sun, Y., and Li, M. (2014). Effects of shade treatments on photosynthetic characteristics, chloroplast ultrastructure, and physiology of Anoectochilus roxburghii. *PLoS ONE.* **9**(2): 46–57.

Shehata, S., Elsagheer, A. A., El-Helaly, M. A., Saleh, S. A., and Abdallah, A. M. (2013). Shading effect on vegetative and fruit characters of tomato plant. *J. Appl. Sci. Res*. **9**(3): 1434–1437.

Shi, X.D., Wen, Z.Q., Liu, Y.F. and Wang,W.J. (2006). Effects of shading on growth and photosynthetic capabilities of tobacco leaves of cigar-wrapper use. *Acta Bot. Boreal.-Occid. Sin.* **26(**8): 1718-1721.

Shi, J.G., Cui, H.Y., Zhao, B., Dong, S.T., Liu, P.. and Zhang, J.W. (2013). Effect of light on yield and characteristics of grain filling of summer maize from flowering to maturity. *Sci. Agric. Sin.* **46**(21): 4427-4434.

Smith, H. (2000). Phytochromes and light signal perception by plants--an emerging synthesis. *Nature*. **407**(6804): 585-591.

Song, Y.X., Yang, W.Y., Li, Z.X., Yong, T.M. and Liu, L. (2010). Effect of maize-soybean relay cropping shade on nitrogen metabolism of soybean seedlings. *Chin. J. Oil Crop Sci.* **32**(3): 390-394.

Steinger, T., Roy, B. A. and Stanton, M. L. (2003). Evolution in stressful environments II: adaptive value and costs of plasticity in response to low light in Sinapis arvensis. *J.Evol.Biol.* **16**:313-323.

Sulistyowati, D., Chozin, M. A., Syukur, M., Melati, M., and Guntoro, D. (2016). Selection of shade-tolerant tomato genotypes. *J. Appl. Sci. Res*. **18**(2): 154–159.

Sultan, S.E.,Wilczek,A.M., Bell,D,L. and Hand, G.(1998). Physiological response to complexenvironments in annual Polygonum species of contrasting ecological breadth. *Oecologia.* **115**: 564-578.

Sunaryanti, D.P. and Chozin, M.A. 2018). Growth analysis and physiological characteristics ofseveral tomato genotypes under the low light intensity. *J. ISSAAS.* **24**(2): 129-140.

Susanto, G. and Sundari, T.(2011). The changes of agronomy characters of soybean germplasm under shading condition. *Indones. J. Agric.* **39** (1): 1-6.

Sysoeva, M.I., Markovskaya, E.F. andShibaeva, T.G. (2010). Plants under continuous light: a review. *J. Plant Stress.* **4**(1):5-17.

Taiz, L. and Zeiger,E. (2008). Plant Physiology, Fourth Edition. Sinauer Associates. Sunderland, MA. pp. 180-187

Tateno, M. and Taneda, H. (2007). Photosynthetically versatile thin shade leaves: a paradox of irradiance-response curves. *Photosynthetica.* **45**(2):299–302

Terashima, I., Fujita, T., Inoue, T., Chow, W. S. and Oguchi, R. (2009). Green light drives leaf photosynthesis more efficiently than red light in strong white light: revisiting the enigmatic question of why leaves are green. *Plant Cell Physiol.* **50**:684-697.

Thanos, C. A., and Skordilis, A. (1987). The effects of light, temperature and osmotic stress on the germination. *Seed Sci.Technol*. **14**(1): 235-238.

Tombesi, A.,Antognozzi, E. andPalliotti, A. (1993). Influence of light exposure on characteristics and storage life of kiwifruit. *N. Z. J. Crop Hortic. Sci.* **21**:87-92.

Veloso, A. C. R., Silva, P. S., Siqueira, W. K., Duarte, K. L. R., Gomes, I. L. V., Santos, H. T., and Fagundes, M. (2017). Intraspecific variation in seed size and light intensity affect seed germination and initial seedling growth of a tropical shrub. *Acta Bot. Brasilica*. **31(**4): 736–741.

Venkateswarlu, B., Prasad, V.V.S.S., Rao, A.V. (1977) Effects of low light intensity on different growth phases in rice (*Oryza sativa* L.). *Plant Soil*. **47**(3): 37–47.

Vyas, S.P., Kathju, S, Garg, B.K. andLahiri, A.N. (1996). Response of clusterbean genotypes to shade. *Indian J. Plant Physiol.* **1**:234-238.

Wang, F. and Zhu, C. (2012). Effects of nitrogen and light intensity on tomato (*Lycopersicon esculentum* Mill) production under soil water control. *Afr. J. Agric. Res*.**7(**31): 4408–4415.

Wijeratne, T. L., Mohotti, A. J., and Nissanka, S. P. (2008). Impact of long-term shade on physiological, anatomical, and biochemical changes in tea (*Camellia sinensis* L.). *Trop. Agric. Res*.**20:** 376–387.

Xie, X.J.,Yang, X.H. and Chen, X.Y.(2013). Effects of shading on leaf shape and photosynthetic characteristics of the transgenic *Lespedeza formosa*with expressing *BADH* gene. *Sci. Sil. Sin.* **49**(3): 33-42.

Yang, Y., Dong, L., Shi, L., Guo, J., Jiao, Y., Xiong, H.,Shi, A. (2020). Effects of Low Temperature and Low Light on Physiology of Tomato Seedlings. *Am. J. Plant Sci.* **11**(2): 162–179.

Yao, X., Li, C., Li, S., Zhu, Q., Zhang, H., Wang, H., Xie, F. (2017). Effect of shade on leaf photosynthetic capacity, light-intercepting, electron transfer and energy distribution of soybeans. *Plant Growth Regul*. **83**(3): 409–416.

Zhang, S., Ma, K. and Chen, L. (2003). Response of photosynthetic plasticity of Paeonia suffruticosa to changed light environments. *Environ.Exp.Bot*. **49**:121-133.

Zhang, J., Shi, L, Shi, P. and Zhang, X. (2004). Photosynthetic responses of four Hosta cultivars to shade treatments. *Photosynthetica.* **42**(2):213–218

Zhang, Y., Liu, A., Zhang, X., and Huang, S. (2018). Effects of shading on some morphological and physiological characteristics of begonia semperflorens. *Pak. J. Bot*. **50**(6): 2173–2179.

Zhao, D., Hao, Z. and Tao, J.(2012). Effect of shade on plant growth and flower quality in the herbaceous peony (*Paeonia lactiflora*Pall.). *Plant. Physiol. Biochem*. **61**: 187-196.

Zhi, Z.G., Meng, Y.L. and Pei, S. (2001). Effect of shading during seedling period on the structure of cotton stem and leaf and photosynthetic performance of functional leaf. *Sci. Agric. Sin.* **34**(5): 465-468.

Zhu, H., Li, X., Zhai, W., Liu, Y., Gao, Q., Liu, J. and Zhu, Y. (2017). Effects of low light on photosynthetic properties, antioxidant enzyme activity, and anthocyanin accumulation in purple pak-choi (*Brassica campestris*). *PLoS ONE*. **12**(6): 1–17.

Zoran, S.L., Lidija, M., Ljiljana, S., Dragan, C. and Elazar, F. (2012). Effects of the modification of light intensity by color shade nets on yield and quality of tomatofruits. *Sci. Hortic.***139**:90-95.

PLATES

Plate 1: Different low light treatments

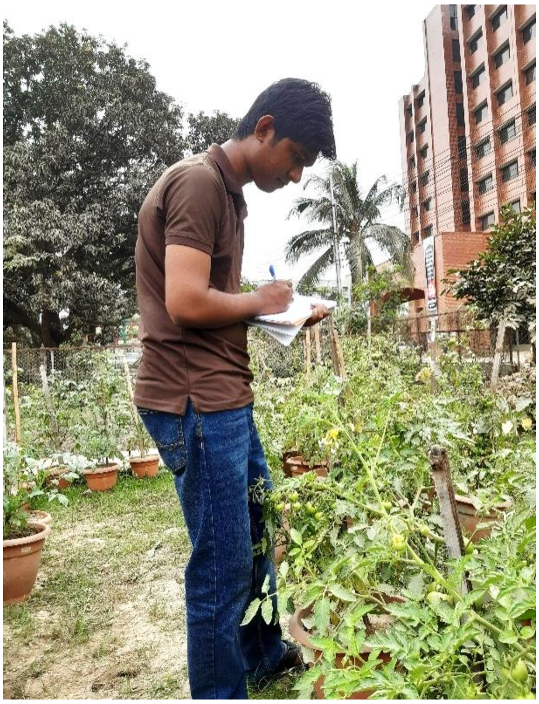


Plate 2: Collecting data of control treatment

Plate 3: Measuring different parameters

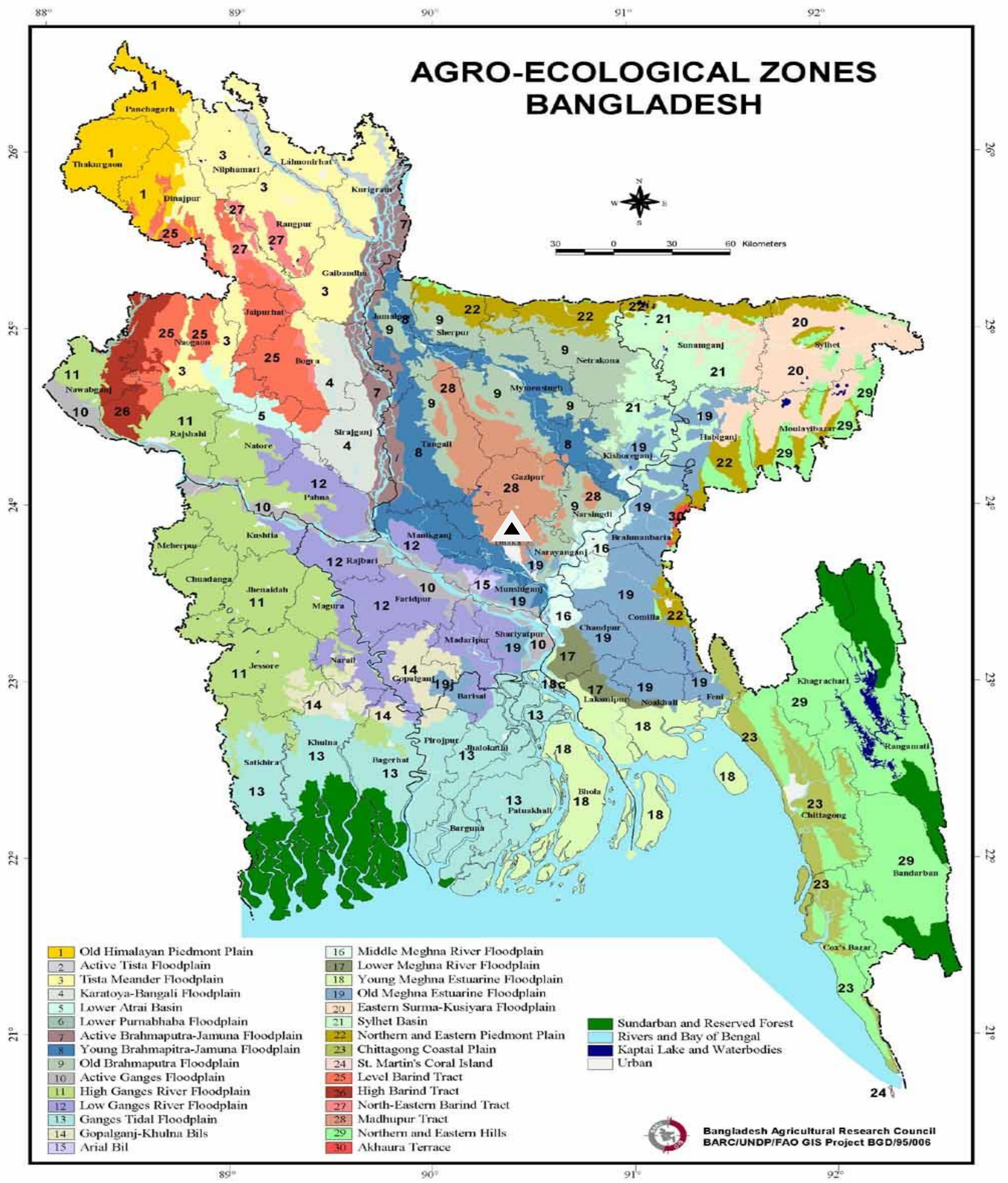
Plate 4: Collecting data of shade treatment

Plate 5: Counting tomato per cluster

Plate 6: Measuring weight

APPENDICES

Appendix I. Map showing the experimental site of the study



▲ The experimental site under study

Appendix II. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from October 2019 to March 2020.

Month	Year	Monthly average air temperature (°C)			Average relative humidity (%)	Total rainfall (mm)	Total sunshine (hours)
		Maximum	Minimum	Mean			
Oct.	2019	36	21	28	69	Trace	219
Nov.	2019	31	18	24	63	Trace	216
Dec.	2019	28	16	22	61	Trace	212
Jan.	2020	27	13	20	57	Trace	198
Feb.	2020	29	18	23	70	3	225
Mar.	2020	32	22	25	73	4	231

Source:
Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1207.

Appendix III. The mechanical and chemical characteristics of soil of theexperimental site as observed prior to experimentation (0 -15 cm depth).

Mechanical composition:

Particle size	Constitution
Texture	Loamy
Sand	40%
Silt	40%
Clay	20%

Chemical composition:

Soil characters	Value
Organic matter	1.44 %
Potassium	0.15 meq/100 g soil
Calcium	1.00 meq/100 g soil
Magnesium	1.00 meq/100 g soil
Total nitrogen	0.072
Phosphorus	22.08 µg/g soil
Sulphur	25.98 µg/g soil
Boron	0.48 µg/g soi
Copper	3.54 µg/g soil
Iron	262.6 µg/g soil
Manganese	164 µg/g soil
Zinc	3.32 µg/g soil

Source: Soil Resources Development Institute (SRDI), Khamarbari, Dhaka

Appendix IV. Factorial ANOVA Table for all the growth and yield parameters of three tomato varieties under control and light intensity treatment

Factorial ANOVA Table for Plant height at 30 DAT

Source	DF	SS	MS	F	P
Replication	2	4.222	2.111		
Variety	2	9.431	4.715	7.62	0.0031
Treatment	3	842.472	280.824	453.90	0.0000
Variety*Treatment	6	18.903	3.150	5.09	0.0021
Error	22	13.611	0.619		
Total	35	888.639			

Grand Mean 33.306
CV 2.36

Factorial ANOVA Table for Plant height at 60 DAT

Source	DF	SS	MS	F	P
Replication	2	4.97	2.48		
Variety	2	575.36	287.68	73.60	0.0000
Treatment	3	4135.53	1378.51	352.68	0.0000
Variety*Treatment	6	211.60	35.27	9.02	0.0000
Error	22	85.99	3.1		
Total	35	5013.46			

Grand Mean 72.589
CV 2.72

Factorial ANOVA Table for Number of leaves per plant at 30 DAT

Source	DF	SS	MS	F	P
Replication	2	1.556	0.7778		
Variety	2	15.722	7.8611	38.91	0.0000
Treatment	3	85.917	28.6389	141.76	0.0000
Variety*Treatment	6	5.167	0.8611	4.26	0.0054
Error	22	4.444	0.2020		
Total	35	112.806			

Grand Mean 11.361
CV 3.96

Factorial ANOVA Table for Number of leaves per plant at 60 DAT

Source	DF	SS	MS	F	P
Replication	2	4.514	2.257		
Variety	2	195.389	97.694	138.79	0.0000
Treatment	3	535.639	178.546	253.65	0.0000
Variety*Treatment	6	29.944	4.991	7.09	0.0003
Error	22	15.486	0.704		
Total	35	780.972			

Grand Mean 23.528
CV 3.57

Factorial ANOVA Table for branch number at 50 DAT

Source	DF	SS	MS	F	P
Replication	2	0.0417	0.02083		
Variety	2	4.6667	2.33333	19.56	0.0000
Treatment	3	4.8056	1.60185	13.43	0.0000
Variety*Treatment	6	0.1111	0.01852	0.16	0.9859
Error	22	2.6250	0.11932		
Total	35	12.2500			

Grand Mean	4.5833
CV	7.54

Factorial ANOVA Table for branch number at 70 DAT

Source	DF	SS	MS	F	P
Replication	2	1.1250	0.56250		
Variety	2	4.6667	2.33333	12.70	0.0002
Treatment	3	4.8056	1.60185	8.72	0.0005
Variety*Treatment	6	0.1111	0.01852	0.10	0.99955
Error	22	4.0417	0.18371		
Total	35	14.7500			

Grand Mean	6.4167
CV	6.68

Factorial ANOVA Table for fresh weight at harvest

Source	DF	SS	MS	F	P
Replication	2	70.7	35.3		
Variety	2	8632.7	4316.3	585.29	0.0000
Treatment	3	35056.4	11685.5	1584.54	0.0000
Variety*Treatment	6	381.9	63.7	8.63	0.0001
Error	22	162.2	7.4		
Total	35	44303.9			

Grand Mean	122.72
CV	2.21

Factorial ANOVA Table for dry weight at harvest

Source	DF	SS	MS	F	P
Replication	2	0.15	0.075		
Variety	2	600.97	300.484	601.54	0.0000
Treatment	3	1557.57	519.190	1039.38	0.0000
Variety*Treatment	6	76.99	12.831	25.69	0.0000
Error	22	10.99	0.500		
Total	35	2246.67			

Grand Mean	21.761
CV	3.25

Factorial ANOVA Table for SPAD unit

Source	DF	SS	MS	F	P
Replication	2	0.39	0.194		
Variety	2	1.06	0.528	0.69	0.5144
Treatment	3	1412.97	470.991	611.52	0.0000
Variety*Treatment	6	22.94	3.824	4.97	0.0024
Error	22	16.94	0.770		
Total	35	1454.31			

Grand Mean 52.639
CV 1.67

Factorial ANOVA Table for fruit number per cluster

Source	DF	SS	MS	F	P
Replication	2	0.0117	0.00583		
Variety	2	0.1667	0.08333	5.95	0.0086
Treatment	3	19.7267	6.57556	469.17	0.0000
Variety*Treatment	6	1.4867	0.24778	17.68	0.0000
Error	22	0.3083	0.01402		
Total	35	21.7000			

Grand Mean 5.3333
CV 2.22

Factorial ANOVA Table for fruit number per plant

Source	DF	SS	MS	F	P
Replication	2	0.237	0.119		
Variety	2	29.641	14.820	43.34	0.0000
Treatment	3	389.728	129.909	379.91	0.0000
Variety*Treatment	6	34.608	5.768	16.87	0.0000
Error	22	7.523	0.342		
Total	35	461.736			

Grand Mean 16.469
CV 3.55

Factorial ANOVA Table for fruit diameter

Source	DF	SS	MS	F	P
Replication	2	0.09389	0.04694		
Variety	2	0.17556	0.08778	18.20	0.0000
Treatment	3	6.11417	2.03806	422.55	0.0000
Variety*Treatment	6	0.28000	0.04667	9.68	0.0000
Error	22	0.10611	0.00482		
Total	35	6.76972			

Grand Mean 4.7472
CV 1.46

Factorial ANOVA Table for fruit length

Source	DF	SS	MS	F	P
Replication	2	0.04667	0.02333		
Variety	2	0.45500	0.22750	50.05	0.0000
Treatment	3	5.00556	1.66852	367.07	0.0000
Variety*Treatment	6	0.18278	0.03046	6.70	0.0004
Error	22	0.10000	0.00455		
Total	35	5.79000			

Grand Mean 4.6500
CV 1.45

Factorial ANOVA Table for individual fruit weight

Source	DF	SS	MS	F	P
Replication	2	0.03	0.02		
Variety	2	999.68	499.84	825.05	0.0000
Treatment	3	7416.18	2472.06	4080.44	0.0000
Variety*Treatment	6	17.97	2.99	4.94	0.0024
Error	22	13.33	0.61		
Total	35	8447.19			

Grand Mean 75.089
CV 1.04

Factorial ANOVA Table for fruit weight per plant (kg)

Source	DF	SS	MS	F	P
Replication	2	0.00088	0.00044		
Variety	2	0.03914	0.01957	7.82	0.0027
Treatment	3	7.78009	2.59336	1036.21	0.0000
Variety*Treatment	6	0.15323	0.02554	10.20	0.0000
Error	22	0.05506	0.00250		
Total	35	8.02840			

Grand Mean 1.2797
CV 3.91

Factorial ANOVA Table for yield (t/ha)

Source	DF	SS	MS	F	P
Replication	2	0.50	0.25		
Variety	2	22.17	11.09	7.82	0.0027
Treatment	3	4406.95	1468.98	1036.21	0.0000
Variety*Treatment	6	86.80	14.47	10.20	0.0000
Error	22	31.19	1.42		
Total	35	4547.61			

Grand Mean 30.457
CV 3.91