INFLUENCE OF DAY LENGTH EXTENSION WITH LED LIGHT SUPPLEMENT ON GROWTH, YIELD AND SEED PRODUCTION OF BROCCOLI (*Brassica oleracea* var. *italica* L.)

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CERTIFICATE

*This is to certify that the thesis entitled " **INFLUENCE OF DAY LENGTH EXTENSION WITH LED LIGHT SUPPLEMENT ON GROWTH , YIELD AND SEED PRODUCTION OF BROCCOLI (Brassica oleracea var. italica L.)** " 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 (MS)** in **HORTICULTURE,** embodies the results of a piece of bona fide research work carried out* **ISMOT ARA JAHAN,** *Registration. No.* **14-06329** *under my supervision and guidance. No part of this 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 duly been acknowledged.

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The Authoress

INFLUENCE OF DAY LENGTH EXTENSION WITH LED LIGHT SUPPLEMENT ON GROWTH, YIELD AND SEED PRODUCTION OF BROCCOLI (*Brassica oleracea* var. *italica* L.)

BY

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ABSTRACT

An experiment was accomplished at the Horticulture farm of Sher-e-Bangla Agricultural University, Dhaka, during the period from December 2015 to March 2016 to evaluate the influence of day length extension with supplement LED light on growth, yield and seed production of Broccoli. Five LED light treatments viz. Blue LED Light, L_B; White LED light, L_W and Red LED Light, L_R; Combined Red and Blue LED light, L_{R+B}; Control(no artificial light),L_C were used in this experiment. The experiment was laid out in a Randomized Complete Block Design with three replications. The highest plant height(56.7cm),maximum no. of leaves(19.0),length of stem(25.3cm) were found in L_B and the L_{R+B} also showed statistically similar results as $L_{B,}$ the minimum plant height(45.1cm), no. of leaves(12.6),length of stem(16.2cm) were found in control. Maximum weight of curd(382.5g), number of pods/plant (106.3),curd yield/ha(7.4t) were found in L_R and the L_{R+B} also showed statistically similar results as L_R in most of the cases and the minimum results of those parameters were found in L_c(control),while the minimum no. of pods (49.6) was found from L_W .The highest number of seeds/pod (12.0),seed/plant (1279.0) were found in L_R and lowest number of seeds/pod (6.0),number of seeds/plant (302.0) were found in L_W . So, the reproductive growth under L_R and vegetative growth under L_B were found better but L_{R+B} showed the better results in most of the cases throughout the experiment. And the better pod and seed production was found under Red LED light.

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ABBREVIATIONS AND ACRONYMS

SAU	---	Sher-e-Bangla Agricultural University
SAURES	---	Sher-e-Bangla Agricultural University Research System
BARI	---	Bangladesh Agricultural Research Institute
Intl.	---	International
Biol	---	Biological
ANOVA	---	Analysis of Variance
Agril	---	Agricultural
CV	---	Coefficient of Variation
RCBD	---	Randomized Complete Block Design
df	---	Degrees of freedom
J	---	Journal
Sci.	---	Science
ASRBC	---	Advanced Seed Research and Biotech Centre
Res.	---	Research
Viz	---	Namely
et al.	---	And others

CHAPTER I

INTRODUCTION

Broccoli, (*Brassica oleracea* var. *italica* L.) belongs to the family Brassicaceae is a biennial and herbaceous "Cole" crops. The word "broccoli" means "branch" or "arm" for the cross-shaped stems, like mini trees bearing the blossoms. It is often boiled or steamed but may be eaten raw. At present broccoli is cultivated in Europe, America and most of the Asian countries. In western countries broccoli is highly popular as fresh as well as frozen vegetables. In Bangladesh broccoli was introduced about two decade ago. The edible portion of the broccoli plant consists of tender stem and unopened flower buds. Brassicas are high in Ca content and low in oxalate compounds that can bind to Ca and reduce absorption. Broccoli is specially leafy crops harvested just above the roots after the first true leaves have emerged and usually consumed fresh as a salad green (Kopsell *et al*., 2012). Broccoli is valued for significant concentrations of cancer-fighting glucosinolates (GSs) as well as being a rich source of carotenoid phytochemicals and essential mineral elements. It is an excellent source of nutrients such as vitamin C, folic acid, vitamin K, and essential minerals and also contains powerful health-promoting phytochemicals and antioxidants, including phenolic acid derivatives, flavonols, and organo-sulphur compounds, the glucosinolates, which plays a defensive role against infection. Broccoli may help us solve our vitamin D deficiency epidemic. Broccoli can provide with some special cholesterol-lowering benefits if it is cooked by steaming. It is particularly rich source of a flavonoid called kaempferol. Recent research has shown the ability of kaempferol to lessen the impact of allergy-related substances in our body. So Broccoli is a very beneficial crop for Bangladesh and all.

In an early study, it is well known that red and blue light are important factors for the plant growth (Yorio *et al*., 2001). Blue light suppresses hypocotyl elongation and induces biomass production and red light induces hypocotyl elongation and expansion in leaf area (Johkan *et al*., 2012). Green light also affects plant morphology and physiology; including leaf growth, stomatal conductance and early stem elongation (Folta, 2004; Kim *et al*., 2004).LEDs now provide the ability to measure impacts of narrowband wavelengths of light on seedling morphology and physiology (Lefsrud *et al*., 2008). The LED (light emitting diode) is a solid state light source, durable and narrow band (Gupta and Jatothu, 2013; Xu *et al*., 2012) that can be used in a variety of horticultural and photo-biological applications (Stutte, 2009), including controlled research environments (Avercheva *et al.*, 2009). These devices can be implemented in dynamic lighting to control growth, development, production and physiological responses of plants (Folta *et al*., 2008; Lefsrud *et al*., 2008). The benefits that this technology brings are greater light intensity, lower energy consumption (energy cost savings of 40%), increased device longevity compared to other lighting systems, increasing the speed switching, better color control (Fillipo *et al*., 2010) and is a device that can be environmentally friendly because it does not use toxic gases, such as fluorescent lamps and mercury (Zhang and Wong, 2007). Present-day super bright light-emitting diodes allow producing the photon flux levels sufficient for plant growing (Berkovich *et al*., 2005).

The very first experiments with growing plants under light-emitting diodes showed that a light source based on red diodes (640–660 nm) with an addition of 10% (according to photon flux level) blue light (470 nm) provides for better lighting conditions than light sources based on only red diodes (Goins *et al*., 1997; Yorio*et al*., 2001). Various studies have used LED light for vegetable cultivation. Among which we can mention the tomato (*Solanum esculentum*) (Xiaoying *et al*., 2012), cucumber (*Cucumis sativus*) (Hogewoning *et al*., 2010; Brazaityté *et al*., 2009), pepper (*Capsicum annuum*) (Brown *et al*., 1995; Schuerger *et al*., 1997), spinach (*Spinaciaoleracea*) (Ohashi-Kaneko *et al*., 2007), radish (*Raphanus sativus*) (Samuolienė *et al*., 2011), strawberries (*Fragaria*× *ananassa* Duch.) (Samuolienė *et al*., 2010) and lettuce (*Lactuca sativa* L.) (Lin *et al*.,2013). The responses of different colors of LED lights vary according to the type of plant, so more research is needed with this type of light at different wavelengths to enhance growth and development of crops. Exposure to only red LED light resulted in plant height and biomass for lettuce (*Lactuca sativa* L.) (Hoenecke *et al*., 1992) and pepper (*Capsicum annuum* L.) (Brown *et al*.,1995). The flexibility of matching wavelengths of LEDs to plant photoreceptors may provide more optimal production, influencing plant morphology and metabolism (Kim *et al*., 2004; Massa *et al*., 2008; Morrow, 2008). Pardo *et al.* (2014) demonstrated that the use of high intensity LED light is a viable option to improve plant growth in controlled environments. Pardo *et al.* (2014) observed that Seedlings of broccoli with green light exposed to high intensity LED light, showed statistically significant differences in average length of hypocotyl with increments of 33% compared to control respectively. The highest fresh and dry weight in broccoli seedlings was obtained in red light treatment with increases of 15% and 10% respectively, compared to its control.

It is evident that uses of LEDs in Broccoli production can be beneficial for the growth and development of broccoli and other crops. The aim of this work was to evaluate the influence of LED light on the growth, yield and seed production of Broccoli under Bangladesh condition with the following objectives:

1. To find out the impact of day length extension with supplement different LED lights on growth and yield of Broccoli.
2. To find out the impact of day length extension with supplement different LED lights on seed production of Broccoli.

CHAPTER II

REVIEW OF LITERATURE

Broccoli (*Brassica oleracea*) is a biannual and herbaceous winter vegetable crop under Brassicaceae family in Bangladesh. Limited research reports on the influence of LED light on growth, yield, head formation, coloration and seed production of broccoli have been done in various part of the world including Bangladesh and the work so far done in Bangladesh is not adequate and conclusive. Some of the important research reports regarding broccoli and some other related crops have been reviewed here in this chapter.

Lee *et al.* (2016) opined that Light emitting diode (LED) lights play an important role in the plant physiology and alter the metabolites in a significant manner. Glucosinolates (GSLs), polyphenols, flavonoids and antioxidant properties of Chinese cabbage and kale cultivated in varying LED lights were investigated. Analysis revealed 7 aliphatic, 3 indolyl and 1 aromatic GSLs in Chinese cabbage and kale. The total GSL content ranged from 1.5–19.08 and 1.85–24.87 μmol g^{-1} DW and glucobrassicanapin was the predominant GSL (3) in Chinese cabbage, whereas; sinigrin (3.49 μmol g^{-1} DW) was in kale. Blue and red LED lights produced significantly higher amount of GSLs in Chinese cabbage and kale respectively. Results revealed higher amount of total polyphenol (3.845 μg/mL) and total flavanoids (3.939 μg/mL) in Chinese cabbage. Chinese cabbage and kale showed significant antioxidant activities when compare with positive control, and the antioxidant assays were slightly correlated with total GSLs, polyphenols and flavonoids contents. The influence of LED lights on glucobrassicin in Chinese cabbage and kale should be studied extensively, because GSL is the precursor of indole-3-carbinol, a potent anticancer isothiocyanate.

Steindal *et al.* (2016) carried out an experiment on broccoli (*Brassica oleracea* L. var. *italica*) plants which were grown in climate-controlled chambers under supplemental wavelengths (red, far-red, red + far-red or blue) from light-emitting diodes (LEDs). The light treatments were combined with two cold climate temperatures (12 and 15 °C) during broccoli head formation to investigate the effects on morphology and content of health- and sensory-related compounds: glucosinolates, flavonols, ascorbic acid and soluble sugars. Supplemental far-red and red + far-red light led to elongated plants and the lowest total glucosinolate content in broccoli florets. The content of quercetin was highest with supplemental red light. Vitamin C was not significantly affected by the light treatments, but 12 °C gave a higher content than 15 °C. The effects of supplemental red and far-red light suggest an involvement of phytochromes in the regulation of glucosinolates and flavonols. A shift in red: far-red ratio could cause changes in their content besides altering the morphology. The sugar and vitamin C content appears to be unaffected by these light conditions. Supplemental blue light had little effect on plant morphology and content of the health- and sensory related compounds.

Jin *et al.* (2015) conducted an experiment to investigate the effect of light treatment (fluorescent and light-emitting diode (LED) green light) on shelf life, visual quality and bioactive compounds in broccoli florets. The results showed that light treatment extended shelf life and inhibited the decrease of *H* value and chlorophyll contents in broccoli florets stored at 25°C. Fluorescent and LED green light treatment extended shelf life of broccoli florets stored at 25°C.

LED green light significantly inhibited the decrease of chlorophyll contents in broccoli florets stored at 25°C. LED green light enhanced total phenols and glucosinolates content in broccoli florets stored at 25°C. The content of total phenols and glucosinolates were markedly increased by LED green light, but no effect on sulforaphane. Fluorescent and LED green light treatment significantly increased DPPH radical scavenging activity in broccoli, but little effect was found between the two light treatments. These results indicated that LED green light could be a useful technique for extending shelf life, maintaining visual quality and preventing decrease of bioactive compounds in broccoli florets.

Li *et al.* (2015) conducted an experiment in order to study on effect of different treat of LED composite light on preservation of broccoli; fresh broccoli was used as the main materials. By measuring the indicators at 4°C low temperature conditions, such as sensory quality, vitamin-C content, chlorophyll content and broccoli ethylene production rate, effect of LED composite light on preservation for broccoli was determined. The results showed that treatment with LED composite of red and blue was better for the quality of broccoli compared with non-light treatment. The former could extend storage time by 10–15 days. Meanwhile, it could get a higher score of sensory evaluation, prevented the rapid decline in important nutrient substance vitamin C content of broccoli, delayed the time of the evolution of ethylene and the appearance of respiration peak, decreased the respiration variable peak and reduced membrane lipid peroxidation damage of broccoli during storage.

Kwack *et al.* (2015) conducted an experiment to investigate the effects of light intensity and quality on the growth and total phenolic content of the vegetable sprouts. Vegetable sprouts (alfalfa, broccoli, clover, kohlrabi, radish, and red radish) were cultivated under three monochromatic light regimes (red, green, and blue) with five different light intensities (0, 12.5, 25, 50, and 100 µmol m^{-2} s^{-1}). They set five different light intensity treatments of photosynthetic photon flux (PPF) for each light source. The photo/dark periods were 18/6 hour, and the air temperatures during the photo/dark periods were 25/20 °C. The light quality and intensity had a direct effect on hypocotyl elongation in vegetable sprouts. Increasing blue light intensity enhanced suppression of hypocotyl elongation in all of the vegetable sprouts. The fresh weight of broccoli sprouts markedly increased when red light intensity was 100 µmol m^{-2} s^{-1}; however, light use efficiency (LUE) decreased with increasing light intensity. When light use efficiency (LUE) was calculated using fresh weight (mg) and energy input (MJ), increasing the intensity of red, green, and blue lights reduced the LUE of all the vegetable sprouts mainly because increasing light intensity required more energy input. The PPF/W ratios of red, green, and blue lights used in this study were 5.36, 1.46 and 5.20, respectively. As energy input in green light was higher than that in red and blue lights, the LUE of six vegetable sprouts was low in green irradiation treatment. In broccoli, total phenolic content was lowest when the sprouts were cultivated in dark conditions. From the results of this study it appeared that the total phenolic content of vegetable sprouts is not significantly affected by the manipulation of light quality and intensity. As the cultivation period of sprouts was only 5–7 days after sowing and photosynthesis can occur after the appearance of cotyledon, the nutrients used for the growth of sprouts are mostly supplied by seed (endosperm, cotyledon, etc.). Consequently, it would be difficult to control total phenolic content by modifying light conditions during the cultivation of vegetable sprouts. The quality and intensity of LEDs modifies plant growth and phytochemical accumulation. In this study, the researchers confirmed that the monochromatic light of various wavelengths and intensities can affect directly the morphological characteristic of vegetable sprouts, while their effects on phytochemical accumulation in sprouts are nearly negligible.

Paniagua-Pardo *et al.* (2015) evaluated the effect of high-intensity LED light of different wavelengths (red, blue and green), on germination and growth of broccoli seedling for 10 days, evaluating the variables germination rate (VG), germination percentage (PGF), average length of hypocotyl (LMH), fresh (PF) and dry weight (PS) of seedling, in search of alternative lighting for production in controlled environment. Exposure times of red, blue and green light of high-intensity LEDs were 12, 6 and 3 hours, with a complementary time for the last two treatments with white LED light. A completely randomized experimental design was used with four replications of 30 seeds per experimental unit. Statistically significant differences between treatments for evaluated variables were obtained: red light treatments showed the highest values of VG, where the red for 12 hours was the best with increases of 25 % versus control. The LMH variable for the green treatment of 12 hours had an increase of 39% compared to control, becoming the best. On the other hand in PF variable, the greatest weight was presented in green treatment for 12 hours with an increase against the control of 16 %. Finally in PS variable, the greatest weight was presented in red treatment for 12 hours with an increase of 6% against the control. These results showed that the physiological responses produced by exposure to different wavelengths of high intensity LED light in broccoli seed, varied according to the exposure time and type of wavelength used, in addition this type of lighting proved to be a viable option to improve the physiological quality of broccoli.

Ares *et al.* (2014) carried out an experiment to observe the effect of temperature and light exposure on the detection of total intact glucosinolate content by LC-ESI-MS in Broccoli Leaves. Total intact glucosinolate content in broccoli leaf extracts (*Ramoso calabrese* cultivar) has been determined by liquid chromatography coupled to tandem mass spectrometry with the aim of detecting potential differences in this value due to the effects of the drying temperature or the working and storage conditions (temperature and light exposure). Those broccoli leaf extracts were obtained with two different sample treatments based on heating the sample (microwave or oven), and using boiling water as extraction solvent. The highest total intact GLS content in broccoli leaves (*R. calabrese* cultivar) was obtained when using a drying temperature of 60 °C. In addition, this drying process should be performed during 12 h (overnight) in order to obtain a constant dried material percentage. There were not found significant differences related to the working and storage conditions on the total intact GLS content within samples obtained with different heating procedures. Furthermore, the variation of the total intact GLS content during the test time (15 days) was lower (less than 9 % of the initial value) when the broccoli leaf extracts (water) was stored at 4 °C in amber glass vials. Meanwhile, light exposure must be reduced as much as possible when working at typical laboratory temperatures, especially 25 °C, in order to avoid a remarkable decrease in the total intact GLS content (more than 20 % of the initial value). The researchers demonstrated that the drying temperature, working and storage conditions should be studied and controlled in order to obtain and maintain the highest total intact GLS content in broccoli leaf extracts. Significant differences were observed in the total intact glucosinolate content depending on the drying temperature and light exposure under typical working conditions. Meanwhile, those differences were less remarkable when the extracts were stored at low temperature and protected from light exposure.

Dean *et al.* (2014) conducted an experiment with a view to measuring the impact of different percentages of blue light on the concentrations of nutritional quality parameters of sprouting broccoli microgreens and to compare incandescent/fluorescent light with light-emitting diodes (LEDs). Microgreen seeds were cultured hydroponically on growing pads under light treatments of: (1) fluorescent/incandescent light; (2) 5% blue (442 to 452 nm)/95% red (622 to 632 nm); (3) 5% blue/85% red/10% green (525 to 535 nm); (4) 20% blue/80% red; and (5) 20% blue/70% red/10% green in controlled environments. Microgreens were grown at an air temperature of 24 °C and a 16-hour photoperiod using a light intensity of 250 μ mol m^{-2} s^{-1} for all light treatments. On emergence of the first true leaf, a nutrient solution of 42 mg L^{-1} nitrogen (N) (20% Hoagland's #2 solution) was used to submerge the growing pads. Microgreens were harvested after 20 days under the light treatments and shoot tissues were processed and measured for nutritionally important shoot pigments, glucosinolates, and mineral nutrients. Microgreens under the fluorescent/incandescent light treatment had significantly lower shoot fresh mass than plants under the 5 % blue/95 % red, 5 % blue/85 % red/10 % green, and the 20 % blue/80 % red LED light treatments. The highest concentrations of shoot tissue chlorophyll, β-carotene, lutein, total carotenoids, calcium (Ca), magnesium (Mg), phosphorus (P), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn), glucoiberin, glucoraphanin, 4-methoxyglucobrassicin, and neoglucobrassicin were found in microgreens grown under the 20% blue/80% red light treatment. In general, the fluorescent/incandescent light treatment resulted in significantly lower concentrations of most metabolites measured in the sprouting broccoli tissue. Results from the current study clearly support data from many previous reports that describe stimulation of primary and secondary metabolite biosynthesis by exposure to blue light wavelengths from LEDs.

Lee *et al.* (2014) carried out an experiment to investigate the effects of light emitting diode (LED) irradiation on maintaining freshness and nutrition in cabbage during low temperature storage. Cabbage, 'Dongdori' was stored at 4–5 °C for 18 days under white, green, blue, and red LED light. On day 15 of storage, the total chlorophyll content of cabbage was highest for green, followed by white, red, blue, and a non-irradiated control group. The vitamin-C content was highest for blue, followed by white, green, red, and the control. On day 18 of storage, the total polyphenolic content in cabbage was highest for blue followed by white, red, green, and the control. LED irradiation is effective for enriching the chlorophyll, vitamin-C, and polyphenol contents of cabbage stored at a low temperature and results suggest that LED colors have different effects.

Maa *et al.* (2014) investigated the effects of red and blue light-emitting diode (LED) lights on the senescence of broccoli (*Brassica oleracea* L. var. *italica*) after harvest. The result showed that irradiation with red LED light was effective in delaying senescence in broccoli after harvest. Under red LED light, the yellowing process was delayed, and ethylene production and reduction of ascorbate (AsA) were suppressed in broccoli after harvest. In contrast, the blue LED light treatment did not significantly affect the senescence process of broccoli after harvest. As the red light is inconvenient for customers in selecting broccoli in the supermarket, they designed a type of modified white LED light. In this modified white LED light, the ratio of blue light was decreased, while the ratio of red light was increased. Under the modified white LED light, AsA reduction in broccoli was slightly delayed on the first and second days after harvest. Moreover, the modulation of AsA reduction by the modified white LED light treatment was highly regulated at the transcriptional level. The up-regulation of the AsA biosynthetic genes (*BO-VTC2* and *BO-GLDH*) and AsA regeneration genes (*BO-MDAR1* and *BO-MDAR2*) contributed to the higher AsA content in the modified white LED light treatment on the first and second days after harvest. The results might provide new strategies to improve the nutritional quality of broccoli after harvest.

Pardo *et al.* (2014) carried out an experiment to evaluate the effects of high intensity LED light with different wavelengths (red, blue, green and magenta filter) in physiology and absorption spectrum of lettuce (*Lactuca sativa* L.) and broccoli (*Brassica oleracea* L.) seedlings, with exposure times of 12 hours, in order to improve the growth of vegetables. Four treatments of light (red, blue, green, magenta filter) and one control (White light). The experimental design was completely randomized, with two replications of 14 seedlings per experimental unit. Seedlings were grown with alternating cycles of light (12 hours) and darkness (12 hours). The period of growth of lettuce and broccoli was 29 and 15 days respectively. Physiological variables (fresh and dry weight, average length of hypocotyl, leaf number) and absorption spectrum of these vegetable seedlings were evaluated. Seedlings of broccoli with green light and lettuce with red light exposed to high intensity LED light, showed statistically significant differences in average length of hypocotyl with increments of 33%

and 42% compared to control respectively. The highest fresh and dry weight in broccoli seedlings was obtained in red light treatment with increases of 15% and 10% respectively, while in lettuce seedlings was 50 % and 41 % but with blue light compared to its control. The physiological responses produced by exposure to different wavelengths of high intensity LED light in broccoli and lettuce seedlings, varied according to the wavelength used, where the red LED light treatment had the best results in seedlings of broccoli, and lettuce seedlings was the blue LED light. Based on this observation, the researcher suggested that the use of high intensity LED light is a viable option to improve plant growth in controlled environments.

Kopsell and Carl (2013) conducted an experiment with an objective to measure the impact of short-duration blue light on phytochemical compounds, which impart the nutritional quality of sprouting broccoli microgreens. Light emitting diodes (LEDs) now provide the ability to measure impacts of narrow-band wavelengths of light on seedling physiology. The carotenoid zeaxanthin has been hypothesized to be a blue light receptor in plant physiology. Broccoli microgreens were grown in a controlled environment under LEDs using growing pads. Seeds were cultured on the pads submerged in deionized water and grown under a 24-hour photoperiod using red (627 nm)/blue (470 nm) LEDs (350 μ mol m^{-2} s^{-1}) at an air temperature of 23 °C. On emergence of the first true leaf, a complete nutrient solution with 42 mg L^{-1} of nitrogen (N) was used to submerge the growing pads. At 13 days after sowing, broccoli plantlets were grown under either: (1) red and blue LED light (350 μ mol m^{-2} s^{-1}); or (2) blue LED light (41 μ mol m^{-2} s^{-1}) treatments for 5 days before harvest. The experiment was repeated three times. Frozen shoot tissues were freeze-dried and measured for carotenoids, chlorophylls, glucosinolates, and mineral elements. Comparing the two LED light treatments revealed the short duration blue LED treatment before harvest significantly increased shoot tissue b-carotene, violaxanthin, total xanthophyll cycle pigments, glucoraphanin , epiprogoitrin , aliphatic glucosinolates , essential micronutrients of copper (Cu), iron (Fe), boron (B), manganese (Mn), molybdenum (Mo), sodium (Na), zinc (Zn) and the essential macronutrients of calcium (Ca), phosphorus (P), potassium (K), magnesium (Mg), and sulfur (S). Results demonstrated that management of LED lighting technology through pre-harvest, short-duration blue light acted to increase important phytochemical compounds influencing the nutritional value of broccoli microgreens.

Nooprom *et al.* (2013) studied the effects of shadings and varieties on the growth and yield of broccoli (*Brassica oleracea* L. var. *italica* Plenck). The experiment was conducted in split-plot in a randomized complete block design with four replications. There was a positive impact of the shading on yield and yield attribute of the three varieties. The highest total yield was obtained from the Yok Kheo under the both full sunlight and shading (10.92 and 8.29 t ha^{-1}, respectively), followed by the Green Queen under the shading (6.21 t ha^{-1}). Particularly, those grown under the shading because of the decreasing light intensive and maximum temperature and the increasing relative humidity compared to the full sunlight. These factors would support the increasing growth and yield of broccoli. According to the researcher, broccoli can be adapted to shading by increasing seedling survival rate, plant height and plant width. Consequently, the broccoli under the shading had the highest in head diameter, head weight and yield which was significantly better than full sunlight.

Duarte-Sierra *et al.* (2012) conducted an experiment to find out the influence of UV-C on color development and free amino acid profile in broccoli florets during postharvest storage. There is interest in enhancing the levels of health-promoting phytochemicals in vegetables by application of hormetic doses of abiotic stresses such as UV radiation during the postharvest phase. The objective of this work was to determine the hormetic dose of UV-C for broccoli and the effect of UV-C on the color (Hue angle). Amino acid content of the tissue was determined (GC-MS) during 12, 24, 48 and 96 h following UV-C treatment. The color change of broccoli florets was dose-dependent with minimal changes with UV-C doses between 0.9 and 1.2 kJ m^{-2}. However, at the dose of 1.2 kJ m^{-2} the rate of color change was the lowest and therefore was considered hormetic for broccoli. Doses either below or higher than the 0.9–1.2 kJ m^{-2} range, color change was more rapid. The amino acids with high titers (more than 100 μmol g^{-1}) were serine, aspartic acid and glutamic acid. Amino acid pools decreased with UV-C dose, either reaching maximum depletion above 1.2 kJ m^{-2} (considered as a hormetic dose from color retention of broccoli florets) or all amino acids except those of branched chain amino acids, which recorded a minimum at that dose but increased above that dose. Leucine appears to be a marker of yellowing of broccoli florets and its time-average titer increased with UV-C dose and storage time. Results suggested that hormetic dose had biochemical significance from the standpoint of secondary metabolites in broccoli and that the changes in the free amino acid profile in response to UV-C can provide some insight into UV-C induced modifications in the secondary metabolites derived from those amino acids.

Li *et al.* (2012) carried out an experiment to evaluate the effects of light-emitting diodes (LEDs) light sources (blue, blue + red, red), fluorescent lamps and sunlight on growth and vitamin C, soluble protein, sucrose, soluble sugar, starch and pigment concentrations in non-heading Chinese cabbage (*Brassica campestris*) seedlings. The dry mass of shoots and the fresh and dry masses of roots were highest in seedlings grown under red LEDs with weak lights. The fresh mass of roots and starch concentration were highest under red LEDs despite of the altered photosynthetic photo flux density (PPFD) levels. The concentrations of chlorophylls and vitamin C were greatest under blue LEDs with altered PPFD levels. The numbers of flower buds and open flowers were highest under red LEDs and blue plus red LEDs and were higher under LEDs than fluorescent lamps. The duration of flowering was highest under red LEDs and blue plus red LEDs. The results demonstrated that LED light sources are more effective than fluorescent lamps for vegetative and reproductive growth of non-heading Chinese cabbage. Moreover, blue LEDs benefit vegetative growth, while red LEDs and blue plus red LEDs support reproductive growth in non-heading Chinese cabbage. In the artificial cultivation and subsequent transplanting of the life cycle of plants, the light source can be selected to meet the requirements of different growth stages of plants and be used to promote the subsequent process in the industrial production of non-heading Chinese cabbage.

Büchert *et al.* (2011) assayed the effect of continuous and periodic exposure to low-intensity white light at 22 °C on postharvest senescence of broccoli heads. Broccoli is a rapidly perishable vegetable crop and that’s why several postharvest treatments have been applied in order to delay de-greening. Since light has been shown to have an effect on pigment accumulation during development and darkness is known to induce senescence; that’s why this experiment was carried out. Exposure to a constant dose of 12 µmol m^{-2} s^{-1}

was selected as the most suitable treatment and was employed for subsequent experiments. During the course of the treatments, hue and L^* values as well as chlorophyll content and visual observation of florets indicated an evident delay in yellowing in treated samples compared with controls. No statistically significant differences in total protein content were found, but soluble protein content was higher in treated samples. Total and reducing sugar as well as starch levels decreased during postharvest senescence, with lower values in control samples. The results of this study indicated that storage under continuous low-intensity light is an efficient and low-cost treatment that delays postharvest senescence while maintaining the quality of harvested broccoli florets.

Mizuno *et al.* (2011) investigated the effects of monochromatic lights on the growth of seedlings and the biosynthesis of plant pigments in leaves. Seedlings of cabbages (*Brassica oleracea* var. *capitata* L. 'Kinshun' (green leaf), 'Red Rookie' (red leaf)) at the stage of having 2 unfolded true leaves were transferred under four monochromatic lights, such as blue, blue-green, green and red LEDs which have peak wavelengths of 470, 500, 525 and 660 nm; respectively and cultivated for 30 days at 50 µmol m^{-2} s^{-1} PPFD. The elongation of main stem and petioles in 'Kinshun' was promoted under blue light. Seedlings of 'Red Rookie' showed different responses from those of 'Kinshun'. Although petiole elongation was promoted under blue light, there were no significant differences in main stem length. Top fresh weight in both cultivars also showed no significant difference among respective light treatments. In 'Red Rookie', red light irradiation caused to increase the anthocyanin content, though there was no difference in chlorophyll contents. On the other hand, in 'Kinshun', anthocyanin contents were the same level regardless of light quality, and chlorophyll contents were higher under blue and blue-green light than under green and red light.

Lemoine *et al.* (2010) analyzed the effect of a combination of UV-C and heat treatment on quality and senescence of fresh-cut broccoli florets stored at 0 °C. Combined treatment delayed yellowing as evidenced by higher Hue values and lower chlorophyll degradation. The treatment diminished respiratory activity indicating higher tissue integrity. Treated samples showed higher phenolic content and antioxidant capacity. On day 21 of storage, treated samples had higher levels of total sugars, and total proteins. The results suggested that a combined treatment with heat and UV-C may reduce senescence, tissue damage and helps to maintain a better quality of the product during storage at 0 °C.

Avercheva *et al.* (2009) compared growth and 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 ± 24μmol m^{-2} s^{-1}) (normal level); the other, at a PPF level of 107 ± 9 μmol m^{-2} s^{-1}) (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 indicated 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 non-photochemical 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. Their results 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.

Lefsrud *et al.* (2008) studied the effect of irradiance from distinct wavelength light-emitting diodes on secondary metabolites in kale. In their experiment, hydroponically cultured kale plants (*Brassica oleracea* L. var. *acephala* D.C.) were grown under specific LED wavelength treatments of 730, 640, 525, 440 and 400 nm to determine changes in the accumulation of chlorophylls, carotenoids, and glucosinolates. Peak accumulation of the Chls, L, and sinigrin occurred under the 640 nm wavelength, which corresponded to the maximum measured irradiance. A second peak was also measured at 440 nm, corresponding to the second highest irradiance for Chls and L (Lutein). Although not significant, the peak for BC (β-carotene) was reversed with the major peak at 440 nm and another at 640 nm. The research produced two peaks of maximum carotenoid pigment concentrations at 440 and 640 nm. However, the Chls only had one peak of maximum concentration occurring at 640 nm, which closely conforms to the maximum irradiance level from the LEDs. Maximum accumulation, on a fresh mass basis, of chlorophyll a and b and lutein occurred at the wavelength of 640 nm, whereas β-carotene accumulation peaked under the 440-nm treatment. However, when lutein was measured on a dry mass basis, maximum accumulation was shifted to 440 nm. Sinigrin was the only glucosinolate to respond to wavelength treatments. Wavelength control using LED technology can affect the production of secondary metabolites such as carotenoids and glucosinolates with irradiance levels also a factor in kale. Management of irradiance and wavelength may hold promise to maximize nutritional potential of vegetable crops grown in controlled environments. This study demonstrated LED arrays may facilitate investigation on the impact of specific wavelengths on secondary metabolite production in vegetable crops.

Pérez-Balibrea *et al.* (2008) carried out a research to see the influence of light on health-promoting phytochemicals of broccoli sprouts. Germinated broccoli sprouts contain much higher levels (10–100 times) of aliphatic (glucoraphanin) and indolic glucosinolates than the inflorescences. Although it is known that genetic and environmental factors can affect the composition of broccoli inflorescences, the influence of such factors on the seeds and sprouts has not been widely reported. Therefore the aim of this study was to determine the effect of light versus dark growth conditions on the phytochemical composition (vitamin C, phenolic compounds and glucosinolates) of broccoli sprouts. Broccoli sprouts grown in the light were found to have much higher concentrations of vitamin C (by 83%), glucosinolates (by 33%) and phenolic compounds (by 61%) than those grown in the dark. During a 7 day period there was a clear and analogous trend in both treatments, with a general reduction in concentrations over time. Among the different organs studied (seeds, cotyledons, stems and roots), the cotyledons contained the highest levels of bioactive compounds, while the roots contained the lowest. Light treatment of sprouting broccoli seeds increased their concentration of health-promoting phytochemicals, mainly during the first 3–5 days of development. Therefore the younger broccoli sprouts are a better source of bioactive compounds for the consumer than the inflorescences.

Lemoine *et al.* (2007) conducted an experiment to find out the influence of postharvest UV-C treatment on refrigerated storage of minimally processed broccoli (*Brassica oleracea* var. *italica*). Minimally processed broccoli was treated with UV-C light (8 kJ m^{-2}) and subsequently stored for 21 days at 4 °C. The UV-C treatment delayed yellowing and chlorophyll degradation during storage. Treated broccoli florets displayed lower electrolyte leakage and respiratory activity, indicating higher tissue integrity. Treated samples showed higher phenolic and ascorbic acid contents as well as higher antioxidant activity than controls. Treated samples also had a higher content of soluble sugars, but no differences in the content of soluble proteins between control and treated samples were detected. The UV-C treatment also affected bacterial and mould populations. After 21 days at 4 °C, the number of colony-forming units of both pathogenic populations was lower in treated florets than in control broccoli florets. The results suggested that UV-C treatment reduced tissue damage of minimally processed broccoli during storage at 4 °C, thus maintaining nutritional quality and reducing microbial growth.

Rahman *et al.* (2007) conducted two field experiments to assess the response of cauliflower cv. "Nautilus F1" to different radiation integrals after curd initiation by covering the plants with different levels (0 %, 38 %, 50 % and 68 %) of neutral shading materials. Cauliflower growth and development declined with increasing shade levels after curd initiation. Total above ground dry matter increased linearly with accumulated incident radiation integral after curd initiation, however, under lower radiation conditions, the rate of increase per unit incident radiation integral was greater than under higher radiation conditions. Moreover, radiation conversion coefficient declined linearly with increasing incident radiation integrals up to approximately 6.1 MJ m^{-2} d^{-1} and thereafter, declined more slowly with further increase in incident radiation integrals. Therefore, dry matter accumulation was potentially more efficient under lower incident radiation than higher incident radiation levels. Radiation conversion coefficients for plants under low incident radiation levels were greater than under high incident radiation levels. Curd growth also increased linearly with increasing accumulated incident radiation integral with greater mean relative curd dry matter increase per MJ under lower incident radiation conditions than higher incident radiation levels.

Bengtsson *et al.* (2006) studied the effects of post-harvest radiation treatments on several parameters of broccoli related to taste and human health. Norwegian grown broccoli were treated with various combinations of visible light and UV radiation for 10–12 days in controlled climate at 5 °C and 10 °C, respectively. L-ascorbic acid, chlorogenic acid and flavonoids were quantitated by HPLC, and total phenols, soluble solids and titratable acidity by other methods. Antioxidant capacity was measured in methanol extracts by the ORAC (Oxygen Radical Absorbance Capacity) method. In broccoli, the levels of flavonols and the antioxidant capacity were much higher in flower buds than in stalks. The natural variation between broccoli plants was very large in flower buds: tenfold for flavonol content and twofold for antioxidant capacity. This variation was not reduced by the radiation treatment. Flavonol levels in flower buds tended to increase after treatment with visible light + UV-A + UV-B, but the increase was just outside the border of statistical significance. Radiation treatment did not change the antioxidant capacity in broccoli. The broccoli experiment was probably carried out at sub-optimal conditions and the number of properties studied was small. The fact that controlled radiation treatment postharvest can change the health-related quality is an indication that also the incident light during distribution of vegetables could have an effect, which might be positive or negative depending upon the conditions. It could be said that postharvest irradiation with Visible light and UV-B can increase the health value, and at the same time maintain an acceptable quality for marketing. Irradiation with other composition and intensity may have other effects and this should be investigated further.

Costa *et al.* (2006) carried out an experiment on broccoli where central broccoli heads (cv. de Cicco) were harvested and treated with UV-C light (4, 7, 10 and 14 kJ m^{-2}). All treatments delayed yellowing and chlorophyll degradation at 20 $^{\circ}C$ but the irradiation dose of 10 kJ m^{-2} allowed retaining the highest chlorophyll content yet had lower amounts of pheophytins than every treatment other than 7 kJm^{-2}. This dose was selected to analyze the effect of UV-C on postharvest broccoli senescence at 20 $^{\circ}C$. The UV-C treatment delayed yellowing, chlorophyll *a* and *b* degradation, and also the increase in pheophytins during storage. The activity of chlorophyll peroxidase and chlorophyllase was lower in UV-C treated broccoli. Instead, Mg-dechelatase activity increased immediately after the treatment, but after 4 and 6 days this activity was lower in UV-C treated florets than in controls. Treated broccoli also displayed lower respiration rate, total phenols and flavonoids, along with higher antioxidant capacity. The results suggest that UV-C treatments could be a useful non-chemical method to delay chlorophyll degradation, reduce tissue damage and disruption, and maintain antioxidant capacity in broccoli.

Lefsrud *et al.* (2006) studied the effect of irradiance levels on growth parameters and carotenoid pigments in kale grown in a controlled environment. Carotenoids play critical roles in both light harvesting and energy dissipation for the protection of photosynthetic structures. However, limited research is available on the impact of irradiance on the production of secondary plant compounds, such as carotenoid pigments. The objectives of this study were to determine the effects of different irradiance levels on tissue biomass, elemental nutrient concentrations, and lutein β-carotene and chlorophyll (chl) pigment accumulation in the leaves of kale. 'Winterbor' kale was grown in nutrient solution culture in growth chambers at average irradiance levels of 125, 200, 335, 460, and 620 $\mu mol\ m^{-2}\ s^{-1}$. Highest tissue lutein β-carotene and chls in leaves occurred at 335 $\mu mol\ m^{-2}\ s^{-1}$ for kale. The accumulations of lutein and β-carotene were significantly different among irradiance levels for kale. The carotenoid and chl concentration increased linearly for kale from 125 to 300 $\mu mol\ m^{-2}\ s^{-1}$. At irradiance levels above 300 $\mu mol\ m^{-2}\ s^{-1}$ for the kale, the carotenoid and chl levels start to decrease and remain fairly constant after 400 $\mu mol\ m^{-2}\ s^{-1}$. The decrease in carotenoid and chl concentrations could be due to a combined effect of photo-degradation of the pigment molecules and dilution of the concentration as the plant grows. The moisture content of the plants changed significantly as the irradiance increased. The kale percentage

DM increased from 9.7 to 15.0 %. The larger change in percentage DM for kale followed an increasing linear trend after removing the lowest irradiance level. This change in percentage DM may result in dilution of the carotenoids, which could explain the reason for the significant effect irradiance had on kale. Identifying effects of irradiance on carotenoid accumulation in kale is important information for growers producing the crop for dry capsule supplements and fresh markets. Average field irradiance levels can vary dependent on location, time of year, shading, and atmospheric conditions. Therefore, the influence of irradiance levels on kale carotenoid concentrations should be considered when selecting appropriate growing conditions for this cool-season crop. Changes in carotenoid concentrations would be expected to influence the nutritional value of kale.

Sato *et al.* (2002) investigated the effect of dim light on the growth and photosynthetic ability of cabbage plug-transplants stored for 14 days at 10 °C. Transplants stored in darkness were elongated succulently by etiolation and their leaf chlorophyll content and photosynthetic rate decreased. Both intermittent and continuous lighting at a photosynthetic photon flux density (PPFD) of 10 μmol m^{-2} s^{-1} suppressed the succulent elongation. Longer photoperiod resulted in greater shoot elongation accompanied by dry matter deposition. The leaf chlorophyll content and photosynthetic rate in all lighting conditions remained higher than those in darkness. The photosynthetic rate in intermittent lighting was higher than that in continuous lighting. In intermittent lighting with a 1-hour light/23-hour dark cycle, the succulent elongation and the reduction of photosynthetic rate were suppressed to some extent at a PPFD from 0.5 to 10 μmol m^{-2} s^{-1}. These results suggest that intermittent dim light could be used for preserving the quality of cabbage plug-transplants during low-temperature storage.

Rosa and Rodrigues (1998) carried out an experiment to observe the effect of light and temperature on glucosinolate concentration in the leaves and roots of cabbage seedlings. The study showed total and individual glucosinolate variation during a single day. Seedlings of cabbage grown under controlled conditions and at 14 and 15 days after emergence were moved to 20 °C (Exp. A) and 30 °C (Exp. B), with a constant photosynthetic photon flux density of 480 μmol m^{-2} s^{-1} and 75 % relative humidity, over a 2-day period, during which time aerial parts and roots were sampled at regular intervals. Whilst the glucosinolate patterns of the aerial part of the plant and of the roots remained the same, the levels of major glucosinolates in the aerial part, averaged over all sampling times and 2 days, were 233 ± 60 μmol 100 g^{-1} DW for 3-methylsulphinylpropyl and 72 ± 22 for 2-propenyl; in the roots, 2-phenylethyl and 1-methoxyindol-3-ylmethyl showed the highest average concentrations, with 678 ± 355 μmol 100 g^{-1} DW and 411 ± 122, respectively. Total and individual glucosinolate levels showed very high significant differences between the two plant parts. Despite the constant temperature, light and relative humidity, glucosinolates varied within a 24-hour period, showing ultradian rhythms that are common to several metabolic processes in plants. The results confirmed the observations that at a temperature of 20 °C, close to the optimum for growth and development, the diurnal variation in glucosinolate concentration, was smaller than at 30 °C.

Wilson *et al.* (1998) carried out an experiment to observe the responses of broccoli seedlings to light quality during low-temperature storage in vitro: II.

sugar content and photosynthetic efficiency. Broccoli (*Brassica oleracea* L. Botrytis group `Green Duke') seeds were cultured photoautotrophically (without sugar) or photomixotrophically (with sugar) in vitro for 3 weeks at 23 °C and 150 μmol m^{-2} s^{-1} photosynthetic photon flux (PPF). In vitro seedlings were stored for 0, 4, 8 and 12 weeks at 5 °C in darkness or under 5 μmol m^{-2} s^{-1} of white (400–800 nm), blue (400–500 nm) and red (600–700 nm) light. Photosynthetic ability and soluble sugar contents were determined after removal from storage. Photomixotrophic seedlings contained approximately five times more soluble sugars than did photoautotrophic seedlings. Dark storage reduced soluble sugars in both photoautotrophic and photomixotrophic plants, but photosynthetic ability was maintained for up to 8 weeks in the latter whereas it decreased in the former. Illumination in storage increased leaf soluble sugars in both photoautotrophic and photomixotrophic seedlings. Soluble sugars in stems decreased during storage regardless of illumination, but remained higher in illuminated seedlings. Red light was more effective in increasing or maintaining leaf and stem soluble sugars than was white or blue light. Regardless of media composition or illumination, storage for more than 8 weeks resulted in dramatic losses in quality and recovery, as well as photosynthetic ability. Seedlings stored for 12 weeks completely lost their photosynthetic ability regardless of media composition or illumination. The results suggested that carbohydrate, supplied in the media or through illumination, is essential for maintenance of photosynthetic ability during low-temperature storage for up to 4 or 8 weeks.

Olesen and Grevsen (1997) carried out an experiment to see the effects of temperature and irradiance on vegetative growth of cauliflower (*Brassica oleracea* L. *botrytis*) and broccoli (*Brassica oleracea* L. *italica*). Cauliflower and broccoli plants were grown in large pots in growth chambers for a range of temperatures (mean air temperatures from 7.0–25.3 °C) and irradiances (from 9.3–50.8 mol m^{-2} d^{-1} or 4.7–25.4 MJ m^{-2} d^{-1}). The extinction coefficient for PAR decreased with plant size reaching a value of 0.55 in cauliflower and 0.45 in broccoli at plant leaf areas of 0.235 m^2 and 0.227 m^2, respectively. The leaf area expansion rate was unaffected by irradiance when compared at identical leaf surface temperatures. The response of expansion rate to surface temperature was fitted to a broken stick model with a base temperature of —0.7 °C and an optimum temperature of 21 °C. The radiation conversion coefficient increased with air temperature below 13.8 °C and remained constant above this. The estimated radiation conversion coefficient above 13.8 °C and for a PPFD (Photosynthetic Photon Flux Density) of 20 mol m^{-2} d^{-1} was 0.77 g mol^{-1} in cauliflower and 0.87 g mol^{-1} in broccoli. The radiation conversion coefficient declined with increasing irradiance level from a maximum of 1.89 g mol^{-1} at near nil irradiance in cauliflower.

Goins *et al.*, 1997, investigated the effect of LED-based light systems on the yield and physiological responses of several crop plants, including wheat .They observed that, Red light-emitting diodes(LEDs) are a potential light source for growing plants in spaceflight 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 photomorphogenesis for successful growth and seed yield.To determine the influence of gallium aluminium arsenide (GaAIAs) red LEDs on wheat photomorphogenesis, photosynthesis, and seed yield, wheat *[Triticum aestivum* L., cv. 'USUSuper Dwarf) plants were grown under red LEDs and compared to plants grown under daylight 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 (70 DAP). 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 subtillers and a lower seed yield compared to plants grown under white light. Wheat grown under red LEDs + 1 0 % 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.

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site description, climatic condition, crop or planting materials, treatments, crop growing procedure, intercultural operations, data collection and statistical analysis. The details of experiments and methods for achieving stated objectives are presented under the following headings and sub-headings:

3.1 Experimental period

The experiment was conducted during the period from December 2015 to March 2016 in Rabi season.

3.2 Experimental site

The experiment was accomplished at The Horticulture Farm, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh. Geographically the experimental area is located at 23°41' N latitude and 90°22' E longitudes at the elevation of 8.6 m above the sea level.

3.3 Characteristics of soil

The experimental soil belongs to the Modhupur Tract under AEZ No.28 (Anon., 1988a).The selected experimental plot was medium high land and the soil series was Tejgaon (Anon., 1988b). Soil of the experimental field was silty loam in texture. Soil sample of the experimental plot was collected from a depth of 0–30 cm before conducting the experiment and analyzed in the Soil Resources Development Institute (SRDI), Soil Testing Laboratory, Khamarbari, Dhaka.

3.4 Climate

The climate of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to February and the pre-monsoon or hot season from March to April and the monsoon period from May to October (Edris *et al*., 1979). Details of the meteorological data during the period of the experiment was collected from the Bangladesh Meteorological Department, Sher-e-Bangla Nagar, Agargaon, Dhaka.

3.5 Design and layout of the experiment

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Seedlings were transplanted on December , 2015 in 3 m × 1 m sized bed. In each plot row to row distance was maintained 60 cm and plant to plant distance was at 45 cm. There were 10 plants accommodated in each plot .Total plot number was fifteen.

3.6 Spacing and plot size

Each of the plot size was 3.0 m ×1.0 m and 50 cm was left for irrigation and drainage between two beds. 25 days old seedlings were transplanted in plots.

3.7 Planting material

BARI Broccoli variety seeds were collected from BARI and they were sown in the soil of germination trays in December, 2015. The trays were kept under favorable condition. Light watering and weeding were done several times. No chemical fertilizers were applied for rising of seedlings. Seedlings were not attacked by any kind of insect or disease. Healthy and 25 days old seedlings were transplanted into the experimental field.

3.8 Treatments of the experiment

A single factor experiment was designed with five treatments.

treatments:

L_C	-	Control(no artificial light)
L_W	-	White LED light
L_R	-	Red LED light
L_B	-	Blue LED light
L_{R+B}	-	Red + Blue LED light

3.9 Land Preparation

The plot selected for conducting the experiment was opened with a power tiller and left exposed to the sun for a week. After one week the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain good tilth. Weeds and stubbles were removed and finally a desirable tilth of soil was found for transplanting of seedling. In order to avoid water logging due to rainfall during the study period, drainage channels were made around the land. The soil was treated with Furadan 5G @ 15 kg ha^{-1} when the plot was finally ploughed to protect the young seedlings from attack of cut worm. Afterwards the plots were covered with net hedge and the roofs of the plots were covered with polythene sheet.

3.10 Experimental setup of land

The experiment was conducted with five treatments where in the plots different types of LED light supplemented and some plots were control where no artificial light was supplemented. In the plots where light supplemented, for white light, Red light, Blue light per plot four(4) lights were applied. In case of Red +Blue light plot two Red light and two Blue lights was applied in a plot. Each light was of 800lumen, total 3200lumen applied in $3m^2$ plot. Everyday just at the onset of evening lights were on for supplementation and at the 10pm of night the lights were off. Every day in the same way lights were supplemented to the field throughout the total experiment up to seed production.

3.11 Fertilization

The experimental plot was fertilized with following dose of urea, Triple Super Phosphate (TSP), Muriate of Potash (Mop) and gypsum.(Krishi projukti hatboi)

Fertilizers	Dose
Cow dung	10 t/h
Urea	160 kg/ha
TSP	155 kg/ha
MoP	110 kg/ha
Gypsum	10–12 kg/ha

3.12 Transplanting

The seedlings of 25 days old were transplanted in the field. The seed bed was watered one day ahead of transplanting. This facilitated easy uprooting of seedlings. The seedlings were uprooted in the afternoon. After transplanting, soil around the seedling was pressed.

3.13 Intercultural operations

3.13.1 Gap filling

Very few seedlings were damaged after transplanting and new seedlings from the same stock were replaced.

3.13.2 Weeding

The plants were kept under careful observation. Weeding was done at two times. First weeding was done two weeks after transplanting. Another weeding was done after 30 days of first weeding.

3.13.3 Irrigation and drainage

After transplanting, plants were watered for the following 4–5 days. Afterwards irrigation was given at an interval of 10 days. Drainage was provided when too much water gathered in the field.

3.13.4 Earthing up

Earthing up was done only by taking the soil from the space between the rows at 15 days after transplanting.

3.13.5 Insects and diseases management

Precautionary measures against Fusarium rot were taken by spraying Dithane M-45 @ 2 g /liter water. The crop was attacked by mole cricket and field cricket during the early stage of growth of seedlings in the month of February. This insect was controlled initially by beating and hooking afterwards by spraying Dieldrin 20 EC @ 0.1%.

3.14 General observation

The field was frequently observed to notice any changes in plants, pest and disease attack and necessary action was taken for normal plant growth.

3.15 Harvesting and seed collection

Main curds were harvested at different dates according to maturity indices. Main curds were harvested when the plants formed compact curd. The curds were harvested with 10 cm of stem attached with the sprouts. It took 45–55 days to initiate curd and after 60–70 days they become ready for harvesting. After reaching proper stage of compactness and size, the curds were harvested by cutting the stem below the curd with a sharp knife. The curds were harvested with surrounding enclosed leaves to protect the curd from getting any injury. Some plants were kept in each plot in the field without harvesting for the collection of seed data. Then the light supplement was continued to the plot on plants. After pod formation the no. of pods per plant were counted and no. of seeds per pod were also counted.

3.16 Data collection

Data were collected in respect of following parameters:

Growth related parameters:

- Plant height
- Number of leaves
- Length of stem
- Diameter of stem
- Fresh weight of leaves

Yield related parameters:

- Days to first visible curd
- Weight of curd
- Diameter of curd
- Curd Yield /plot
- Curd Yield /ha
- No. of pod/ plant
- No. of seed/ pod
- No. of seed/ plant

3.16.1 Plant height

Plant height of each sample plant was measured in centimeter from the ground level to the tip of the longest leaf and mean value was calculated and expressed in cm.

3.16.2 Number of leaves per plant

The total number of leaves per plant was counted from each selected plant with the observation of fully open leaves. Data were recorded as the average of 5 plants selected at random from the inner rows of each plot. After the plants became fully matured, number of leaves on each plant was counted.

3.16.3 Length of stem

The length of stem was taken from the ground level to base of the main curd of plant during harvesting. A meter scale used to measure the length of stem and was expressed in centimeter (cm).

3.16.4 Diameter of stem

The diameter of the stem was measured at the point where the central curd was cut off. The diameter of the stem was recorded by slide calipers and was expressed in centimeter (cm).

3.16.5 Fresh weight of leaves per plant

The fresh weight of leaves was recorded from the average of five (5) selected plants in gram (g) with a beam balance.

3.16.6 Days from transplanting to first visible curd

Each plant of the experiment plot was kept under close observation for recording the data on days from transplanting to first visible curd. Total number of days from the date of transplanting to the first visible curd was recorded.

3.16.7 Weight of curd

The weight of curd per plant was recorded in gram (g) by a weight measuring balance.

3.16.8 Diameter of curd

The diameter of curd was measured in several directions with meter scale and the average of all directions was finally recorded and expressed in centimeter (cm).

3.16.9Curd Yield / plot

The yield per unit plot was calculated by adding the weight of all the curds produced in the respective plot. The yield of all plants in each unit plot was recorded and was expressed in kilogram (kg).

3.16.10 Curd Yield / hectare

The yield per hectare was calculated by converting from the per plot yield data to per hectare and was expressed in ton (t).

3.16.11 No. of pod/ plant

The number of pod counted for all five plants and average value was taken.

3.16.12 No of Seed / pod

The numbers of seed from each of the five pods were counted and average value was taken.

3.16.13 No. of seed/ plant

Seeds were collected by splitting the pods from the five plants individually and then counted and average value was taken.

3.16.13Viability of seed

The viability percentage or germination percentage of seed was calculated with the following formula-

Viability %= (Number of germinated seeds/Total number of seeds) X 100

3.17 Statistical analysis

The data obtained for different characters were statistically analyzed by using MSTAT-C computer package program to find out the significance of the difference for planting time and organic manure on yield and yield contributing characters of broccoli. The mean values of all the recorded characters were evaluated and analysis of variance was performed by the 'F' (variance ratio) test. The significance of the difference among the treatment combinations of means was estimated by Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984)

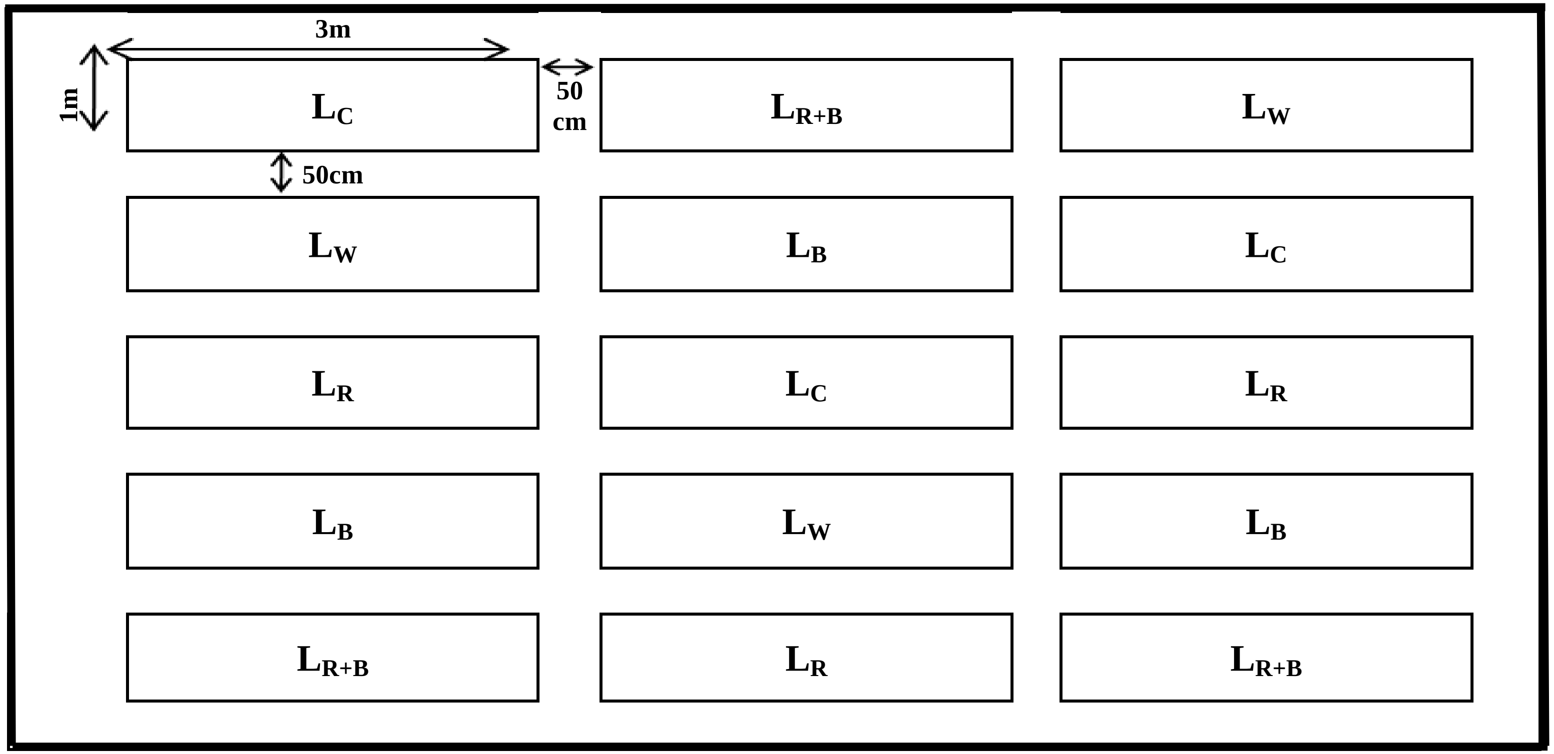

Figure 1: A layout of the experimental plot ; Here , L_c , Control; L_w ,White LED light treatment; L_R ,Red LED light treatment; L_B, Blue LED light treatment; L_{R+B}, Red & Blue LED light combined application.

Plate 1: Photographs showing a. red light application, b. blue light application, c. red & blue combination application, d. control(no artificial light) application e LED light application at night time.

a

b

Plate 2. photographs showing-a. Number of leaves Measuring, b. plant height measuring.

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 tabular and graphical forms. The results obtained from the experiment have been presented under separate headings and sub-headings as follows:

4.1 Crop growth attributes

4.1.1 Plant height

Different color of LED light showed significant impact on plant height of Broccoli(Fig.2). The tallest Broccoli plant (56.7 cm) was attained from plants treated with blue light which was statistically similar with red and blue light combination (55.7cm). On the other hand, the shortest plant (45.1cm) was recorded from control treatment. The results are in conformity with the findings of Li *et al.* (2012) who also found that blue LEDs are benefited for the vegetative growth in non-heading Chinese cabbage.

4.1.2 Number of leaves

Number of leaves in Broccoli plant was significantly influenced by different color of LED light treatments (Table.1). The maximum number of leaves per plant (19.0) was found from blue light which was statistically similar (18.3) to red and blue light combination treatments. In contrary, the minimum number of leaves (12.6) was found in control treatment. Li *et al.* (2012) also found similar results with blue LED lights in case of non-heading Chinese cabbage.

4.1.3 Length of stem

Stem length of Broccoli showed significant difference when treated with different LED light treatments (Table 1). The longest stem of Broccoli (25.3cm) was obtained from blue light which was statistically similar (24.8cm) to red and blue light combination. Whereas, the shortest stem of Broccoli (16.2cm) was seen in control treatment. Mizuno *et al.* (2011) also found that the elongation of main stem and petioles in 'Kinshun' cabbage variety were promoted under blue light. Seedlings of 'Red Rookie' variety of cabbage showed different responses from those of 'Kinshun'. Although petiole elongation was promoted under blue light, there had no significant difference in main stem length.

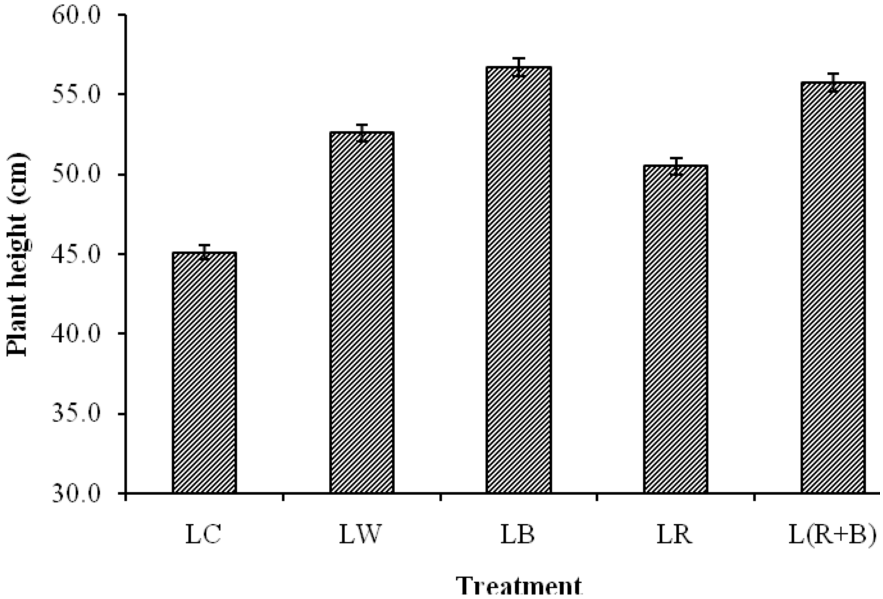

Figure 2.Plant height of Broccoli under differentLED light application.
Here, L_W, White LED light (Control); $L_{B,}$ Blue LED light ; $L_{R\,,}$Red LED light; $L_{R+B,}$ Red +Blue LED light.

Table 1: Effect of different LED light on vegetative growth of Broccoli

Treatments	Number of leaves	Length of stem (cm)
L_C	12.7c	16.2c
L_W	14.7b	21.8b
L_B	19.0a	25.3a
L_R	13.0c	21.0b
L_{R+B}	18.3a	24.8a
CV (%)	4.2	2.2
LSD (0.05)	1.2	0.9

Here, L_c, Broccoli under control treatment; L_W, White LED light treatment on Broccoli; $L_{B,}$ Broccoli under Blue LED light treatment; L_R ,, Broccoli under Red LED light treatment; $L_{R+B,}$ Broccoli under Red+Blue LED light treatment;

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) are very significantly as per 0.05 level of probability

4.1.4 Diameter of stem

Different color of LED light showed significant variation on stem diameter of Broccoli(Table.2). The largest stem diameter (4.3cm) was found from Broccoli plant treated with blue light which was statistically similar (4.2cm) to plants treated with red and blue light in combination. On the other hand, the smallest diameter of stem (3.2cm) was recorded in control treatment.

4.1.5 Fresh weight of leaves

Fresh weight of Broccoli leaves was significantly influenced by different color of LED light treatments(Table.2). The highest fresh weight of leaves (245.0 g) was recorded from blue light which was statistically similar to red and blue light combination (243.3 g) and white light (234.6g); whereas, the lowest fresh weight of leaves (175.0 g) was obtained from control treatment. Kwack *et al.* (2015) also found that the fresh weight of Broccoli sprouts markedly increased when red light intensity was 100 µmol $m^{-2}s^{-1}$.

Table 2: Effect of different LED light on growth of stem of Broccoli

Treatment	Diameter of stem (cm)	Fresh weight of leaves (g)
L_C	3.2 c	175.0 c
L_W	3.6 b	234.6ab
L_B	4.3 a	245.0 a
L_R	3.6 b	230.8 b
L_{R+B}	4.2 a	243.3ab
CV%	2.6	3.0
LSD (0.05)	0.2	12.9

Here, L_c, Broccoli under control treatment; L_W, White LED light treatment on Broccoli; $L_{B,}$ Broccoli under Blue LED light treatment; L_R ,, Broccoli under Red LED light treatment; $L_{R+B,}$ Broccoli under Red+Blue LED light treatment

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) are very significantly as per 0.05 level of probability

4.2 Crop yield and yield attributes

4.2.1 Days to first visible curd

Different level of treatments with LED lights had significant effect on the emergence of curd in Broccoli(Table.3). Maximum days required (59.6) for the emergence of first curd was found in control treatment and the minimum days required for the first visible curd (50.3) was recorded in red LED light treatment.

4.2.2 Weight of curd

Weight of Broccoli curd showed significant difference when treated with different colored LED lights(Fig.3). The highest curd weight (382.5 g) was observed from plant treated with red light which was statistically similar to (380.5 g) red and blue light combination. On the other hand, the lowest weight of curd (266.8 g) was recorded in control treatment. Li *et al.* (2012) also found that red LEDs and blue plus red LEDs support reproductive growth in case of non-heading Chinese cabbage.

4.2.3 Diameter of curd

Different color of LED light showed significant variation on curd diameter of Broccoli (Table 3). The largest curd diameter (10.5cm) was observed in Broccoli plant treated with red light whereas the smallest diameter of curd (8.3cm) was recorded from blue light which was statistically similar to (8.5cm) control treatment. Similar findings were described by Li *et al.* (2012) with blue and red LEDs in case of non-heading Chinese cabbage.

4.2.4 Curd Yield /plot

Curd yield per plot of Broccoli was significantly influenced by different color LED light treatment(Table 3). The maximum Curd yield per plot (8.4kg) was obtained from red light treated plants which was statistically at (8.3kg) to red and blue light combination. In contrary, the minimum curd yield per plot (5.8kg) was reported in control treatment.

4.2.5 Curd yield /ha

LED lights of different color had significant effect on curd yield of Broccoli per ha (Table 3). The highest curd yield/ ha (7.4t) was obtained from red light treatment which was statistically similar (7.1t) with red and blue light combined treatments; while the lowest curd yield /ha (5.0t) was found in the control treatment.

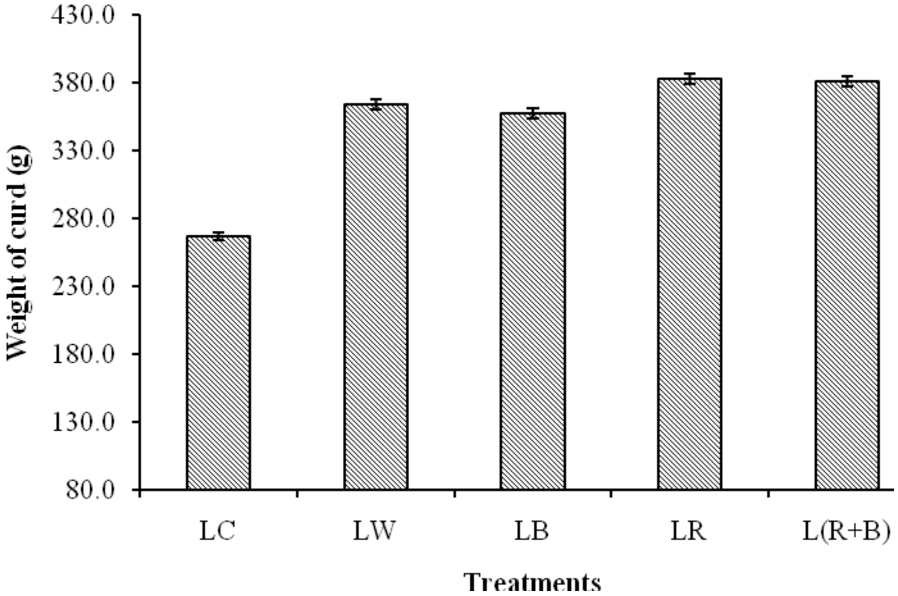

Figure.3.Weight of curd(g) of Broccoli under different LED light application. Here, L_W, White LED light (Control); $L_{B,}$ Blue LED light ; $L_{R\,,}$Red LED light; $L_{R+B,}$ Red +Blue LED light.

Table 3: Effect of different LED light on yield of Broccoli

Treatment	Days to first visible curd	Diameter of curd	Curd yield/plot (kg)	Curd yield/ha (t)
L_C	59.7 a	8.5 d	5.8 c	5.0d
L_W	53.3 c	9.1 c	8.0b	6.7 b
L_B	55.0 b	8.3 d	7.8 b	5.9 c
L_R	50.3 e	10.5 a	8.4 a	7.4 a
L_{R+B}	52.0 d	9.9b	8.3 a	7.1ab
CV (%)	1.3	3.4	1.6	3.9
LSD (0.05)	1.3	0.6	0.2	0.4

Here, L_c, Broccoli under control treatment; L_W, White LED light treatment on Broccoli; $L_{B,}$ Broccoli under Blue LED light treatment; L_R ,, Broccoli under Red LED light treatment; $L_{R+B,}$ Broccoli under Red+Blue LED light treatment;

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) are very significantly as per 0.05 level of probability

4.2.6 No. of pod/ plant

Number of pods per plant was significantly influenced by different color LED light treatments (Table 4). Among the plants where pods were formed, the maximum number of pods per plant (106.3) was recorded in red light treated plants which was statistically similar (101.7) to red and blue light combined treatments; while the minimum number of pods (49.6) were obtained due to white light. No pods were found in control treatment.

4.2.7 No. of seed/ pod

LED lights showed significant influence on number of seeds per pod (Table 4). Among the plants where seeds were formed, the highest number of seeds per pod (12.0) was observed in red light treated plants and the lowest number of seeds per pod (6.0) was found due to white light. No seeds were found in control treatment. Goins *et al.*, 1997, investigated that, Red light-emitting diodes (LEDs) must satisfy requirements for plant photosynthesis and photo morphogenesis for successful growth and seed yield and larger plants and greater amounts of seed are produced in the presence of red LEDs supplemented with a quantity of blue light.

4.2.8 No. of seed/ plant

Number of seeds per Broccoli plant was significantly differed by different LED light treatments (Table 4). Plants under control treatment formed no seed. Among the plants where seeds were formed, the maximum number of seeds per plant (1279.0) was found from red light treated plants and the lowest number of seeds per plant (302.0) was reported due to white light. Goins *et al.*, 1997, investigated that,Red light-emitting diodes(LEDs) must satisfy requirements for plant photosynthesis and photo morphogenesis for successful growth and seed yield and larger plants and greater amounts of seed are produced in the presence of red LEDs supplemented with a quantity of blue light.

Table 4. Effect of different LED light on seed production of Broccoli

Treatment	No. of pod/ plant	No. of seed/ pod	No. of seed/ plant
L_C	0.0 d	0.0 d	0.0 d
L_W	49.70 c	6.00 c	302.0 c
L_B	89.30 b	8.70 b	778.7 b
L_R	106.30 a	12.00 a	1279.0 a
L_{R+B}	101.70 a	9.00 b	917.7 b
CV%	7.7	7.9	13.3
LSD (0.05)	10.1	1.1	163.5

Here, L_c, Broccoli under control treatment; L_W,White LED light treatment on Broccoli; $L_{B,}$Broccoli under Blue LED light treatment; L_R ,,Broccoli under Red LED light treatment; $L_{R+B,}$Broccoli under Red+Blue LED light treatment;

In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) are very significantly as per 0.05 level of probability

4.2.9 Viability of seeds

Viability of seeds was significantly influenced by different color LED light treatments (Table 5).After collecting, the seeds were sown in 36 plug tray with soil and sand mixture then after germination, the germination (%) was calculated and the maximum number of seeds were found viable (87.3%) recorded from red light treated plants which was statistically near about (86.7%) to red and blue light combined treatment; while the minimum number of viability (65.3%) was obtained from white light.

Table 5. Viability test of seeds produced under different LED light treatments

Treatment	Viability (%)
L_W	65.3b
L_B	68.4b
L_R	87.3a
L_{R+B}	86.7a
CV (%)	11.6
LSD (0.05)	17.8

Treatment-L_W,White LED light(Control); L_B, Blue LED light ; L_R , Red LED light L_{R+B}, Red+Blue LED light.
In a column means having similar letter (s) are statistically identical and those having dissimilar letter (s) are very significantly as per 0.05 level of probability

Plate 3. Photographs showing plant growth of Broccoli under different LED light application, Here, a. plant growth under control, b. plant growth under red LED, c. plant growth under red and blue combined LED light, d. plant growth under blue LED light.

Plate 4.a. Photographs showing the inflorescence and flowering of Broccoli. b. photographs showing the pod formation of Broccoli.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the Horticulture Research Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka during the period from December 2015 to March 2016 to observe the influence of LED light on growth, yield and seed production of Broccoli. The test crop used in the experiment was Festival Broccoli variety collected from BARI. The experiment consisted of single factor: 5 level of LED lights- i) Control, ii) White, iii) Red, iv) Blue and v) Red + Blue; thus five treatments. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications thus comprised 15 plots. Data on different growth and yield parameters were recorded .

Different colored LED light treatments had significant impact on growth parameters under consideration. The tallest broccoli plant (56.7cm) was attained from blue light and the shortest plant (45.1cm) was recorded in control treatment. The maximum number of leaves per plant (19.0) was found from blue light whereas the minimum number of leaves (12.6) was observed in control treatment. The longest stem of broccoli (25.3 cm) was obtained from blue light while the shortest stem of broccoli (16.2cm) was seen in control treatment. The largest stem diameter (4.3 cm) was observed from blue light and the smallest diameter of stem (3.2cm) was recorded in control treatment. The highest fresh weight of leaves (245.0 g) was reported from blue light whereas, the lowest fresh weight of leaves (175.0 g) was attained in control treatment.

Yield attributes were also significantly influenced by different colored LED light treatments. Maximum days required (59.6) for the emergence of first curd was found in control treatment and the minimum days required for the first visible curd (50.3) was recorded in red LED light treatment. The highest curd weight

(382.5 g) was observed from red light and the lowest weight of curd (266.8 g) was recorded in control treatment. The largest curd diameter (10.5 cm) was attained from broccoli plant treated with red light whereas the smallest diameter of curd (8.3 cm) was recorded in blue light. The maximum yield per plot (8.4 kg) was obtained from red light treated plants while the minimum yield per plot (5.8 kg) was reported from control treatment. The highest yield/ ha (7.4 t/ha) was obtained from red light treatment while the lowest yield /ha (5.0 t/ha) was found from the control treatment. The maximum number of pod per plant (106.3) was recorded from red light treated plants and the minimum number of pods per plant (49.6) was obtained from white light. The highest number of seeds per pod (12.00) was observed from red light treated plants and the lowest number of seeds per pod (6.0) was found from white light. The maximum number of seed per plant (1279.0) was attained from red light treated plants and the lowest number of seeds per plant (302.0) was reported from white light.Plants under control treatment produced no pod or seed.

Blue light treatment was found to be beneficial for plant growth while red light influenced Broccoli yield more positively compared to others. Red and blue light combination also was found to be effective for Broccoli. Red LED light application is also beneficial for seed production of Broccoli.

Conclusion:

Based on the experimental results, it may be concluded that-

i) Red LED lights can be treated as the best light source among the five treatments for the reproductive growth and better yield of Broccoli.

ii) Blue LED light can be treated as the better light source for good vegetative growth of Broccoli.

iii) Under Red LED light treatment, seed production of Broccoli is possible.

iv) It should also mentioned that,Red and Blue LED light combined application among the five treatments showed better results in every stage of Broccoli production.

REFERENCES

Anonymous. (1988a). The Year Book of Production. FAO, Rome, Italy.

Anonymous.(1988b). Land Resources Appraisal of Bangladesh for Agricultural Development. Report No. 2. Agro-ecological Regions of Bangladesh, UNDP and FAO. pp. 472–496.

Ares, A.M., Nozal, M.J., Bernal, J.L. and Bernal, J. (2014).Effect of Temperature and Light Exposure on the Detection of Total Intact Glucosinolate Content by LC-ESI-MS in Broccoli Leaves.*Food Anal. Methods*,**7**(8): 1687–1692.

Avercheva, O.V., Berkovich, Y.A., Erokhin, A.N., Zhigalova, T.V., Pogosyan, S.I. and Smolyanina, S.O. (2009).Growth and photosynthesis of Chinese cabbage plants grown under light-emitting diode-based light source.*Russian J. Plant Physiol.*,56(1): 14–21.

Bengtsson, G., Hagen, S.F., Borge, G.I.A., Schöner, R., Lombardo, E., Schöner, J., Bilger, W., Berge, A., Haffner, K. and Solhaug, K.A. (2006). Effect of postharvest irradiation on health and sensory related properties of apples and broccoli.*Vegetable Crops Res. Bulletin.*65: 153–160.

Berkovich, Yu. A., Krivobok, N.M., Smolyanina, S.O. and Erokhin, A.N. (2005).*Kosmicheskieoranzherei: nastoyashchee i budushchee*(Space Greenhouses: Now and in Future), Moscow: Slovo.

Brazaityté, A., Duchovskis, P., Urbonaviciuté, A., Samuolienė, G., Jankauskiené, J., Kasiuleviciuté, A., Bliznikas, Z., Novickovas, A., Breivé, K. and Zukauskas, A. (2009). The effect of light emitting diodes lighting on cucumber transplants and after-effect on yield.*Zemdirbyste-Agriculture*.96:102–118.

Brown, S.C., Schuerger, C.A. and Sager, C.J. (1995).Growth and Photo morphogenesis of Pepper Plants under Red Light-emitting Diodes with Supplemental Blue or Far-red Lighting.*J. Amer. Soc. Hort. Sci.*,120(5): 808–813.

Büchert, A.M., Gómez-Lobato, M.E., Villarreal, N.M., Civello, P.M. and Martínez, G.A. (2011).Effect of visible light treatments on postharvest senescence of broccoli (*Brassica oleracea* L.).*J. Sci. Food Agric.*,91(2): 355–361.

Costa, L., Vicente, A.R., Civello, P.M., Chaves, A.R. and Martínez, G.A. (2006). UV-C treatment delays postharvest senescence in broccoli florets. *Postharvest Biology and Technology*.39(2): 204–210.

Dean, A.K., Carl, E.S., Barickman, T.C. and Morrow, R.C. (2014).Sprouting Broccoli Accumulate Higher Concentrations of Nutritionally Important Metabolites under Narrow-band Light-emitting Diode Lighting.*J. Amer. Soc. Hort. Sci.*,139**:** 469–477.

Duarte-Sierra, A., Corcuff, R., Angers, P., Arul, J. and Forney, C. (2012). Influence of UV-C on color development and free amino acid profile in broccoli florets during postharvest storage. *ActaHortic*.945**:** 97–103.

Edris, K.M., Islam, A.T.M., Chowdhury, M.S. and Haque, A.K.M. (1979).Detailed Soil Survey of Bangladesh.Department Soil Survey, Govt. of the People’s Republic of Bangladesh.p. 118.

Fillipo, R.V.H., Cano, G.H.B. and Chaves, O.J.A. (2010).LED lighting applications.*ScientiaetTechnica*.45: 13–18. [Spanish].

Folta, K.M. and Childers, K.S. (2008). Light as a Growth Regulator: Controlling Plant Biology with Narrow-bandwidth Solid-state Lighting Systems. *Hort. Sci.*43(7): 1957–1964.

Folta, K.M. (2004). Green light stimulates early stem elongation, antagonizing light mediated growth inhibition. *Plant Physiol.,*135**:** 1407–1416.

Goins, G.D., Yorio, N.C., Sanwo, M.M. and Brown, C.S. (1997).Photo morphogenesis, Photosynthesis, and Seed Yield of Wheat Plants Grown under Red Light-Emitting Diodes (LEDs) with and without Supplemental Blue Lighting.*J. Exp. Bot.,*48**:** 1407–1413.

Gomez, K.A. and Gomez, A.A. (1984).Statistical Procedure for Agricultural Research (2nd edn.).*Int. Rice Res. Inst., A Willey Int. Sci*., pp. 28–192.

Gupta, S.D. and Jatothu, B. (2013).Fundamentals and applications of light-emitting diodes (LEDs) in *in vitro* plant growth and morphogenesis.*PlantBiotechnol. Rep.,***7**(3): 211–220.

Hahn, E.J., Kozai, T. and Paek, K.Y. (2000).Blue and red light-emitting diodes with or without sucrose and ventilation affects *in vitro* growth of *Rehmanniaglutinose*plantlets.*J. Plant Biol*.**43**(4): 247–250.

Hoenecke, M.E., Bula, R.J. and Tibbitts, T.W. (1992). Importance of ‘Blue’ photon levels for lettuce seedlings grown under red-light-emitting diodes. *Hort. Sci.* **27:** 427–430.

Hogewoning, S.W., Trouwborst, G., Maljaars, H., Poorter, H., van Ieperen W. and Harbinson, J. (2010). Blue light dose–responses of leaf photosynthesis, morphology, and chemical composition of *Cucumissativus*grown under different combinations of red and blue light.*J. Experimental Botany.*,61**:** 3107–3117.

Hogewoning, S.W., Trouwborst, G., Engbers, G.J., Harbinson, J., van Ieperen W., Ruijsch, J., van Kooten O., Schapendonk, A.H.C.M. and Pot, C.S. (2007). Plant physiological acclimation to irradiation by light-emitting diodes (leds).*Acta Hort.*,761**:** 183–191.

Ilieva, I., Ivanova, T., Naydenov, Y., Dandolov, I. and Stefanov, D. (2010).Plant experiments with light emitting diode module in Svet space greenhouse.*Advances in Space Research*.46**:** 840–845.

Jaimez, R.E. and Rada, F. (2011).Gas exchange in Sweet Pepper (*Capsicum chinense*Jacq) under different light conditions.*J.Agril. Sci.* 3**:** 134–142.

Jao, R.C., Lai, C.C., Fang, W. and Chang, S.F. (2005).Effects of red light on the growth of *Zantedeschia*plantlets *in vitro* and tuber formation using light-emitting diodes.*Hort.Sci.*40(2): 436–438.

Jin, P., Yao, D., Xu, F., Wang, H. and Zheng, Y. (2015).Effect of light on quality and bioactive compounds in postharvest broccoli florets.*Food Chemistry.***172:** 705–709.

Johkan, M., Shoji, K., Goto, F., Hahida, S. and Yoshihara, T. (2012).Effect of green light wavelength and intensity on photo-morphogenesis and photosynthesis in *Lactucasativa*.*Environmental and Experimental Botany*.**75:** 128–133.

Kim, H.H., Goins, G.D., Wheeler, R.M. and Sager, J.C. (2004).Green light supplementation for enhanced lettuce growth under red- and blue-light-emitting diodes.*Hort. Sci.***39**(7): 1617–1622.

Kim, S.J., Hahn, E.J., Heo, J.W., Paek, K.Y. (2004). Effects of LEDs on net photosynthetic rate, growth and leaf stomata of *Chrysanthemum* plantlets *in vitro*.*Sci.Hortic.*101(1): 143–151.

Kopsell, D.A. and Carl, E.S. (2013).Increases in Shoot Tissue Pigments, Glucosinolates and Mineral Elements in Sprouting Broccoli after Exposure to Short-duration Blue Light from Light-Emitting Diodes.*J. Amer. Soc. Hort. Sci.*,138(1): 31–37.

Kopsell, D.A., Pantanizopoulos, N.I., Sams, C.E. and Kopsell, D.E. (2012). Shoot tissue pigment levels increase in ‘Florida Broadleaf’ mustard (*Brassica juncea* L.) microgreens following high light treatment. *Sci. Hort.*,140**:** 96–99.

Kwack, Y., Kim, K.K., Hwang, H. and Chun, C. (2015).Growth and quality of sprouts of six vegetables cultivated under different light intensity and quality.*Hortic. Environ. Biotechnol.*,**56**(4): 437–443.

Lee, M.K., Arasu, M.V., Park, S., Byeon, D.H., Chung, Sun-Ok., Park, S.U., Lim, Yong-Pyo and Kim, Sun-Ju. (2016). LED lights enhance metabolites and antioxidants in Chinese cabbage and kale. *Braz. Arch. Biol. Technol.*,**59:** 1–9.

Lee, Y.J., Ha, J.Y., Oh, J.E. and Cho, M.S. (2014). The effect of LED irradiation on the quality of cabbage stored at a low temperature. *Food Sci. Biotechnol.*,23(4): 1087–1093.

Lefsrud, M.G., Kopsell, D.A. and Sams, E.C. (2008). Irradiance from distinct wavelength light-emitting diodes affects secondary metabolites in Kale. *Hort. Sci*. **,**43(7): 2243–2244.

Lefsrud, M.G., Kopsell, D.A., Kopsell, D.E. and Curran-Celentano, J. (2006). Irradiance levels affect growth parameters and carotenoid pigments in kale and spinach grown in a controlled environment. *PhysiologiaPlantarum*. **127**(4): 624–631.

Lemoine, M.L., Civello, P.M., Chaves, A.R. and Martínez, G.A. (2010). Influence of a combined hot air and UV-C treatment on quality parameters of fresh-cut broccoli florets at 0 °C. *International J. Food Sci. Technol.* ,45(6): 1212–1218.

Lemoine, M.L., Civello, P.M., Martínez, G.A. and Chaves, A.R. (2007). Influence of postharvest UV-C treatment on refrigerated storage of minimally processed broccoli (*Brassica oleracea* var. *Italica*). *J. Sci. Food Agric.*,**87**(6): 1132–1139.

Li, H.M., Tang, C. and Xu, Z. (2013).The effects of different light qualities on rapeseed (*Brassica napus*L.) plantlet growth and morphogenesis *in vitro*.*Sci. Hortic*.**150:** 117–124.

Li, H.M., Tang, C.M., Xu, Z.G., Liu, X.Y. and Han, X.L. (2012).Effects of different light sources on the growth of non-heading Chinese cabbage (*Brassica campestris*L.).*J. Agric. Sci.,***4**(4): 262–273.

Li, N., Yan, Rui-xiang and Zhang, N. (2015).Effect of LED Composite Light on Preservation of Broccoli during Cold Storage.*ActaAgriculturaeBoreali-Sinica*.30(1): 188–193.

Lin, K.H., Huang, M.Y., Huang, W.D., Hsu, M.H., Yang, Z.W. and Yang, C.M. (2013). The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (*Lactuca sativa* L. var. *capitata*). *ScientiaHorticulturae.* 150**:** 86–91.

Lin, Y., Li, J., Li, B., He, T. and Chun, Z. (2011).Effects of light quality on growth and development of protocorm-like bodies of *Dendrobiumofficinale in vitro*.*Plant Cell Tissue Organ Cult*.105(3): 329–335.

Maa, G., Zhanga, L., Setiawana, C.K., Yamawakia, K., Asaia, T., Nishikawab, F., Maezawac, S., Satod, H., Kanemitsue, N. an Katoa, M. (2014). Effect of red and blue LED light irradiation on ascorbate content and expression of genes related to ascorbate metabolism in postharvest broccoli. *Postharvest Biology and Technology*.94**:** 97–103.

Martineau, V., Lefsrud, M.G., Naznin, M.T. and Kopsell, D.A. (2012).Comparison of supplemental greenhouse lighting from light emitting diode and high pressure sodium light treatments for hydroponic growth of Boston lettuce.*Hort. Sci*.**47:** 477–482.

Massa, G.D., Kim, H.H., Wheeler, R.M. and Mitchell, C.A. (2008).Plant productivity in response to LED lighting.*Hort. Sci*.**43:** 1951–1956.

Mizuno, T., Amaki, W. and Watanabe, H. (2011). Effects of monochromatic light irradiation by led on the growth and anthocyanin contents in leaves of cabbage seedlings. *ActaHortic*.**907:** 179–184.

Morrow, R.C. (2008).LED lighting in horticulture.*Hort. Sci*.**43:** 1947–1950.

Nooprom, K., Santipracha, Q. and Te-Chato, S. (2013). Effect of shading and variety on the growth and yield of broccoli during the dry season in southern Thailand.*International J. Plant, Animal and Environmental Sci.* **3**(2): 111–115.

Ohashi-Kaneko, K., Takase, M., Kon, N., Fujiwara, K. and Kurata, K. (2007).Effect of light quality on growth and vegetable quality in leaf lettuce, spinach and komatsuna.*Environmental Control in Biology*.**45:** 189–198.

Olesen, J.E. and Grevsen, K. (1997).Effects of temperature and irradiance on vegetative growth of cauliflower *(Brassica oleracea*L. *botrytis)* and broccoli(*Brassica oleracea*L. *italica*).*J. Experimental Botany*. 48**:** 1591–1598.

Paniagua-Pardo, G., Hernández-Aguilar, C., Rico-Martínez, F., Domínguez-Pacheco, F.A., Martínez-Ortiz, E. and Martínez-González, C.L. (2015).Effect of high intensity LED light on the germination and growth of broccoli seedlings (*Brassica oleracea* L.)*Polibotánica*.40**:** 199–212.

Paniagua, P.G., Hernández, A.C., Rico, M.F., Domínguez, P.A., Martínez. C.L. and Martínez, O.E. (2013). High intensity LED light in lettuce seed physiology (*Lactuca sativa* L.). *ActaAgrophysica*. **20**(4): 665–677.

Pardo, G.P., Aguilar, C.H., Martínez, F.R., Pacheco, A.D., González, C.M. and Canseco, M.M. (2014).Effects of Light Emitting Diode High Intensity on Growth of Lettuce (*Lactuca sativa* L.) and Broccoli (*Brassica oleracea*L.)Seedlings.*Annual Research & Review in Biology*.**4**(19): 2983–2994.

Pérez-Balibrea, S., Moreno, D.A. and García-Viguera, C. (2008). Influence of light on health-promoting phytochemicals of broccoli sprouts. *J. Sci. Food Agric.*,**88**(5): 904–910.

Rahman, H.U., Hadley, P., Pearson, S.M.D. and Dennett. (2007). Effect of incident radiation integral on cauliflower growth and development after curd initiation.*Plant Growth Regul.*,**51**(1): 41–52.

Rosa, E.A.S. and Rodrigues, P.M.F. (1998).The effect of light and temperature on glucosinolate concentration in the leaves and roots of cabbage seedlings.*J. Sci. Food Agric.*,**78**(2): 208–212.

Samuolienė, G., Brazaityté, A., Urbonaviciuté, A., Sabajevienė, G. and Duchovskis, P. (2010).The effect of red and blue light component on the growth and development of frigo strawberries.*Zemdirbyste-Agriculture*.**97:** 99–104.

Samuolienė, G., Sirtautas, R., Brazaitytė, A., Sakalauskaitė, J., Sakalauskienė, S. and Duchovskis, P. (2011).The impact of red and blue light-emitting diode illumination on radish physiological indices.*Central European J. Biology.*,**6:** 821–828.

Sato, F., Yoshioka, H. and Fujiwara, T. (2002).Effect of Dim Light on Growth and Photosynthetic Ability of Cabbage Plug-Transplants during Low-Temperature Storage.*Environment Control in Biology*.**40**(3): 317–320.

Schuerger, C.A., Brown, S.C. and Stryjewski, C.E. (1997). Anatomical Features of Pepper Plants (*Capsicum annuum*L.) Grown under Red Light-emitting Diodes Supplemented with Blue or Far-red Light.*Annals of Botany*.**79:** 273–282.

Shin, S.K., Murthy, N.H., Heo, W.J., Hahn, J.E. and Paek, Y.K. (2008). The effect of light quality on the growth and development of *in vitro* cultured *Doritaenopsis*plants. *Acta Physiol. Plant.***30**(3): 339–343.

Shoemaker, J.S., Benjamin, J.E. and Teskey.(1962). Practical Horticulture.Johnwiley&sons.Inc. New York. p. 219.

Steindal, A.L.H., Johansen, T.J., Bengtsson, G.B., Hagen, S.F. and Mølmann, J.A. (2016).Impact of pre-harvest light spectral properties on health- and sensory-related compounds in broccoli florets.*J. Sci. Food Agric.***96**(6): 1974–1981.

Stutte, G.W. (2009). Light-emitting Diodes for Manipulating the PhytochromeApparatus.*Hort. Sci.***44:** 231–234.

Thompson, H.C. and Kelly, W.C. (1988).Vegetable crops. Fifth edition, Tata McGraw Hill Publishing Co. Ltd., York, New Delhi, India. p. 611.

Wilson, S.B., Iwabuchi, K. and Rajapakse, N.C. (1998). Responses of broccoli seedlings to light quality during low-temperature storage in vitro: II. Sugar content and photosynthetic efficiency. *Hort. Sci.,***33**(7): 1258–1261.

Xiaoying, L., Shirong, G., Taotao, C., Zhigang, X. and Tezuka, T. (2012). Regulation of the growth and photosynthesis of cherry tomato seedlings by different light irradiations of light emitting diodes (LED). *African J. Biotechnology.,*11(22): 6169–6177.

Xu, H.I., Xu, Q., Li, F., Feng, Y., Qin, F. and Fang, W. (2012). Applications of xerophyto-physiology in plant production-LED blue light as a stimulus improved the tomato crop. *ScientiaHorticulturae.* 148**:** 190–196.

Yeh, N. and Chung, J.P. (2009).High-brightness LEDs-Energy efficient lighting sources and their potential in indoor plant cultivation.*Renewable and Sustainable Energy Reviews*.13: 2175–2180.

Yorio, N.C., Goins, G.D., Kagie, H.R., Wheeler, M.R. and Sager, J.C. (2001).Improving Spinach, Radish and Lettuce Growth under Red Light emitting Diodes (LEDs) with Blue Light Supplementation.*Hort. Sci.***36**(2): 380–383.

Zhang, L. and Wong, M.H. (2007). Environmental mercury contamination in China: Sources and impacts. *Environment International*.33**:** 108–121.

APPENDICES

Appendix I. Analysis of variance of the data on plant height (cm), number of leaves/plantand length of stem/plantof Broccoli plant underdifferent LED light application .

Source of Variation	Degrees of Freedom (df)	Mean Square Values		
		Plant height (cm)	No. of leaves $plant^{-1}$	Length of stem
Replication	2	18.301	5.600	0.992
Factor A	4	64.807^{**}	25.233^{**}	40.088^{**}
Error	8	0.393	0.433	0.224

** Significant at 0.05 level

Appendix II. Analysis of variance of the data on diameter of stem, fresh weight of leaves per plant, days from transplanting to first visible curd of Broccoli plant under different LED light application

Source of Variation	Degrees of Freedom (df)	Mean Square Values		
		Diameter of stem	Fresh weight of leaves per plant	Days from transplanting to first visible curd
Replication	2	0.099	12.869	5.067
Factor A	4	0.625^{**}	2523.288^{**}	38.233^{**}
Error	8	0.009	46.694	0.483

** Significant at 0.05 level

Appendix III. Analysis of variance of the data on Weight of curd , Diameter of curd, Yield per plot of Broccoli plant under different LED light application

Source of Variation	Degrees of Freedom (df)	Mean Square Values		
		Weight of curd	Diameter of curd	Yield per plot
Replication	2	4.776	0.441	0.002
Factor A	4	6870.566**	2.658**	3.333**
Error	8	32.063	0.100	0.016

** Significant at 0.05 level

Appendix IV.Analysis of variance of the data on Yield/hectare, No. of pod/plant,No. of. Seed /pod of Broccoli plant under different LED light application

Source of Variation	Degrees of Freedom (df)	Mean Square Values		
		Yield per hectare	No. of pod/ plant	No. of.seed / pod
Replication	2	0.116	84.200	4.067
Factor A	4	2.702**	6006.233**	61.267**
Error	8	0.065	28.783	0.317

** Significant at 0.05 level

Appendix V. Analysis of variance of the data onno. of seed/ plant of Broccoli plant under different LED light application

Source of Variation	Degrees of Freedom (df)	Mean Square Values
		No. of seed/ plant
Replication	2	0.116
Factor A	4	2.702**
Error	8	0.065

** Significant at 0.05 level