INDOOR PRODUCTION OF VEGETABLE UNDER LED (LIGHT EMITTING DIODE) SPECTRUMS

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INDOOR PRODUCTION OF VEGETABLE UNDER LED (LIGHT EMITTING DIODE) SPECTRUMS

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*This is to certify that the thesis entitled **"INDOOR PRODUCTION OF VEGETABLE UNDER LED (LIGHT EMITTING DIODE) SPECTRUMS"** submitted to the Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS) in HORTICULTURE**, embodies the result of a piece of bona fide research work carried out by **SHUMSUNNAHER RINI,** Registration No. **11-04611** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information received during the course of this investigation has been duly acknowledged.

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The greatest gift from Allah I ever had
“I had come to the world through my parents”

DEDICATED TO

My Beloved Parents

The person who taught me
“*Always Trust Your Struggle*”

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----The author

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ABSTRACT

An experiment was accomplished at *2a Biotech lab*, Dept. of Horticulture, Sher-e-Bangla Agricultural University, Dhaka, during August, 2017- July, 2018. Four LED light treatments viz. T_0: White; T_1: White + Blue; T_2: White + Red; T_3: White + Blue + Red were used in this experiment. The experiment was laid out in a Completely Randomized Design with three replications. In case of tomato, the highest plant height (172cm) was observed from (T_1) treatment, the maximum leaf number (122) from (T_3) treatment, the highest leaf area (115.2 cm^2), 1st flowering (32 days), flower cluster (22), flower/cluster (22), 1st fruiting (36 days), fruit/cluster (16), fruit length (44.3 mm), fruit diameter (25.6 mm), brix (3.6%), fruit number (117), fruit weight (9.88g) and yield/plant (1.0 kg) were found from (T_3) treatment where minimum were found in T_0 treatment. In case of brinjal, the highest plant height (83.60 cm) was found from T_1 treatment, the maximum leaf number (23), leaf area (455 cm^2), branch no. (5.0), fruit length (26.2 cm), fruit breadth (6.8 mm), fruit number (35.52), single fruit weight (90.5g) and yield/plant (2.34 kg) were observed from (T_3) treatment while the lowest value in these parameters were found from T_0 treatment . So, the vegetative growth of tomato and brinjal under T_1 treatment and reproductive growth under T_3 treatment were found better.

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ABBREVIATION AND ACCORONYMS

AEZ = Agro-ecological Zone
Agric. = Agricultural
ANOVA = Analysis of Variance
BARI = Bangladesh Agricultural Research Institute
Biol. = Biology
CV = Coefficient of Variation
CRD = Completely Randomized Design
DAP = Days After Planting
et al. = And Others
Ex. = Experiment
FAO = Food and Agricultural Organization of The United Nations
g = Gram
Hort. = Horticulture
i.e. = That is
J. = Journal
Kg = Kilogram
LED = Light Emitting Diode
LSD = Least Significant Difference
mm = Millimeter
Res. = Research
SAU = Sher-e-Bangla Agricultural University
Sci. = Science
Spp. = Species
Technol. = Technology
UNDP = United Nations Development Programme
Viz. = Namely

CHAPTER I

INTRODUCTION

Plant life depends on light in two ways : light provides the energy for the production of organic matter in photosynthesis, and it is perceived as a morphogenetic stimulus. Photo morphogenetic responses include growth effects (such as seed germination, phototropism, and organ elongation) and differentiation (for example flower bud and leaf formation, and the regulation of photosynthetic pigments). Light also induces movements of leaves, stomata, and chloroplasts, which are involved in the regulation of photosynthesis. Major factors affecting plant growth are light quality, light intensity, photoperiod, and the day/night cycle. These parameters can be controlled under greenhouse conditions using artificial light sources. Moreover, application of light pulses and short-term changes of the spectral composition are effective ways to stimulate plants and to induce desired morphological developments. Controlling spectral qualities of the irradiation applied enables faster growth or higher yield at a given radiation energy, and the production of plants of optimized nutritional value. Therefore it is hardly surprising that large-scale plant production under controlled light conditions has become common in industrialized countries.

Effects of light quality on plant growth have been studied for more than 50 years. McCree (2012) measured the action spectrum, absorbance and quantum yield of photosynthesis in crop plants and Inada, L. (1973) determined action spectra for photosynthesis in several higher plant species. These studies triggered research into photosynthesis and dry matter production under irradiation of different spectral qualities. Recent developments of lighting technology have enabled not only researchers but also farmers to control spectral qualities by combinations of various light sources with different waveband emissions.

Vegetables make a major portion of human diet. Though the vegetable requirement is 250 g/day/person, we are able to meet about 30% of the requirement only. A large number of vegetables in Bangladesh have been introduced & vegetable cultivation has become highly commercialized but still there is a wide gap between current production, processing & marketing (Samantaray *et al.*, 2009). Being an over populated country our arable land is becoming limited day by day. Moreover, every year natural calamities e.g. excessive rainfall, drought, hail storm etc. create a great barrier in successful vegetable production. In Bangladesh most of the vegetables are grown in rural area in open field and use of chemicals is a common practice to control the insect- pest diseases and also to increase the total production which is very harmful and also adds large quantities of heavy metals e.g. arsenic, mercury, cadmium, lead etc. (Manirul *et al.,* 2015). On the other hand, our transportation facilities are not well developed. Although lots of vegetables are produced year round but due to poor handling & transportation facilities most of the vegetables loss their nutritive as well as market value (Hassan *et al.*, 2010). However, a planned development in the field of vegetable production will not only improve the nutritional requirement but can also meet the challenge of adequate food supply to the growing population. Indoor farming system can offer a solution for the production of vegetable crops. Artificial lighting is a key component of indoor growing facilities because it is crucial to healthy and rapid plant growth and can impact other aspects of the operation like temperature, space requirements and growth cycles. Light emitting diodes represent a promising technology that has technical advantages over traditional lighting sources, but are only recently being tested for horticultural applications (Mitchell *et al.,* 2012).

LED (light emitting diode) is a unique type of semiconductor diode. The wavelength of the light emitted (the color of light) depend on the properties of semiconductor material. LEDs can have peak emission wavelengths from UV-C (250nm) to infrared (1000nm) (Bourget, 2008) and it is the first light source to have the capability of true spectral control, allowing wavelengths to be matched to plant photoreceptors to provide more optimal production and to influence plant morphology and composition (Morrow, 2008). According to LED manufacturers, LED grow lights maximize blue and red spectrums to provide an excellent balance for vegetables. Therefore, an attempt will be made to study to generate a production technology of indoor vegetable farming by using different LED spectrums.

Objectives:

i. To evaluate LED technology for the production of tomato and brinjal.
ii. To find out appropriate light spectrums for production of specific vegetables.

CHAPTER II
REVIEW OF LITERATURE

Plants are exposed to a variety of spectral qualities governed by geographical location, seasonality, changes in cloud patterns, and effects of surrounding vegetation. Additionally, plants under greenhouse cultivation in areas where natural light is not sufficient to grow a productive crop are exposed to significant changes in spectral quality caused by supplemental lighting with spectra dissimilar to natural light (Hogewoning, 2010). Plant responses to the light spectrum can be generally classified in two major aspects: growth responses and photomorphogenic responses. The growth responses are governed by the photosynthetically active radiation composed of wavelengths between 400-700 nm. The photomorphogenic responses are generally triggered by the blue (400- 500 nm), UV (250-380 nm) and the interaction of red (600-700 nm) and far-red (700-800 nm) wavelengths. Radiation with wavelengths between 400 and 700 nm is known as photosynthetically active radiation (PAR). The irradiance in this range is quantified by the photosynthetic photon flux (PPF) (number of photons per second per square meter of absorbing surface) and it is the driver of photosynthesis in higher plants.

Supplemental lighting in greenhouse is commonly used in areas and seasons where solar radiation is not sufficient for productive plant growth. Solar radiation inside the greenhouse varies in terms of photosynthetic photon flux, daily light integral and spectral quality. The most apparent variable is geographical variation. For example, greenhouses in The Netherlands operated under an average yearly global radiation of 3650 $MJ \cdot m^{-2}$, whereas greenhouses in the southwestern United States are under much higher global radiation (e.g. Arizona has 6687 $MJ \cdot m^{-2}$ per year, averaged during the same period) (Hemming *et al.*, 2008). In addition, seasonal variation, shading from structural members and glazing, cloud patters, aerosols, and dust molecules also limit light interception and spectral quality available for plant growth (Hemming *et al.*, 2006; Kanniah *et al.*, 2012).

Daily light integral is a useful metric of the measured amount of PAR that plants receive daily. Daily light integral is commonly a limiting factor for greenhouse-grown plants. For example, a daily light integral of 30-35 mol m^{-2} d^{-1} should maximize greenhouse tomato production (Spaargaren, 2001), whereas a daily light integral of 13 mol m^{-2} d^{-1} is considered optimal for vegetable-seedling production (Fan *et al.* 2013). Spaargaren (2001) reported that the average daily light integral outside a greenhouse in The Netherlands from September to March was 12 mol m^{-2} d^{-1}. Assuming a 30 to 40% glazing and structural-member reduction, the estimated daily light integral inside the greenhouse is 8.4 to 7.2 mol m^{-2} d^{-1} during the corresponding time in The Netherlands. Also, based on the outside daily light integral in Arizona (Tucson) reported by Kania and Giacomelli (2008) and assuming a 40% glazing and structural-member reduction in the greenhouse, the yearly natural light inside a greenhouse located in Arizona may range from 18 to 36 mol m^{-2} d^{-1} with a yearly average of 25 mol m^{-2} d^{-1}, a suboptimal level for growing tomato plants. For this reason, supplemental lighting can be an effective tool for production of greenhouse crops around the world. A number of light fixtures are available to growers to increase average daily light integral, among those, high pressure sodium lamps and metal halide lamps are commonly used by growers, and LED lamps show potential for future adoption.

High pressure sodium lamps are one of the most energy-efficient lamps for supplemental lighting. About 27 % of the electrical energy input is converted into PPF (400-700nm, 1000 W electronic ballast) (Nelson and Bugbee, 2013). Fourteen percent of the PPF emitted is in the wavelengths between 400 and 565 nm and the rest in the wavelengths up to 700 nm (Spaargaren, 2001). High pressure sodium lamps can be as efficient as 1.30 µmol J^{-1} input electric energy to PPF conversion (Nelson and Bugbee, 2013) and the useful life of the lamp is twice that for metal halide lamps (Spaargaren, 2001). High pressure sodium lamps are characterized by having a high surface temperature (max. 450 °C) and they need to be installed with enough distance above the plant to avoid causing thermal damage (Spaargaren, 2001).

Metal halide lamps produce a more balanced light spectrum than do high pressure sodium lamps. About 50% of the PPF emitted falls in the 400-565 nm range. The highest peaks are in the green and orange/red wavelengths (495-565 nm and 590-625 nm, respectively) (Spaargaren, 2001). In the early days of commercial greenhouse production, there was much interest in metal halide lamps mainly due to their spectral distribution. However, initially these lamps were less energy efficient than high pressure sodium. Also, their lifespan was half that of high pressure sodium, and light output during their lifespan dropped quickly. The current ceramic metal halides have an energy-photon conversion efficiency of 1.34-1.44 µmol J^{-1} PPF (315 W 3100K), which is comparable to or greater than that of high pressure sodium lamps (Nelson and Bugbee, 2013).

Light emitting diodes are a promising technology to be used as supplemental lighting. LEDs have been used extensively as a sole source of lighting for plant growth in research (Massa *et al.* 2008) and commercially in plant factories (Kubota and Chun, 2000). Currently, research on the use of this technology as supplemental lighting in vegetables (Gómez *et al.*, 2013; Hernández and Kubota, 2012; Yang *et al.* 2012) and ornamentals (Craig and Runkle, 2013; Currey and Lopez, 2013) is revealing the potential of this technology. Bourget (2008) described LEDs as robust, solid-state semi-conductors designed to produce desirable, narrow-spectrum light of a quality that will increase quantum efficiency in plants. LEDs have increased in efficiency very rapidly. In 2008, LEDs were less efficient than high pressure sodium lamps, and now they are up to 50% for blue LEDs and 38% for red LEDs (electrical energy input converted into PPF) (Philips, 2012), with commercial fixtures ranging from 0.84 to 1.60 µmol J^{-1} PPF efficiency (Nelson and Bugbee, 2013). Furthermore, in contrast to high pressure sodium and metal halide, LEDs are capable of frequent "on" and "off" switching, or dimming without negative impacts to diode lifetime. This capability offers the opportunity to investigate the potential benefits of pulsed lighting to plants. Pulsed lighting is characterized by frequency (number of on/off cycles that occur per second) and duty ratio (ratio of 'on' time to 'off' time in one on/off cycle). The concept is to provide pulses of light at specific frequencies in order to optimize net photosynthetic rate (Sager and Giger, 1980; Tennessen *et al.,* 1995). If pulsed lighting can optimize net photosynthetic rate and consequently increase growth rate in greenhouse plants, then it is possible to reduce electrical energy consumption of LED supplemental lighting.

Other studies testing LEDs as a commercial light source for indoor cultivation have shown the potential of LEDs for vegetable-transplant production. For example, Fan *et al.* (2013) tested various PPF using B:R LED (1:1 ratio) for the production of tomato transplants and demonstrated that dry mass did not increase above 300 µmol m^{-2} s^{-1}. Also, Jang *et al.* (2013) tested the healing of grafted pepper plants under fluorescent lamps vs. R, B, or B:R LEDs and found that dry-mass response after healing to B:R was similar to that for the fluorescent lamp control, and healing quality between the two treatments was the same.

As reviewed in the previous section, a vast number of studies using LEDs as the only lighting source have shown the importance of red and blue light for healthy growth and development (Brown *et al.,* 1995; Hogewoning *et al.*, 2010; Kim *et al.,* 2005; Liu *et al.,* 2011; Massa *et al.,* 2008; Nanya *et al.,* 2012; van Ieperen *et al.,* 2012). However, limited research is available on plant developmental responses to different red and blue photon flux percentages supplementing solar light. Solar radiation has approximately 31% blue and 34 % red radiation (sun-facing, 37° tilted surface, energy basis W m^{-2} data representing direct and diffuse light spectrum) (ASTM, 2003). Plant responses to LED lights supplementing solar light can be different than plant responses to LEDs as a sole lighting source. Recently, research pertaining to greenhouse-transplant responses to different supplemental B:R ratios revealed that morphological responses to LED were species specific. Hernández and Kubota (2012, *unpublished*) tested different percentages of supplementary red and blue LED lighting for tomato (Hernández and Kubota, 2012), pepper, and cucumber transplants under varied solar daily light integrals. It was evident for all three species that the addition of LED light improved morphological parameters such as increased stem diameter and decreased final hypocotyl length compared to unsupplemented controls.

Cucumber, tomato, and pepper had the same responses to different B:R ratios of supplemental LED lighting under high solar daily light integral. However, under low daily light integral, a higher B:R ratio decreased leaf area expansion for cucumber. Hernández and Kubota (2012, *unpublished*) postulate that responses to LED supplemental light quality are species specific and that solar PPF fulfilled blue-light requirements of vegetable transplants under both high and low daily light integral. They also concluded that red light alone was preferred for supplemental lighting. Similar to supplemental LED lighting conditions, plant responses to light quality under sole-source LED lighting are also species specific (Cope and Bugbee, 2013; Hogewoning *et al.* 2010; Nanya *et al.,* (2012).

Olle *et al.,* (2013) carried out an experiment to show the effects of light-emitting diode lighting on greenhouse plant growth and quality. The aim of this study was to present the light emitting diode (LED) technology for greenhouse plant lighting and to give an overview about LED light effects on photosynthetic indices, growth, yield and nutritional value in green vegetables and tomato, cucumber, sweet pepper transplants. The sole LED lighting, applied in closed growth chambers, as well as combinations of LED wavelengths with conventional light sources, fluorescent and high pressure sodium lamp light, and natural illumination in greenhouses are overviewed. Red and blue light are basal in the lighting spectra for green vegetables and tomato, cucumber, and pepper transplants; far red light, important for photo morphogenetic processes in plants also results in growth promotion. However, theoretically unprofitable spectral parts as green or yellow also have significant physiological effects on investigated plants. Presented results disclose the variability of light spectral effects on different plant species and different physiological indices.

Manohar *et al.,* **(**2018) investigate on vegetable growth using artificial sunlight for indoor farming. Indoor planting or better known as indoor farming has become more widely used method as it is able to provide higher yields throughout the year. Currently most of the developed country the shortage of land for agriculture and the time is a major factor effecting agriculture sector, it is a global trend. In this technique, one of the most important things is the use of artificial light sources to replace the sun at indoor environment. Although there is still no such light that capable of replacing the sun completely, but sometimes the artificial light provides better results. The use of artificial light in plant cultivation was first began in 1868 by a Russian botanist Andrei Famintsyn. The use of artificial light changes according to current technology from time to time. The results of previous studies showed similar outcome that were relied on the capabilities of existing equipment at that time. In this study, three different LED color lights, 18W and a fluorescent lamp, 36W were used. The height or growth of the salad plant was taken for 6 weeks period. At the end of the study, the height of the salad plant in the red LED lamp is as high as 10.9cm, followed by the Blue, White and Yellow Lights, 7.41cm, 7.6cm and 5.23cm. From the studies it shows different color lights create an impact on the height growth of a plant or vegetable.

Bliznikas *et al.,* (2012) reported that application of supplementary solid-state lighting within an industrial greenhouse for pre-harvest treatment of various green vegetables (spinach, parsley, dill, mustard, rocket, and onion leaves) grown under high-pressure sodium lamps and natural solar illumination. For 3 days before harvesting, supplementary lighting from red 638-nm light-emitting diodes (LEDs) was applied within a 19-h photoperiod in such a way that the net photo synthetically active flux density of at least ~300 µmol m-2 s-1was maintained. Such a pre-harvest treatment was found to remarkably enhance antioxidant and nutritional properties of green vegetables due to the increased activity of the metabolic system for the protection from a mild photo oxidative stress. However, the effect of supplementary red light was found to be species dependent. The sensitivity of a species to the lighting conditions was determined by the natural level of phenolic compounds accumulated in the leaves. Supplemental lighting evokes a metabolic unbalance in green vegetables that accumulate low amounts of antioxidant compounds, therefore the flux of red light even diminish the nutritional value of spinach and rocket. Meanwhile, application of supplemental LED lighting to dill and parsley results in the accumulation of vitamin C and carbohydrates and in the enhancement of free radical binding activity and the activity of nitrate reducing enzymes.

Brazaityte *et al.,* (2006) found the impact of controlled illumination spectrum on photosynthetic system and productivity of lettuce (*Lactuca sativa* L. cv. Grand Rapids) grown in phytotron was investigated. The variable-spectrum lighting modules were designed using four types of high-power light-emitting diodes (LEDs) with emission peaked in red at the wavelengths of 660 nm and 640 nm, in blue at 455 nm, and in far-red at 735 nm. Biometric characteristics, pigments content and photosynthesis intensity in lettuce grown under eight different light irradiance were measured and compared. A corresponding experiment under a conventional high-pressure sodium lamp was also performed for reference. The treatments were carried out under photoperiod of 14 hand 21115·C (day/night) temperature. Lettuce was grown for 29 days after sowing in a phytotron chamber. Stomata size of lettuce grown under LED was larger than that of the plants growing under high-pressure sodium lamp. The lowest number and largest size of stomata were observed under light without the red component, peaked at 660 nm. Elimination of the blue component (455 nm) resulted in an enhancement of fresh mass production and increased leaf area, but the photosynthetic productivity did not show similar effect. The chlorophylls content in lettuce leaves was high during the entire growth period, but strongly decreased at the end of the treatment without blue light. The photosynthesis in lettuce leaves was most intensive under irradiance without the far-red component (735 nm). We conclude that productivity of lettuce can be optimized by adjusting the light spectrum and flux density.

An experiment conducted by Douglas McCall (1992) to evaluate the effect of supplementary light on tomato transplant growth and the after-effects on yield. Tomato (*Lycopersicon esculentum* Mill.) were grown with supplementary light at photosynthetic photon flux densities of 30, 60 and 90/t mol $m^{-2}s^{-1}$ and constant temperatures of 17, 19 and 21°C to determine the effect of supplementary light level on growth and the after-effects on yield, and to examine interactions with cultivar and temperature. Plant height, leaf number, leaf area and dry weight of aerial plant parts were significantly increased with increasing levels of supplementary light. Greater early yield and market value was found with increasing levels of supplementary light prior to planting, due to an increased number of harvested fruit in the early cropping period. The increased yield and market value was maintained throughout the 16 week harvest period. A reduction in fruit quality with increasing levels of supplementary light was found in the early cropping period but no differences were found after 16 weeks of harvest. No significant interactions with temperature or cultivar were found.

Hernandez (2013) was conducted an experiment to evaluate the growth and development of greenhouse vegetable seedlings under supplemental led lighting. He found that tomato and cucumber seedlings were grown under different supplemental blue and red photon flux ratios (B:R ratios) under high (16-19 mol $m^{-2}d^{-1}$) and low (5-9 mol $m^{-2}d^{-1}$) solar daily light integrals (DLIs).

The supplemental daily light integral was 3.6 mol $m^{-2}d^{-1}$. A treatment without supplemental light served as a control. Both tomato and cucumber seedlings had increased growth rate and improved morphology when grown under the supplemental LED light compared to the control. However, no significant differences were observed for any growth and morphological parameters measured in this study between the different B:R ratios for both cucumber and tomato transplants under high DLI conditions. Cucumber seedlings showed a tendency to decrease dry mass, leaf number and leaf area under low DLI conditions with increasing B:R ratio. Tomato seedlings did not show any differences between the different B:R ratios under low DLI conditions. Seedlings growth and morphology under supplemental LED light were compared to those under supplemental high pressure sodium (HPS) light. Cucumber seedlings under supplemental HPS light had greater shoot dry mass than those under the supplemental red LED light. Tomato shoot dry mass showed no differences between the HPS and red LED supplemental light treatments. Cucumber seedlings were also grown under supplemental LED pulsed lighting and supplemental LED continuous lighting. Cucumber seedlings showed no differences in shoot dry mass and net photosynthetic rate between the treatments. Collectively, these studies concluded that red LED is preferred for supplemental lighting and the increase of blue light does not offer any benefits unless the efficiency of blue LEDs largely exceeds the red LEDs. The results of this research can be used for fixture development by LED manufactures and as a decision making tool for the adoption of supplemental LED lighting by greenhouse growers.

Blue light is suspected to participate in leaf photosynthetic acclimation to irradiance (Anderson *et al.*, 1995; Matsuda *et al.*, 2008; Sanger and Bauer, 1987; Walters, 2005). Blue-light-grown plants show photosynthetic characteristics similar to those of plants grown under high irradiance, such as higher RuBisCO content (Eskin *et al.*, 1991; López-Juez and Hughes, 1995), greater chlorophyll a/b ratio (Buschmann *et al.*, 1978; Lichtenthaler *et al.*, 1980; López-Juez and Hughes, 1995; Matsuda *et al.*, 2008), and higher cytochrome *f* content (Leong and Anderson, 1984; López-Juez and Hughes, 1995). In addition, Matsuda *et al.* (2007) suggested that blue light was involved in acclimation to light at the chloroplast level in spinach.

Furthermore, extensive research has been done regarding the importance of blue light under sole-source artificial lighting conditions using LEDs. For example, Tripathy and Brown (1995) for wheat and Miyashita *et al.* (1997) for potato plantlets showed how blue light improved chlorophyll content of plants otherwise grown under red LEDs only. Also, wheat and *Arabidopsis* produced higher numbers of seeds when red LEDs were supplemented with blue LEDs (Goins *et al.*, 1998; Goins *et al.*, 1997).

Research reports on photomorphogenic responses to blue light are ample. Blue light is known to control guard-cell apertures, which affect CO2 exchange and water relations. Schwartz and Zeiger (1984) studied stomatal opening under white light, blue and red light, and darkness for two plant species, and found that stomatal apertures under blue light were higher than white and red light at all photon fluxes in both species. This response is supported by other studies (Travis and Mansfield 1981, Pemadasa 1982). Schwartz and Zeiger (1984) found that stomatal opening was correlated with the activity of two photoreceptors, a PAR-dependent receptor linked to the guard-cell chloroplast and a second one specific to the blue-light-dependent system. They also observed that the blue-light photo-system saturated at low photon fluxes.

Blue light is also known to inhibit stem elongation. Cosgrove and Green (1981) studied the mechanism of hypocotyl-elongation inhibition by blue light in cucumber (*Cucumis sativus* L.) and sunflower (*Helianthus annuus* L.) seedlings by measuring changes in turgor. In that study, researchers demonstrated that blue light inhibited stem elongation by decreasing the yielding properties of cell walls.

An experiment was conducted by Uddin *et al.,* (2017) at Horticulture Farm of Sher-e-Bangla Agricultural University during the period of December to evaluate the influence of day length extension with LED light supplement on growth, yield and seed production of broccoli (*Brassica oleracea* var. *Italica* L.). Four LED light supplementation treatment viz. LW = White LED, LB = Blue LED, LR = Red LED and LR+B = Both Red & Blue LED were used along with one control (LC = No supplementation) in this experiment arranged in Randomized Complete Blocked Design (RCBD) with three replication. LR + B treatment showed the best result in most of the parameters studied (weight of curd = 382.5 g, diameter of curd = 10.5 cm, yield/plot=8.4 Kg, yield/ha = 7.4 ton, no. of seed/pod = 12.0, no. of seed/plant = 1279.0) and to the rest showed statistical similarity to the highest. Highest germination percentage of the produced seeds was also found from this treatment (87.3%). So, day extension with combination of red and blue led can be used as a sustainable technique to produce viable seeds of broccoli along with better production.

Deram *et al.,* (2013) studied on Light-emitting-diode (LED) lighting for greenhouse tomato production. The primary purpose of this experiment was to test tomato plants (*Solanum lycopersicum*), in a research greenhouse using a full factorial design with three light intensities (High: 135 µmol $m^{-2}s^{-1}$, Medium: 115 µmol $m^{-2}s^{-1}$and Low: 100 µmol $m^{-2}s^{-1}$) at three red to blue ratio levels (5:1, 10:1 and 19:1) compared to 100% HPS, and a control (no supplemental lighting). The exact wavelengths chosen were 449 nm for the blue and 661 nm for the red. Secondary treatments were also tested using 100% red light supplied from the top, 100% red light supplied from the bottom, a 50%:50% LED:HPS and a replicate of the 10:1 ratio with High light intensity. The experiment was replicated over two different seasons (Summer-Fall 2011 and Winter-Spring 2011-2012). During the experiment, the highest biomass production (excluding fruit) occurred with the 19:1 ratio (red to blue), with increasing intensity resulting in more growth, whereas a higher fruit production was obtained using the 5:1 ratio. The highest marketable fruit production (fruit over 90 g, Savoura internal standard) was the 50%:50% LED: HPS, followed by 5:1 High and 19:1 High. From this research, LEDs have been shown to be superior in fruit production over HPS alone, and LEDs can improve tomato fruit production with HPS and have the ability to become the dominant supplemental greenhouse lighting system.

Avercheva (2009) compared growth and the content of sugar, protein, and photosynthetic pigments, as well as chlorophyll fluorescence parameters in 15 and 27 day old Chinese cabbage (*Brassica chinensis* L.) plants grown under a high-pressure sodium (HPS) lamps or a light source built on the basis of red (650 nm) and blue (470 nm) light-emitting diodes (LEDs) with a red to blue photon ratio of 7: 1. One group of plants was grown at a photosynthetic photon flux (PPF) level of 391 ±24 µmol/ (m^2s) (normal level); the other, at a PPF level of 107±9 µmol/ (m^2s) (low light). Plants of the third group were firstly grown at the low light and then (on the 12th day) transferred to the normal level. When grown at the normal PPF level, the plants grown under LEDs didn't differ from plants grown under HPS lamps in shoot fresh weight, but they showed a lower root fresh and dry weights and the lower content of total sugar and sugar reserves in the leaves. No differences in the pigment content and photosystem II quantum yield were found; however, a higher Chl a/b ratio in plants grown under LEDs indicates a different proportion of functional complexes in thylakoid membranes. The response to low light conditions was mostly the same in plants grown under HPS lamps and LEDs; however, LED plants showed a lower growth rate and a higher nonphotochemical fluorescence quenching. In the case of the altered PPF level during growth, the plant photosynthetic apparatus adapted to new conditions of illumination within three days. Plants grown under HPS lamps at a constant normal PPF level and those transferred to the normal PPF level on the 12th day, on the 27th day didn't differ in shoot fresh weight, but in plants grown under LEDs, the differences were considerable. The results of this experiment showed that

LED-based light sources can be used for plant growing. At the same time, some specific properties of plant photosynthesis and growth under these conditions of illumination were found.

Goins *et al.,* (1997) found that red light-emitting diodes (LEDs) are a potential light Source for growing plants in space flight systems because of their safety, small mass and volume, wavelength specificity, and longevity. Despite these attractive features, red LEDs must satisfy requirements for plant photosynthesis and photo morphogenesis for successful growth and seed yield. To determine the influence of gallium aluminium arsenide (GaAIAs) red LEDs on wheat photo morphogenesis, photosynthesis, and seed yield, wheat (*Triticum aestivum* L., cv. 'USU Super Dwarf) plants were grown under red LEDs and Compared to plants grown under day light fluorescent (white) lamps and red LEDs supplemented with either 1 % or 10% blue light from blue fluorescent (BF) lamps. Compared to white light-grown plants, wheat grown under red LEDs alone demonstrated less main culm development during vegetative growth through preanthesis, while showing a longer flag leaf at 40 DAP And greater main culm length at final harvest (70DAP). As supplemental BF light was increased with red LEDs, shoot dry matter and net leaf photosynthesis rate increased. At final harvest, wheat grown under red LEDs alone displayed fewer sub tillers and a lower seed yield compared to plants grown under white light. Wheat grown under red LEDs+10 % BF light had comparable shoot dry matter accumulation and seed yield Relative to wheat grown under white light. These results indicate that wheat can complete its life cycle under red LEDs alone, but larger plants and greater amounts of seed are produced in the presence of red LEDs supplemented with a quantity of blue light.

Neil *et al.,* (2001) conducted an experiment for improving spinach, radish, and lettuce growth under red light emitting diodes (LEDs) with blue light supplementation. Here, radish (*Raphanus sativus* L.), lettuce (*Lactuca sativa* L.), and spinach (*Spinacea oleracea* L.) plants were grown under 660-nm red light-emitting diodes (LEDs) and were compared at equal photosynthetic photon flux (PPF) with either plants grown under cool-white fluorescent lamps (CWF) or red LEDs supplemented with 10% (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$) blue light (400–500 nm) from blue fluorescent (BF) lamps. At 21 days after planting (DAP), leaf photosynthetic rates and stomata conductance were greater for plants grown under CWF light than for those grown under red LEDs, with or without supplemental blue light. At harvest (21DAP), total dry-weight accumulation was significantly lower for all species tested when grown under red LEDs alone than when grown under CWF light or red LEDs + 10% BF light. Moreover, total dry weight for radish and spinach was significantly lower under red LEDs + 10% BF than under CWF light, suggesting that addition of blue light to the red LEDs was still insufficient for achieving maximal growth for these crops.

Brown *et al.,* (1995) conducted an experiment on growth and photo morphogenesis of pepper plants under red light-emitting diodes with supplemental blue or far-red lighting. Light-emitting diodes (LEDs) are a potential irradiation source for intensive plant culture systems and photobiological research. They have small size, low mass, a long functional life, and narrow spectral output. In this study, growth and dry matter partitioning of 'Hungarian Wax' pepper (*Capsicum annum* L.) plants was measured grown under red LEDs compared with similar plants grown under red LEDs with supplemental blue or far-red radiation or under broad spectrum metal halide (MH) lamps. Additionally, it described the thermal and spectra1 characteristics of these sources. The LEDs used in this study had a narrow bandwidth at half peak height (25 nm) and a focused maximum spectral output at 660 nm for the red and 735 nm for the far-red. Near infrared radiation (800 to 3000 nm) was below detection and thermal infrared radiation (3000 to 50,000 nm) was lower in the LEDs compared to the MH source. Although the red to far-red ratio varied considerably, the calculated phytochrome photo stationary state (f) was only slightly different between the radiation sources.

Plant biomass was reduced when peppers were grown under red LEDs in the absence of blue wavelengths compared to plants grown under supplemental blue fluorescent lamps or MH lamps. The addition of far-red radiation resulted in taller plants with greater stem mass than red LEDs alone. There were fewer leaves under red or red plus far-red radiation than with lamps producing blue wavelengths. These results indicate that red LEDs may be suitable, in proper combination with other wavelengths of light, for the culture of plants in tightly controlled environments such as space-based plant culture systems.

Tripathy *et al.,* (1995) found that wheat seedlings grown with roots exposed to constant red light (300-500 pmol m^{-2} s^{-2}) did not accumulate chlorophyll in the leaves. In contrast, seedlings grown with their roots shielded from light accumulated chlorophylls. Chlorophyll biosynthesis could be induced in red-light-grown chlorophyll-deficient yellow plants by either reducing the red-light intensity at the root surface to 100 pmol $m^{-2}s^{-2}$ or supplementing with 6% blue light. The inhibition of chlorophyll biosynthesis was due to impairment of the Mg- chelatase enzyme working at the origin of the Mg-tetrapyrrole pathway. The root-perceived photo morphogenic inhibition of shoot greening demonstrates root-shoot interaction in the greening process.

Spectral effects of supplemental light irradiated during the dark period on growth were examined in spinach grown at either 100 (low level) or 300 (medium level) µmol $m^{-2}s^{-1}$ of photosynthetic photon flux density (PPFD) during the light period. Plants grown under the low level of PPFD during the light period were exposed to 50 µmol $m^{-2}s^{-1}$of supplemental light for six hours at the beginning, the end, or the middle of the dark period. Acceleration of growth including increases in total dry matter, plant height and leaf area was caused by exposure to any of the supplemental lights, blue, green, or red. These supplemental lights did not cause different acceleration of growth by irradiating at the middle of the dark period, while more acceleration of growth was caused by exposure to red light rather than blue light at the beginning of the dark period, and blue light rather than red light at the end of the dark period. Under the medium level of PPFD during the light period, plants were exposed to 50 μmol $m^{-2}s^{-1}$ of supplemental light for 30 minutes at either the beginning or the end of the dark period. As a result, brief exposures to both blue light at the end of the dark period and red light at the beginning of the dark period produced the acceleration of growth including about 20% increase of total dry matter. The other two combinations of quality and lighting hour of supplemental light during the dark period, however, did not produce any accelerative effects on growth. These results suggest that not only photosynthesis but also low-energy responses to blue and red light bring about an increase in total dry matter and other accelerative effects by supplemental lighting at the beginning and the end of the dark period (Hanyu *et al.,* 2002).

Light-emitting diodes (LEDs) with high-intensity output are being studied as a photosynthetic light source for plants by Hoenecke *et al.,* 1992. High-output LEDs have peak emission at 660 nm concentrated in a waveband of ±30 nm. Lettuce (*Lactuca sativa*) seedlings developed extended hypocotyls and elongated cotyledons when grown under these LEDs as a sole source of irradiance. This extension and elongation was prevented when the red LED radiation was supplemented with more than 15 $\mu mol \cdot m^{-2} \cdot s^{-1}$of 400- to 500-nm photons from blue fluorescent lamps. Blue radiation effects were independent of the photon level of the red radiation.

Johkan *et al.,* (2010) determined the effects of raising seedlings with different light spectra such as with blue, red, and blue + red light-emitting diode (LED) lights on seedling quality and yield of red leaf lettuce plants. The light treatments we used were applied for a period of 1 week and consisted of100 $mmol.m^{-2}.s^{-1}$ of blue light, simultaneous irradiation with 50 $mmol.m^{-2}.s^{-1}$ of blue light and 50 $mmol.m^{-2}.s^{-1}$ of red light, and 100 $mmol.m^{-2}.s^{-1}$ of red light. At the end of the light treatment, that is 17 days after sowing (DAS), the leaf area and shoot fresh weight (FW) of the lettuce seedlings treated with red light increased by 33% and 25%, respectively, and the dry weight of the shoots and roots of the lettuce seedlings treated with blue-containing LED lights increased by greater than 29% and greater than 83% compared with seedlings grown under a white fluorescent lamp (FL). The shoot/root ratio and specific leaf area of plants irradiated with blue-containing LED lights decreased. At 45 DAS, higher leaf areas and FWs were obtained in lettuce plants treated with blue-containing LED lights. The total chlorophyll (Chl) contents in lettuce plants treated with blue-containing and red lights were less than that of lettuce plants treated with FL, but the Chl a/b ratio and carotenoid content increased under blue-containing LED lights. Polyphenol contents and the total antioxidant status (TAS) were greater in lettuce seedlings treated with blue-containing LED lights than in those treated with FL at 17 DAS. The higher polyphenol contents and TAS in lettuce seedlings at 17 DAS decreased in lettuce plants at 45 DAS. In conclusion, this results indicate that raising seedlings treated with blue light promoted the growth of lettuce plants after transplanting. This is likely because of high shoot and root biomasses, a high content of photosynthetic pigments, and high antioxidant activities in the lettuce seedlings before transplanting. The compact morphology of lettuce seedlings treated with blue LED light would be also useful for transplanting.

Zheng *et al.,* (2017) examine long-term effects of red- and blue-light emitting diodes on leaf anatomy and photosynthetic efficiency of three ornamental pot plants. Four light treatments were applied at 100 μmol $m^{-2}s^{-1}$ and a photoperiod of 16 h using 100% red (R), 100% blue (B), 75% red with 25% blue (RB), and full spectrum white light (W), respectively in this experiment. B and RB resulted in a greater maximum quantum yield (Fv/Fm) and quantum efficiency (8PSII) in all species compared to R and W and this correlated with a lower biomass under R. B increased the stomatal conductance compared with R. This increase was linked to an increasing stomatal index and/or stomatal density but the stomatal aperture area was unaffected by the applied light quality. Leaf hydraulic conductance (K leaf) was not significantly affected by the applied light qualities. Blue light increased the leaf thickness of F. benjamina, and a relative higher increase in palisade parenchyma was observed. Also in S. speciosa, increase in palisade parenchyma was found under B and RB, though total leaf thickness was not affected. Palisade parenchyma tissue thickness was correlated to the leaf photosynthetic quantum efficiency (8PSII). In conclusion, the role of blue light addition in the spectrum is essential for the normal anatomical leaf development which also impacts the photosynthetic efficiency in the three studied species.

Nhut *et al.,* (2003) examined unrooted strawberry cv. ‘Akihime’ shoots with three leaves obtained from standard mixotrophic cultures were cultured in the ‘‘Culture Pack’’-rockwool system with sugar-free MS medium under CO - enriched condition. To examine the effect of super bright red and blue light-emitting diodes (LEDs) on in vitro growth of plantlets, these cultures were placed in an incubator, ‘‘LED PACK’’, with either red LEDs, red LEDs1blue LEDs or blue LEDs light source. To clarify the optimum blue and red LED ratio, cultures were placed in ‘‘LED PACK 3’’ under LED light source with either 100, 90, 80, or 70% red 10, 10, 20, 30% blue, respectively, and also under standard heterotrophic conditions. To determine the effects of irradiation level, cultures were grown under 90% red LEDs + 10% blue LEDs at 45, 60 or 75mmol $m^{-2}s^{-2}$. Plantlet growth was best at 70% red130% blue LEDs. The optimal light intensity was 60mmol $m^{-2}s^{-2}$. Growth after transfer to soil was also best after in vitro culture with plantlets produced were 70% red + LEDs130% blue LEDs.

Shoji *et al.,* (2010) determined the effects of raising seedlings with different light spectra such as with blue, red, and blue + red light-emitting diode (LED) lights on seedling quality and yield of red leaf lettuce plants. The light treatments were applied for a period of 1 week and consisted of 100mmol.m^{-2} s^{-1} of blue light, simultaneous irradiation with 50m mol.m^{-2} s^{-1} of blue light and 50mmol.m^{-2} s^{-1} of red light, and 100mmol.m^{-2} s^{-1} of red light. At the end of the light treatment, that is 17 days after sowing (DAS), the leaf area and shoot fresh weight (FW) of the lettuce seedlings treated with red light increased by 33% and 25%, respectively, and the dry weight of the shoots and roots of the lettuce seedlings treated with blue-containing LED lights increased by greater than 29% and greater than 83% compared with seedlings grown under a white fluorescent lamp (FL). The shoot/root ratio and specific leaf area of plants irradiated with blue-containing LED lights decreased. At 45 DAS, higher leaf areas and FWs were obtained in lettuce plants treated with blue-containing LED lights. The total chlorophyll (Chl) contents in lettuce plants treated with blue-containing and red lights were less than that of lettuce plants treated with FL, but the Chl a/b ratio and carotenoid content increased under blue-containing LED lights. Polyphenol contents and the total antioxidant status (TAS) were greater in lettuce seedlings treated with blue-containing LED lights than in those treated with FL at 17 DAS. The higher polyphenol contents and TAS in lettuce seedlings at 17 DAS decreased in lettuce plants at 45 DAS. In conclusion, this results indicate that raising seedlings treated with blue light promoted the growth of lettuce plants after transplanting. This is likely because of high shoot and root biomasses, a high content of photosynthetic pigments, and high antioxidant activities in the lettuce seedlings before transplanting. The compact morphology of lettuce seedlings treated with blue LED light would be also useful for transplanting.

Tanaka (1998) evaluate the effects of light generated by super bright blue and red LEDs on the growth of *Cymbidium* plantlets cultured *in vitro* have been studied. Leaf growth, chlorophyll content and shoot and root weights were affected by different LED irradiations. Red light promoted leaf growth but decreased chlorophyll content. This was reversed by blue light. The growth of *Cymbidium* plantlets in terms of increase in total shoot and root weights was comparable under red plus blue LEDs and the fluorescent systems. Generally, the response to different LED was similar for plantlets grown on sugar-free medium with or without CO_2 enrichment and sugar-containing medium but without CO_2 enrichment. The growth of *Cymbidium* plantlets was enhanced by CO_2 enrichment. Our study demonstrates the effectiveness of a total irradiation system for *Cymbidium* plantlets growth *in vitro*. The significance of our findings in relation to the development of a suitable lighting system for plant tissue culture is discussed.

Yorio *et al.,* (2001) were compared radish (*Raphanus sativusL. cv. Cherriette*), lettuce (*Lactuca sativa* L. cv. *Waldmann's* Green), and spinach (*Spinacea oleracea* L. *cv. Nordic* IV) plants under 660-nm red light-emitting diodes (LEDs) at equal photosynthetic photon flux (PPF) with either plants grown under cool-white fluorescent lamps (CWF) or red LEDs supplemented with 10% (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$) blue light (400–500 nm) from blue fluorescent (BF) lamps. At 21 days after planting (DAP), leaf photosynthetic rates and stomatal conductance were greater for plants grown under CWF light than for those grown under red LEDs, with or without supplemental blue light. At harvest (21DAP), total dry-weight accumulation was significantly lower for all species tested when grown under red LEDs alone than when grown under CWF light or red LEDs + 10% BF light. Moreover, total dry weight for radish and spinach was significantly lower under red LEDs + 10% BF than under CWF light, suggesting that addition of blue light to the red LEDs was still insufficient for achieving maximal growth for these crops.

CHAPTER III

MATERIALS AND METHODS

An experiment was conducted at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Bangladesh during August, 2017 to July, 2018 to observe the performance of various indoor vegetables under different LED spectrum. This chapter contains a brief description of location of the experimental site, climatic condition and soil, materials used for the experiment, treatment and design of the experiment, production methodology, intercultural operations, data collection procedure and statistical and economic analysis etc. which are presented as follows:

3.1 Experimental sites

The experiment was conducted at *2a Biotech lab*, Dept. of Horticulture, Sher-e-Bangla Agricultural University during the period from August, 2017 to July, 2018 to find out the performance of various indoor vegetables under different LED light spectrum. The location of the experimental site is $23^{o}74^{/}$N latitude and $90^{o}35^{/}$E longitude and at an elevation of 8.2m from sea level (Anon., 1989).

3.2 Climatic conditions

Experimental site was located in the subtropical monsoon climatic zone, set parted by heavy rainfall during the months from April to September (Kharif season) and scant of rainfall during the rest of the year (Rabi season). Also under the sub-tropical climatic, which is characterized by high temperature, high humidity, heavy precipitation with occasional gusty winds and relatively long in Kharif season (April-September) and plenty of sunshine with moderately low temperature, low humidity and short day period during Rabi season (October- March).

3.3 Characteristics of soil

The experimental soil belongs to the Modhupur Tract under AEZ No. 28 (UNDP -FAO, 1988). The selected experimental plot was medium high land and the soil series was Tejgaon (FAO,1988). The characteristics of soil under experimental plot were analyzed in the SRDI, Soil Testing Laboratory, Khamarbari, Dhaka. The soil of the experimental field initially had a p^H of 6.5.

3.4 Experimental materials

3.4.1 Plantings materials

Brinjal (BARI-4) and Tomato (BARI-11) varieties were used for the present research work. The genetically pure and physically healthy seeds were collected from Advanced Seed Research and Biotech Center (ASRBC), ACI Limited, Dhaka.

3.4.2 Construction of light house

Light house is a structure designed to keep the light house sealed where no outside light was penetrated and/or get out from the light house. For this study, a light house on the rooftop at Sher-e-Bangla Agricultural University was used. Different light combinations were separated by using cork sheet. LED light of different colors were arranged over an irony poles.

3.4.3 Treatments of the experiment

The experiment was conducted to study the influence of different light Emitting Diode (LED) on indoor vegetables production. The experiment consisted of single factor as follows:

Four LED light spectrums

T_0= White

T_1= White + Blue

T_2= White + Red

T_3= White + Blue + Red

3.4.4 Design and layout of the experiment

The single factorial experiment was laid out in completely randomized design with three replications. A total of 12 pots were arranged in the experiment.

The whole experimental plots were divided into four blocks, there were 4 plants accommodated in each block. 25 days old seedlings were transplanted in the pot.

3.5 Production methodology

3.5.1 Pot preparation

Pots were filled up 7 days before transplanting. Weeds and stubbles were completely removed from soil and soil was treated with a little amount of lime to keep soil free from pathogen.

3.6 Intercultural operations

After transplanting of seedlings, various intercultural operations such as irrigation, weeding and top dressing etc. were accomplished for better growth and development of the brinjal and tomato seedlings.

3.6.1 Stalking

When the plants were well established, stalking was given to each plant by bamboo sticks to keep them erect.

3.6.2 Irrigation

Irrigation was given as when as necessary by observing the soil moisture condition. Irrigation was given throughout the growing period. The first irrigation was given 40 days after planting followed by irrigation 20 days after the first irrigation. Each plant was irrigated by a watering cane.

3.6.3 Weeding

Weeding was done as when as necessary. It was done at every 15 days interval after planting followed upto peak flowering stage. As the land was covered by plant canopy by that time weeding was discontinued. Spading was done from time to time specially to break the soil crusts and keep the land weed free after each irrigation.

3.6.4 Application of manure and fertilizers

In case of brinjal; Urea, TSP and MoP were applied at the rate of 375 kg/ha, 150 kg/ha, 250 kg/ha respectively (Table 1) and for tomato; Urea, TSP and MoP were applied at the rate of 300 kg/ha, 200 kg/ha and 220 kg/ha respectively (Table 2).

Table 1. Manures and fertilizer with BARI recommended dose for brinjal

SL No.	Manures/fertilizers	Recommended Dose
1	Cowdung	10-15 t/ha
2	Urea	375 kg/ha
3	TSP	150 kg/ha
4	MoP	250 kg/ha

Table 2. Manures and fertilizer with BARI recommended dose for tomato

SL No.	Manures/fertilizers	Recommended Dose
1	Cowdung	10 t/ha
2	Urea	300 kg/ha
3	TSP	200 kg/ha
4	MoP	220 kg/ha

During experiment whole amount of cowdung, half of urea, whole amount of TSP, MoP has been applied at the time of soil preparation. Rest of the urea has been applied 25-30 DAP and 50-60 DAP with three installments.

3.6.5 Harvesting

Harvesting continued for about one month because fruits of different lines matured progressively at different dates and over long time. Fruits were picked on the basis of horticultural maturity, size, color and age being determined for the purpose of consumption as the fruit grew rapidly and soon get beyond the marketable stage, frequent picking was done throughout the harvesting period.

3.7 Data collection

The plants in each entry were selected randomly and were tagged. These tagged plants were used for recording observations for the following characters.

3.7.1 Plant height (cm)

The plant height was measured from ground level to tip of the plant expressed in centimeters (cm) at different days after transplanting and mean was computed.

3.7.2 Number of leaves per plant

The number of leaves per plant was counted from the selected plants and their average was taken as the number of green leaves per plant. It was recorded during different days after transplanting (15-20 days interval).

3.7.3 Leaf length (cm)

Leaf length was measured by centimeter scale. Mature leaf (from 4th node) were measured once at 60 days after transplanting and expressed in cm. Five mature leaves from each plant were measured and then average it after that mean was calculated.

3.7.4 Leaf width (mm)

Leaf width was measured by centimeter scale. Mature leaf (from 4th node) were measured once at 60 days after transplanting and expressed in centimeters. Five mature leaves from each plant were measured and then average it after that mean was calculated.

3.7.5 Chlorophyll content (%)

Leaf chlorophyll content was measured by using SPAD-502 plus (plate 2). The chlorophyll was measured at 4 different portion of the leaf and then averaged for analysis. Chlorophyll content expressed in percentage.

3.7.6 Total number of branches per plant

The total number of branches arising from the main stem above the ground was recorded during experimental period.

3.7.7 Number of flowers per plant

Total number of flowers was counted from the tagged plants of each treatment and variety and mean was computed.

3.7.8 Number of fruits per plant

Total number of fruits from different pickings during the cropping season was added and the appraisals were made for fruits per plant.

3.7.9 Fruit length (cm)

Length of five mature fruits at marketable stage was measured individually in centimeters from the base of calyx to tip of fruit using centimeter scale, when held vertically and the average was computed.

3.7.10 Fruit diameter (mm)

Five mature fruits at marketable stage were used to measure the diameter of fruit in millimeter (mm) using Digital Caliper-515 (DC-515) at the widest point of the fruit. Average of five fruits diameter was expressed in millimeter (mm).

3.7.11 Single fruit weight (g)

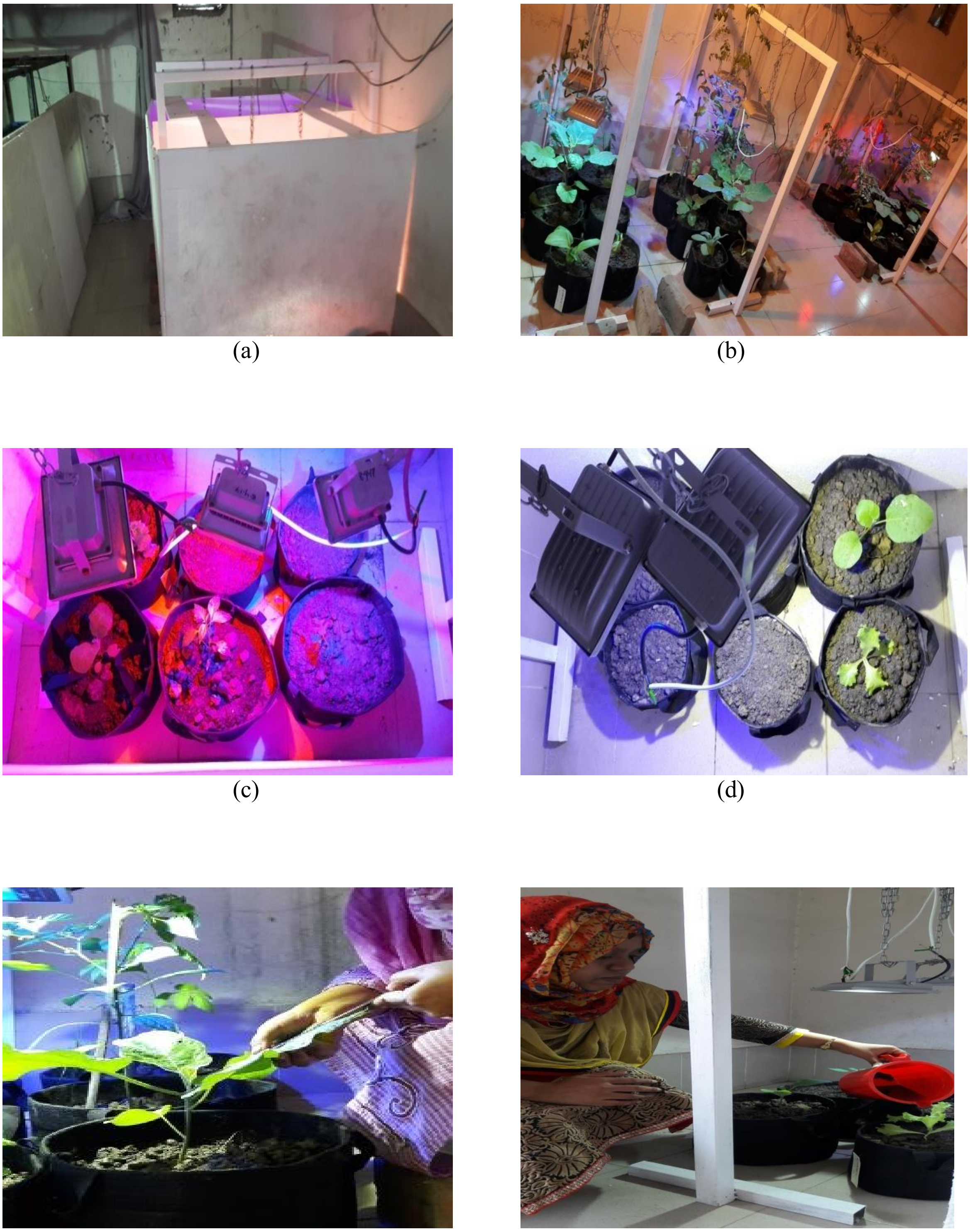
Fruit weight was measured by Electronic Precision Balance in gram. Total fruit weight of each treatment was obtained by addition of weight of the total fruit number and average fruit weight was obtained from division of the total fruit weight by total number of fruit.

3.7.12 Yield per Plant (kg)

Yield/plant was calculated from weight of total fruit divided by number of total plants.

3.8 Statistical analysis

The recorded data for different characters were analyzed statistically using MSTAT-C program to find out the significance of variation among the treatments. The analysis of variance (ANOVA) was performed by F-test, while the significance of difference between the pairs of treatment means were evaluated by the Duncan's Multiple Range Test (DMRT) at 5% and 1% level of probability (Gomez and Gomez, 1984).

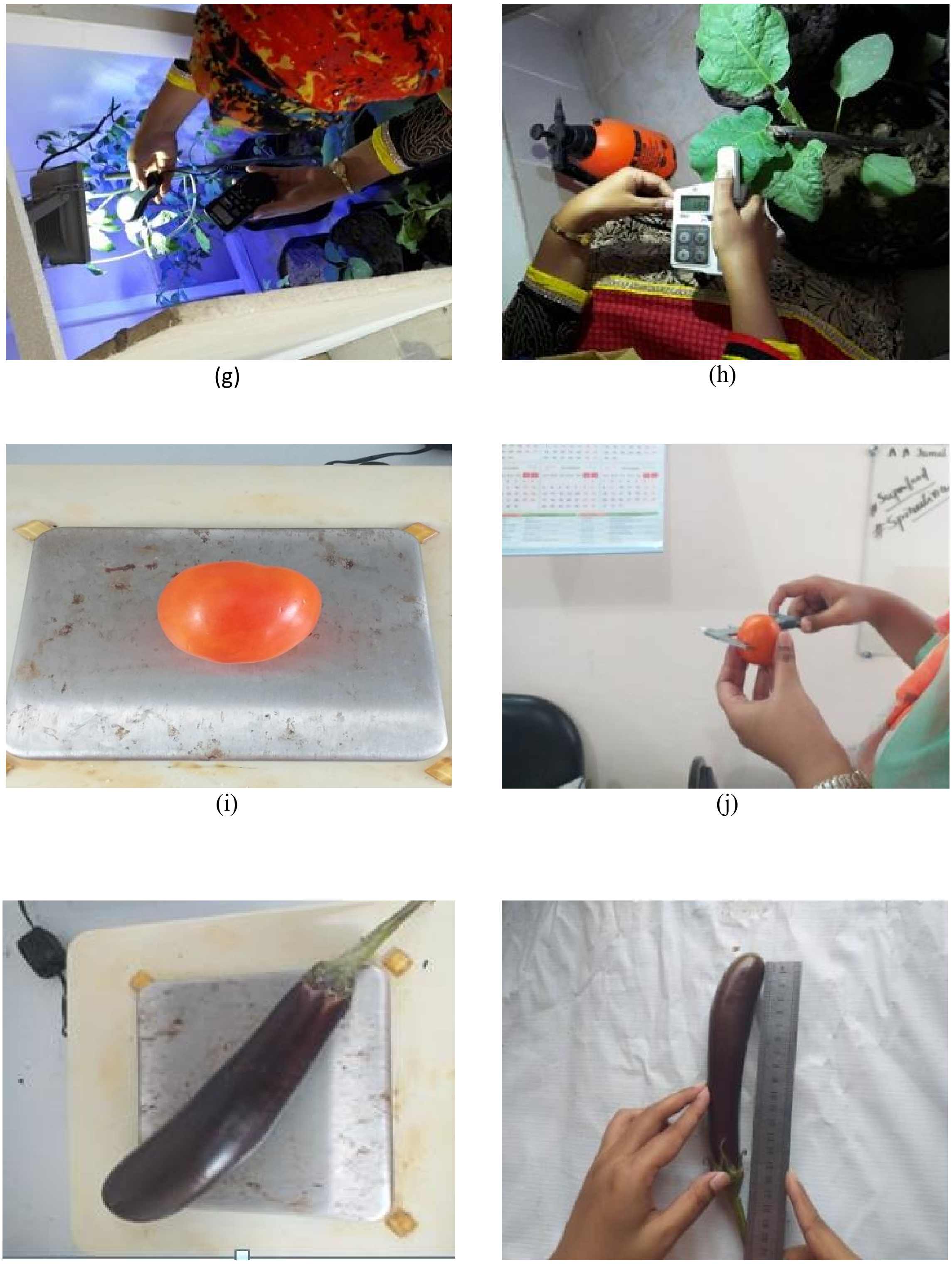


(a) (b)

(c) (d)

(e) (f)

Plate 1. Some pictorial view of this study (a) + (b) Light house; (c) + (d) different treatments; (e) data collection; (f) irrigation of the plant.



(g) (h)

(i) (j)

(k) (l)

Plate 2. Tools used in this study (g) measurement of light intensity using Lux meter; (h) measurement of chlorophyll percentage using SPAD; (i)+(k) measurement of weight using Electric Precision Balance; (j) diameter measurement of tomato; (l) length of brinjal.

CHAPTER IV
RESULTS AND DISCUSSION

This chapter comprises the presentation and discussion of the results obtained from the present study. The results have been presented, discussed and possible interpretations were given in the tabular and graphical forms. The results obtained from the experiment also have been presented under separates headings and sub-headings as follow-

4.1 Growth and yield attribute of tomato

4.1.1 Plant height (cm)

It is considered that plant height is one of the important parameter, which is directly correlated to yield of tomato (Appendix I). Different LED light spectrums showed significant impact on plant height of tomato. The tallest plant was found in T_2 treatment at 30, 50, 70 and 90 DAT whereas the shortest plant was recorded from T_1 treatment (Figure 1). This finding is similar to Li *et al*. (2012) who found that blue LEDs are benefitted for the vegetative growth in cabbage.Tanaka (2008) compared the growth of Cymbidium plantlets observed under blue plus red LEDs and the fluorescent light is encouraging. This demonstrates the effectiveness of the total LED irradiation system for growth of Cymbidium plantlets cultured in vitro.

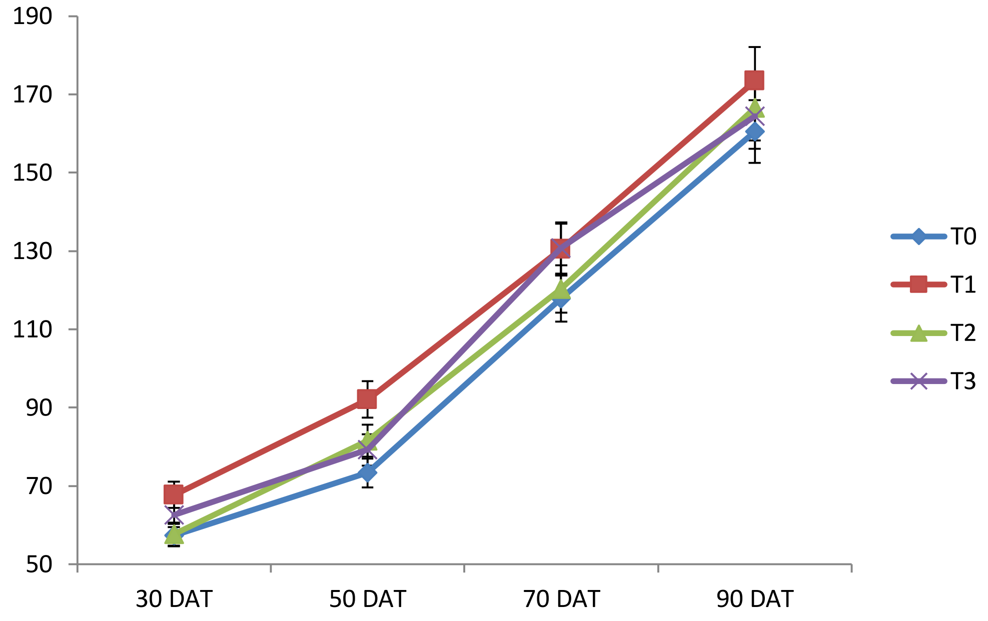


Figure 1. Plant height of tomato under different LED light spectrum.

T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R)

4.1.2 Leaf number

Number of leaves in tomato was significantly influenced by different color of LED light treatments (Appendix II). The maximum number of leaves per plant was found from T_3 treatment in 50, 70 and 90 days after transplanting whereas the lowest number of leaves observed in T_2 treatment (Figure 2). Kuan-Hung Lin *et al*. (2013) observed that mixture of blue, red and white light increased the number of leaves in lettuce.

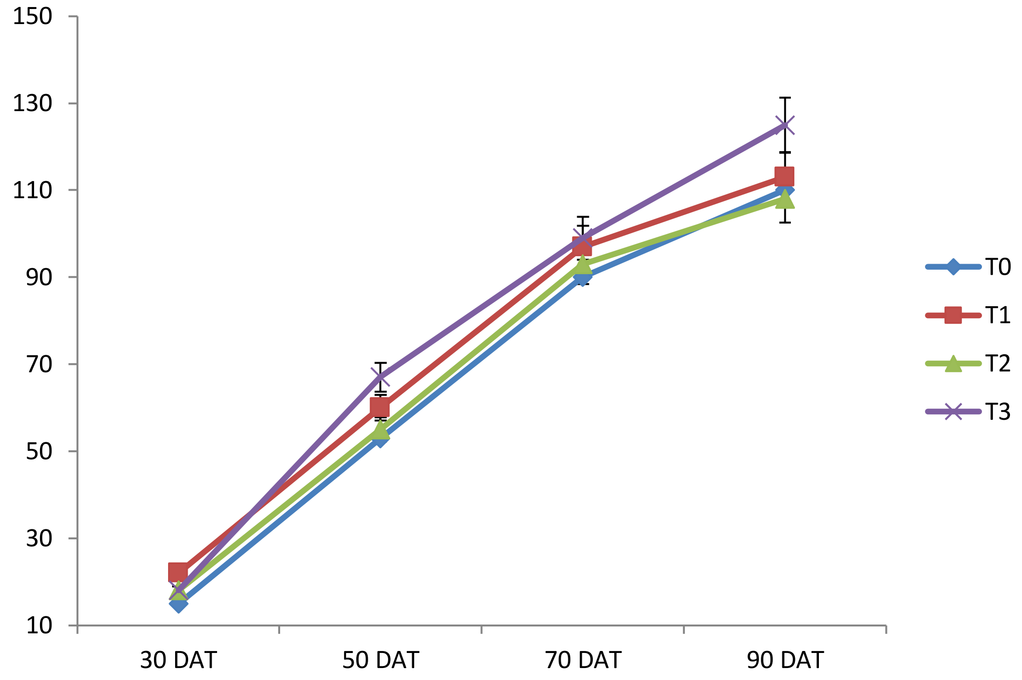


Figure 2. Number of leaves of tomato under different LED light spectrum.
T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R).

4.1.3 Leaf area (cm^2)

Significant variation was detected among treatments performance in terms of leaf area. Leaf area of tomato exposed statistically significant inequality among T_0, T_1, T_2 and T_3 treatments. T_3 (White+Blue+Red LED; 115.2 cm^2) was accorded topmost result in terms of leaf area whereas T_0 (White LED; 99.7 cm^2) was scored as inferior at mature stage (Table 1). Masahumi Johkan *et al.* (2010) observed that combination of blue, red and white LED light have positive influence on leaf area of lettuce. M. Tanaka (2008) reported that plantlets grown under blue plus red LEDs have leaf lengths intermediate higher between those of blue and red LEDs.

4.1.4 Days to 1st flower

Significant variation was received among the treatments in respect of days to flowering from days after transplantation of tomato seedlings. Longest period was required for flowering in treatment T_3 (46 days) while shortest period in T_1

treatment (32 days) (Table 1). Early flowering is required to increase cropping intensity (Appendix III).

4.1.5 Flower cluster

Highly notable dissimilarity was found in tomato with respect to number of flower cluster. The higher number of flower cluster was recorded from T_3 treatment whereas the lowest number of flower clusters was observed from T_2 treatment (Table 3). The insignificant variation was found from T_1 and T_3 treatments (Appendix III).

4.1.6 Flower/cluster

Different treatments remarkably significantly influenced the number of flower per cluster (Appendix III). The maximum flower per cluster (22flower/cluster) was found from T_3 treatment while the minimum flower per cluster (12flower/cluster) was found from T_0 treatment (Table 3).

Table 3. Leaf area, 1st flowering, flower cluster and flower/cluster of tomato under different LED light spectrum.

Treatment	Leaf area (cm^2)	1st flowering	Flower cluster	Flower/cluster
T_0	99.7 d	35 ab	7.0 b	12 d
T_1	109.7 b	32 b	18 a	16 b
T_2	105.9 c	35 ab	5.0 b	14 c
T_3	115.2 a	36 a	22 a	22 a
LSD (0.05)	1.03	11.60	9.38	1.37
CV %	0.51	6.14	7.43	3.95

Here, T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R)

4.1.7 1st fruiting

Days to first fruiting differ treatment to treatments (Appendix III). The earliest fruiting was observed from T_3 treatment whereas the late fruiting was found from T_0 treatment. There is insignificant relations were found form T_1 and T_2 treatments (Table 4).

4.1.8 Fruit/cluster

The number of fruit per cluster differs significantly with the change of different LED light spectrums (Appendix IV). The highest number was found from T_3 treatment which is similar to the treatment of T_1 whereas the lowest number was noticed form T_0 treatment (Table 4).

4.1.9 Fruit length (cm)

Significant variation was recorded for fruit length among tomato under different LED light treatments (Appendix IV). Results indicated that longest fruit length (44.3 mm) was recorded from T_3 treatment while T_0 was the shortest (27.4 mm) one (Table 4).

4.1.10 Fruit diameter (mm)

Significant variation was recorded for fruit diameter among tomato in different LED light spectrums. Results indicated that maximum fruit diameter was recorded from T_2 treatment (33.3 mm) while minimum from T_0 treatment (22.9 mm) (Table 4).

Table 4. 1st fruiting, fruit/cluster, fruit length and fruit diameter of tomato under different LED light spectrum.

Treatment	1st fruiting	Fruit/cluster	Fruit length (cm)	Fruit diameter (mm)
T_0	41 b	9.0 b	27.4 c	22.9 b
T_1	37 ab	16 a	34.9 b	23.9 b
T_2	37 ab	7.0 b	29.4 c	33.3 a
T_3	36 a	16 a	44.3 a	25.6 ab
LSD $_{(0.05)}$	4.36	5.79	4.31	8.60
CV %	5.21	6.64	6.74	6.24

T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R)

4.1.11 Chlorophyll (%)

From Table 5 it was observed that treatment (T_2) showed the highest chlorophyll percentage (44.7%) whereas the T_0 treatment revealed the lowest chlorophyll percentage. McCree, (2012) found that red LEDs supply 660 nm wavelength that correspond to the maximum absorbance of chlorophyll.

4.1.12 Brix (%)

This research work exhibited distinct variations in percentage of brix of tomato. Maximum percentage of brix in fruits (3.6%) were found in T_3 treatment whereas minimum from T_0 treatment (17%) (Table 5).

4.1.13 Fruit Number

The number of fruit directly correlated to the yield of tomato under different LED light spectrum treatments (Appendix IV). T_1 treatment showed the highest amount (117) of fruit in a plant but the T_0 treatment gave the lowest amount (80) (Table 5). Similar result was observed by Bula *et al.*, (2001).

4.1.14 Frit weight (g)

Fruit weight varied significantly with application of different LED light spectrum (Appendix IV). Maximum fruit weight of tomato was found in T_2 treatment (9.81 g) followed by T_3 and T_0 treatments whereas lowest in T_1treatment (5.51 g). Barta *et al.* (2002) reported that red light alone is unacceptable for the quality fresh weight of lettuce (Table 5).

4.1.15 Yield/plant (kg)

It was observed from the results that tomato yield statistically differed by means of the total fruit weight per plant due to different LED light applications. Maximum yield per plant (998.6 g) was found from T_3 treatment whereas the lowest yields form T_0 treatment (Appendix IV). Yorio *et al.* (2001) also reported that there was higher DMW accumulation in lettuce grown under red light supplemented with blue light than in lettuce grown under red light alone. Neil C. Yorio (2001) found that dry-weight accumulation of radish and spinach increased significantly when red LEDs were supplemented with blue light (Table 5).

Table 5. Yield related attributes (cholorophyll%, Brix%, fruit number, fruit weight (g) and yield/plant (kg) of tomato under different LED light spectrum.

Treatment	Cholophyll (%)	Brix (%)	Fruit no.	Fruit weight (g)	Yield/plant (kg)
T_0	30.5 b	1.7 c	80 c	8.04 ab	0.63 d
T_1	33.9 ab	2.9 b	108 ab	5.51 b	0.90 b
T_2	44.7 a	3.0 b	100 bc	8.06 ab	0.82 c
T_3	39.9 ab	3.6 a	117 a	9.88 a	1.00 a
$LSD_{(0.05)}$	3.50	0.30	11.41	3.76	0.10
CV %	6.08	5.81	5.97	5.88	1.65

T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R)

4.2 Growth and yield attribute of brinjal

4.2.1 Plant height (cm)

Plant height of Brinjal varies differently in different treatments of LED light. The tallest plant was found from T_1 treatment (83.60 cm) whereas the shortest one from T_0 treatment (67.80 cm). There was insignificant correlation between T_2 and T_3 treatments (Table 4). This finding is similar to Li *et al.* (2012) who found that blue LEDs are benefitted for the vegetative growth in cabbage. M. Tanaka (2008) compared the growth of Cymbidium plantlets observed under blue plus red LEDs and the fluorescent light is encouraging. This demonstrates the effectiveness of the total LED irradiation system for growth of Cymbidium plantlets cultured in vitro (Appendix V).

4.2.2 Leaf number

The table 3 shows signification variation of leaf number due to application of different LED light spectrums. The maximum leaf number was counted from T_3 treatment (23) while the minimum leaf number was found from T_0 treatment (13) (Table 4). H. Hanyu, et al. (2002) found that more acceleration of leaf number in spinach was induced by exposure to either blue light at the end of the dark period or red light at the beginning of the dark period (Appendix V).

4.2.3 Leaf area (cm^2)

Significant variation was detected among treatments performance in terms of leaf area (Appendix V). The highest leaf area was found from T_3 treatment (455.00 cm^2) while the lowest leaf area from T_0 treatment (321.20 cm^2) (Table 6).

4.2.4 Branch number

Branch number of brinjal varies treatment to treatment (Appendix V). The highest branch number was observed from T_3 treatment whereas the lowest one from T_0 treatment (Table 6).

Table 6. Growth related attributes (plant height, leaf number, leaf area and branch number of brinjal under different LED light spectrum.

Treatment	plant height (cm)	Leaf no.	Leaf area (cm^2)	Branch no.
T_0	67.80 c	13 d	321.20 c	2.0 c
T_1	83.60 a	19 b	417.10 b	3.0 b
T_2	78.60 b	16 c	403.90 b	3.0 b
T_3	80.50 b	23 a	455.00 a	5.0 a
LSD $_{(0.05)}$	2.92	1.49	3.28	0.74
CV %	1.79	3.30	1.58	9.72

Here, T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R)

4.2.5 Flower number

The number of flower directly correlated to yield of brinjal (Appendix VI). The highest flower number was counted from T_3 treatment while the lowest number was found from T_0 treatment (Table 7).

4.2.6 Fruit length (cm)

Fruit length showed significant variation with different LED light treatments (Appendix VI). Longest fruit was found in T_3 treatment (26.2 cm) followed by T_2 treatment (20.5 cm) treatments and shortest in control (14.9 cm) (Table 7).

4.2.7 Fruit breadth (mm)

Significant variation was recorded for fruit breadth among different LED treatments of brinjal (Appendix VI). Results indicated that maximum fruit breadth was recorded from T_3 treatment (6.8 cm) while minimum from T_0 treatment (4.0 cm) (Table 7).

Table 7. Growth related attributes of brinjal under different LED light spectrum.

Treatment	Flower no.	Fruit length (cm)	Fruit breath (mm)
T_0	38 c	14.9 c	4.0 d
T_1	40 c	17.4 bc	4.9 c
T_2	43 b	20.5 b	5.7 b
T_3	58 a	26.2 a	6.8 a
LSD $_{(0.05)}$	2.08	3.75	4.20
CV %	2.10	8.87	0.49

Here, T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R)

4.2.8 Fruit number

Number of fruit per plant was exposed significant inequality with different LED light spectrums (Appendix VI). Maximum number of fruit was observed in T_3 treatment (35.52) followed by T_2 treatment (32.73) whereas minimum from T_0 treatment (23.83) (Table 8).

4.2.9 Fruit weight (g)

Fruit weight varied significantly with application of different LED light treatments. Maximum fruit weight of brinjal was found in T_3 treatment (90.5 g) followed by T_2 treatment (85 g) whereas lowest in control (57.53 g) (Table 8). Bukhov et al. (2016) reported that dry-weight accumulation of radish and spinach increased significantly when red LEDs were supplemented with blue light (Appendix VII).

4.2.10 Yield/Plant (kg)

The Table 4 shows that highest yield (2.34 kg) was found from T_3 treatment and it was higher than T_2 treatment (2.20 kg) whereas the lowest yield from T_0 treatment (1.37 kg) (Table 6). Rajapaske *et al.*, (1992) reported that blue light or the interaction of blue and red lights are increasing the total yield potential of pepper. Similar result was observed by Bula *et al.*, 2001 and Wheeler *et al.*, 2005 (Appendix VII).

Table 8. Yield related attributes (fruit number, single fruit weight and yield/plant) of brinjal under different LED light spectrum.

Treatment	Fruit number	Single fruit weight (g)	Yield/plant (kg)
T_0	23.83 c	57.53 d	1.37 d
T_1	28.35 b	61.3 c	1.74 c
T_2	32.73 a	85.0 b	2.20 b
T_3	35.52 a	90.5 a	2.34 a
$LSD_{(0.05)}$	3.93	1.74	0.24
CV %	6.53	1.19	5.40

Here, T_0: White (W), T_1: White+Blue (W+B), T_2: White+Red (W+R), T_3: White+Blue+Red (W+B+R)

CHAPTER V
SUMMARY AND CONCLUSIONS

The experiment was conducted at *2a Biotech lab* ,Dept. of Horticulture , Sher-e-Bangla Agricultural University, during the period from August, 2017-July, 2018 to investigate the influence of different color LED light on growth and yield of indoor vegetable crops (tomato and brinjal). The seedling of tomato and brinjal were collected from ACI biotech lab. The experiment consisted of single factor. Four LED light treatments viz. T_0: White; T_1: White+Blue; T_2: White+Red; T_3: White+Blue+Red were used in this experiment. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data on different growth and yield parameters were recorded.

Different colored LED light treatments had significant impact on growth and yield parameters of tomato. The tallest tomato plant was found from T_1 treatment which was blue LED whereas the shortest one form T_0 treatment (white LED). Similarly the maximum number of leaves was found from T_3 treatment while the lowest one forms T_0 treatment. The maximum leaf area (115.2 cm^2), flower cluster (22), flower/cluster (22), 1st fruiting (36 days), fruit/cluster (16), fruit length (44.3 mm), fruit diameter (25.6 mm), chlorophyll (39.9%), brix (3.6%), fruit number (117), fruit weight (9.88 g), yield/plant (1.0 kg) were found from T_3 treatment whereas the lowest plant height and leaf number form T_0 treatment and leaf area (99.7 cm^2), flower/cluster (12), delay fruiting (41 days), fruit/cluster (9.0), fruit length (27.4 cm), fruit diameter (22.9 mm), chlorophyll (30.5%), Brix (1.7%), fruit number (80), single fruit weight (8.04 g) and yield/plant (0.63 kg) were observed from T_0 treatment.

Different color LED light spectrum greatly influence vegetative and reproductive growth of brinjal. The tallest plant (83.60cm) was found from T_1 treatment. The maximum leaf number (23), leaf area (455 cm^2), branch number (5.0), flower number (58), fruit length (26.2 cm), fruit breadth (6.8 mm), fruit number (35.52), single fruit wight (90.5 g) and yield/plant (2.34 kg) were found from T_3 treatment while the lowest value of these parameters were observed from T_1 treatment.

CONCLUSIONS

Blue light treatment was found to be beneficial for plant growth while red light influence the reproductive growth of tomato and brinjal. Therefore, White, Blue and Red light combination (T_3) treatment was found to be effective in indoor production of tomato and brinjal.

CHAPTER V
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APPENDICES

Appendix I. Analysis of variance on plant height of tomato at different days after transplanting

Source of variation	Degrees of freedom	Mean square of plant height			
		30 days	50 days	70 days	90 days
Replication	2	15.301	8.017	12.491	2.341
Factor A	3	71.114	179.723	126.731	170.667
Error	6	7.964	4.970	16.892	8.198
*Significant at 0.05 level of probability					

Appendix II. Analysis of variance on leaf number of tomato at different days after transplanting

Source of variation	Degrees of freedom	Mean square of Leaf Number			
		30 days	50 days	70 days	90 days
Replication	2	30.333	39.083	72.333	7.583
Factor A	3	97.444	128.333	88.750	99.333
Error	6	0.444	0.750	3.000	9.583
*Significant at 0.05 level of probability					

Appendix III. Analysis of variance on 1st flowering, 1st fruiting, Flower cluster and Flower/Cluster of tomato at different days after transplanting

Source of variation	Degrees of freedom	Mean square of			
		1st flowering	1st fruiting	Flower cluster	Flower/cluster
Replication	2	30.250	344.333	13.000	45.583
Factor A	3	23.111	24.306	41.556	57.333
Error	6	41.694	5.889	27.222	0.583
*Significant at 0.05 level of probability					

Appendix IV. Analysis of variance on Fruit/Cluster, Fruit Number, Fruit Weight and Yield/Plant of tomato at different days after transplanting

Source of variation	Degrees of freedom	Mean square of			
		Fruit/cluster	Fruit number	Fruit weight	Yield/plant
Replication	2	0.583	26.083	0.139	4134.011
Factor A	3	73.861	118.889	3.528	79546.878
Error	6	10.361	40.306	4.371	203.725
*Significant at 0.05 level of probability					

Appendix V. Analysis of variance on Plant Height, Leaf Number, Branch Number and Leaf Area of Brinjal at different days after transplanting

Source of variation	Degrees of freedom	Mean square of			
		Plant height	Leaf number	Branch number	Leaf area
Replication	2	53.036	90.333	1.583	1403.757
Factor A	3	153.494	61.639	3.889	8644.083
Error	6	2.132	0.556	0.139	44.151
*Significant at 0.05 level of probability					

Appendix VI. Analysis of variance on Flower Number, Fruit Length, Fruit Breadth and Fruit Number of Brinjal at different days after transplanting

Source of variation	Degrees of freedom	Mean square of			
		Flower number	Fruit length	Fruit breadth	Fruit number
Replication	2	95.083	7.870	0.968	59.137
Factor A	3	232.00	91.420	4.228	78.722
Error	6	1.083	3.537	0.061	3.870
*Significant at 0.05 level of probability					

Appendix VII. Analysis of variance on Fruit weight and yield/plant of Brinjal at different days after transplanting

Source of variation	Degrees of freedom	Mean square of	
		Fruit weigh	Yield/plant
Replication	2	6.386	0.378
Factor A	3	824.997	2.261
Error	6	0.763	0.015
*Significant at 0.05 level of probability			