Effect of interlighting on production and quality of cucumber (Cucumis sativus var. sativus) in greenhouses

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Master Thesis 60 credits 2013

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By

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In Partial Fulfillment of the Requirements for the Degree of Master of Science in Plant Science

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December, 2013

ACKNOWLEGEMENT

I would never have been able to complete my research work without contributions and help of many people at different steps.

I am certainly indebted to my supervisor Professor Hans Ragnar Gislerød for the continuous advice, support, motivation and providing me with an excellent atmosphere for doing research. I gratefully acknowledge my co-supervisor Associate Professor Anne Berit Wold for her willing guidance, encouragement and for helping me to shape my interest and ideas throughout my thesis work.

I would like to give special thanks to Dr. Aruppillai Suthaparan for his constant and enduring support throughout lab work and data analysis. I want to acknowledge Karin Svinnset, Kari Grønnerød and Signe Hansen for their help during lab work.

I wish to convey my immense thanks to Solberg Gartneri AS, which provided me the sample materials for my research. Never enough thanks to my colleague for their help and support during entire thesis work.

Finally, I would like to thank my parents, sisters, and brother. They were always supporting me and encouraging me with their best wishes.

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Abstract

The effects of interlighting on the production and quality of cucumber *(Cucumis sativus var. sativus)* in a greenhouse were investigated in this study. Top lighting was provided by high pressure sodium (HPS) lamps and the lighting regimes include Control (Top-lighting), Philips (Top-lighting + Philips 114W interc), Valoya 144W (Top-lighting + Valoya 144W interc) and Valoya 192W (Top-lighting + Valoya 192W interc). Top lighting lamps are all mounted above the canopy. The Philips LEDs were 95 cm and 120 cm above growing bag (GB) whereas Valoya LEDs are 150 cm above GB. The Philips LEDs, Valoya 144W and Valoya 192W added 27%, 49% and 65 % additional light to top lighting. Interlighting affected both production and quality of cucumber. Interlighting increased the production in terms of kg as well as number of pieces. Interlighting increased the yield per week as well as decreased the light requirement per kg production. The top lighting required 72.31 mol/kg while interlighting with Philips required 69.55 mol/kg and Valoya 144W required 67.22 mol/kg. But Valoya 192W interlighting required more than the top lighting. The production was increased by 8.24%, 16.29% and 15.35% by Philips, Valoya 144W and 192W respectively per m^2. The production was increased from the beginning of harvest to the end. There was positive effect on quality of cucumber due to interlighting. Quality of cucumbers Dry matter content, soluble solid, titrable acidity, pH and Vitamin C were influenced with addition of interlighting with top lighting. Interlighting did not influence the chlorophyll content. Cucumbers were harvest three times for quality analysis during production. The cucumber harvest later showed improved quality than early and mid harvest. Storing cucumbers at 13°C could not show negative effect on vitamin C and chlorophyll content but dry matter, soluble solids, titrable acid and pH shows negative effects during storage. The effect of interlighting in greenhouse cucumber cultivation is especially in lower natural light condition.

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1. INTRODUCTION

Cucumber is one of the most important vegetable grown in greenhouses around the world, including Norway. It has a high rate of consumption. Since, the natural light levels are low during the winter season, the production of cucumber is totally dependent on supplementary light for year round production, which increases plant growth and development, leaf photosynthesis rates and fruit yield, and improves quality of greenhouse crops (Dorais 2003; Ehret et al. 1989). Additional to the natural sunlight, supplemental lighting provides the plants with a longer irradiance period during the day usually 16 to 20 hour photoperiod.

Equal distribution of irradiation throughout the canopy benefits the plants since, the amount of light received by each leaf is between the compensation and saturation points. Most of the lights are captured in the upper part of plant canopy in high-wire cultivation method at high plant density, whether lighting is based on natural and artificial top lighting. So, to improve the distribution of light throughout the canopy artificial light can either be used as side lighting or illuminate the inner or lower part of canopy (Hovi et al. 2004; Stasiak et al. 1998).

In a study of cucumber the photosynthetic photon flux (PPF) near the plant rows in the canopy were slightly higher in top + interlighting than in top lighting alone, resulting in a 20% enhancement of total fruit yield (Hovi et al. 2004). Lighting regime also affected external fruit quality. Interlighting increased the fruit skin chlorophyll concentration and extended the post-harvest shelf life of cucumber (Hovi-Pekkanen & Tahvonen 2008). This indicates that cucumber plants benefit from the more equal distribution of irradiation throughout the canopy.

In the season of low natural light the supplemental lighting is shown to promote photosynthesis and increase the yield (Dorais 2003). The benefits of supplemental lighting are expected to decrease during the season of high natural light, from April to October in the northern hemisphere, as the increasing amount of natural light decreases the proportion of artificial light received by the plant. During the season of high natural light also due to limited light penetration in the lower leaves they are less able to contribute to crop photosynthesis (Dueck et al. 2006).

Light quality, quantity and photoperiod can be controlled by light-emitting diode technology. Synchronization of flowering, maintenance of vegetative growth and control of plant structure can be potentially optimized through specific light combination in greenhouse through LEDs (Folta & Childers 2008).

Recent studies on cucumber and sweet pepper produced with top + interlighting with high pressure sodium (HPS) lamps have shown increment in productivity (Hovi-Pekkanen et al. 2006; Pettersen et al. 2010). The productivity of sweet pepper has also been enhanced by means of interlighting between the rows of plants with LEDs without top lighting.

The aim of this study was to investigate the effect of inter-canopy LED lighting (red and blue light) on yield, fruit quality and storability of cucumber.

2. LITERATURE REVIEW

2.1 General Effects of Climatic Factors on Growth

Light is vital for plant growth and development. Light is perceived as a morphogenetic stimulus as it provides energy for the production of organic matter in photosynthesis. Photomorphogenetic responses include growth effects (such as seed germination, organ elongation) and differentiation (flower bud and leaf formation, and regulation of photosynthetic pigments). Movements of leaves, stomata and chloroplasts are induced by light which are involved in the regulation of photosynthesis. Light quality, light intensity, photoperiod and the day/night cycle are the major factors affecting plant growth. In greenhouse these parameters can be controlled by using artificial light sources (Goto 2003).

Changes in the light environment are recognized by plant through sensing light quality using transducing photoreceptors. Three classes of photoreceptors are phytochromes, cryptochromes, and phototropin (Smith 2000). Physiological, morphological, and anatomical features in plants are directly or indirectly affected by signal detected by the photoreceptors.

Natural light levels often limits crop production in intensive greenhouse cultivation. At every moment the spectrum and photoperiod have to be adapted to the needs of the crops to obtain optimum plant production and product quality (Hemming 2011). For an optimum greenhouse production, light has to be optimized together with all other growth factors like temperature, humidity and $CO_{2.}$ Light intensity, light spectrum, daily light integral and the desired photoperiod have to be considered in order to optimize light. Natural sunlight is preferred above the artificial light since, it is available freely.

Maximum photosynthesis and growth of plants are based on very complicated interactions between light, temperature, CO_2, air humidity, water supply and fertilization. Light has to be optimized together with all other growth factors. CO_2 is, in addition to light one of the most important climatic factors for plant production during photosynthesis. Temperature is the mainly focused climatic factor in greenhouse as this is the most energy demanding factor. The plants should be grown at optimal temperature to utilize light and CO_2 concentration in the better way in greenhouse. Both day and night temperatures are important for plant development.

High day temperatures in combination with saturating CO_2 concentration increases the optimal temperature and the CO_2 assimilation compare to ambient CO_2 concentrations (Figure 1). Increasing temperatures can be accepted with increasing light levels up to the optimal temperature in greenhouses.

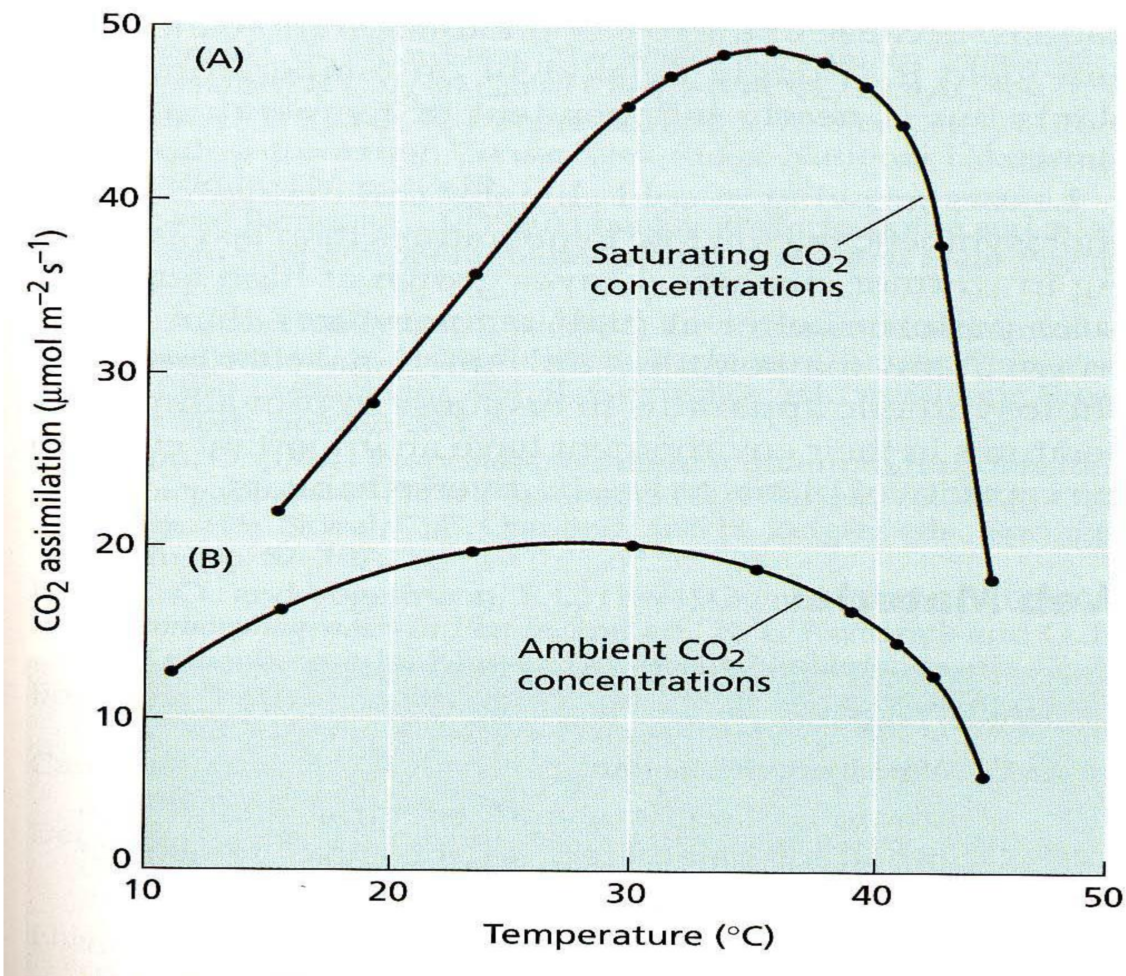

Figure 1. Changes in photosynthesis as a function of temperature at CO_2 concentration that saturate photosynthetic CO_2 assimilation (A) and at normal atmospheric CO_2 concentration (B). Photosynthesis depends strongly on temperature at saturating CO_2 concentration.

While optimizing light interaction with other factors should be considered. Light intensity, daily light integral, light spectrum and the desired photoperiod have to be considered to optimize light (Hemming 2011).

Available sunlight should be preferred for sustainable greenhouse production. About 10% light is lost due to cover materials during addition of layer of transparent materials in greenhouses (Hao & Papadopoulos 1999). Advanced covering materials can be used in order to get more light into the greenhouses such as new plastic films like ETFE material, glass with new anti-reflection coatings or materials with micro-surface (Hemming et al. 2011). These covering materials have higher light transmission than traditional materials and are able to scatter the incoming light and make it diffuse.

In tall crops lights are not evenly distributed and can be improved with diffuse/scattered light. Most of the light entering greenhouses can be transformed into diffuse light through modern greenhouse covering. Plants utilize diffuse light better than direct light. When a plant is growing in diffused light, more leaves can photosynthesize. Better horizontal light distribution in the greenhouse is resulted due to penetration of diffused light on the middle layers of high grown crops (Hemming et al. 2008). Diffuse light penetrates deeper into the canopy which influences the micro climate and increases crop production (Hemming 2011).

To ensure year round production of horticultural crops artificial lights can also be used when sunlight is optimum. The crop energy efficiency under artificial lighting can be improved by changing intensity and duration of lighting, cropping system and plant densities.

2.2 Light

An important growth factor in greenhouses is light as it is vital for photosynthesis. Photosynthesis as well as growth and development of plants are affected by the light intensity, and duration of the daily light that are received by the plant. In winter greenhouse production the major limiting factor is extremely low natural light level. Therefore, to maintain year-round vegetable production in greenhouses supplementary lighting is essential

An increment of 1% light in most greenhouses crops results in an increase in yield of 0.5 to 1% (Marcelis et al. 2006). There was a reduction in cucumber yield between 0.6 to 1.2% due to 1% less radiation.

2.2.1 Light Intensity

In higher latitudes during the winter period light intensity is a limiting factor for growth and development of plant. The valuable information about light saturation point for photosynthesis is given by light intensity concept (Moe et al. 2006). It is measured as photosynthetic photon flux (PPF) µmol m^{-2} s^{-1}. Light intensity influences photosynthesis and plant's growth parameters such as branching, stem thickness, flower number and size as well as fruits colour and shape (Runkle & Heins 2003). .

Daily light intergral (DLI) describes the cumulative amount of light that a plant receives in a 24-hour period and can be expressed as moles per square meter per day (mol/m2/day).

The recommended PPF during propagation from sowing to planting of cucumber plants is up to 250 µmol m^{-2} s^{-1} PAR in 20 h day^{-1}. And the daily light integral is 20 mol m^{-2} day^{-1}. Up to 300 µmol m^{-2} s^{-1} PAR in 20-22 h day^{-1} PPF is recommended during cultivation with up to 25 mol m^{-2} day^{-1} DLI (Moe et al. 2006) .

Reduced yield and serious leaf yellowing was observed due to continuous lighting (24 h). 18-20 h light is best for the growth of plants which allows 4-6 h darkness during a 24-h cycle.

2.2.2 Light Period

The amount of time a plant is exposed to light during the 24 hours cycle is referred as photoperiod. The total energy received by plant in short light period is less at same light intensity than the long light period which effects the growth of plants. Photo periodism is a phenomenon in which specific physiological cycle are induced in many plant species due to length of the photoperiod.

2.2.3 Light Quality

Specific effects on plant morphology, physiology, photosynthesis efficiency and flowering capabilities have been found due to different wavelengths of the light spectrum (Ménard et al. 2006). There have been both positive and negative aspects of most wavelengths; therefore proper combinations of light have been more focus for research (Massa et al. 2008). There have been beneficial effects on tomato and cucumber due to Red light (Ménard et al. 2006). Increase of R:

FR ratio slightly reduces internode length, benefits fruit color and post-harvest conservation in cucumber, but also induces starch molecules inside the chloroplasts in tomatoes (Ménard et al. 2006).

Chlorophyll uses both red and blue light during photosynthesis, and blue light (450 nm) is useful for plant morphology and overall growth and development (Okamoto et al. 1996). Blue light in grape transplants promoted stem growth suppression and increased chlorophyll concentration in shoots compared to red light producing smaller plant and more effective at photosynthesis (Poudel et al. 2008). Generally, blue light reduces cell expansion and inhibits leaf growth as well as reduces chlorophyll content in the leaves. So, blue light is not as effective as red light for photosynthesis (Goto 2003). There has been negative effect on plant morphology such as low number of chloroplast and lower thickness of cell wall due to lack of blue light. Blue light has reported to stimulate stomata opening and increase photosynthesis rate in some species (Ménard et al. 2006).

While using LEDs, the ratio of blue to red light is the most important factor. The plant biomass growth and fruit production was increased while having both blue and red light compared to plants grown under only one of the wavelengths (Goto 2003; Xiaoying et al. 2012).

Plants use phytochromes to sense the Red: Far-red ratio. Far red light is not as readily available on the market as blue and red LEDs but has been shown to have strong biological significance. Plants elongate more rapidly and accelerate flowering when Red: Far-red ratio is low in dense canopies. Photosynthesis and dry matter production are not directly influencd by Far red light (Goto 2003). Combination of red light with blue light is much more important than the combination of red light with far- red light (Brown et al. 1995).

Orange and green light showed significantly reduced photosynthesis when compared to other wavelengths in tomato plants (Xiaoying et al. 2012). However green lights have positive effect on plant growth when used in combination with blue and red light. Treatment with only red and blue light and treatment with green light with combination of red and blue showed no significant difference in production and photosynthesis response. But higher stomatal growth and plant size were observed with added green light (Xiao Ying et al. 2011).

2.3 Artificial Light

The supplemental light is essential for greenhouse production when natural lights are extremely low during the winter months. Winter production of greenhouse plants becomes rather limited in Norway without the use of supplemental lighting since it is situated far north at location from about 59° N to 71° N. Supplemental light is used in year round production in order to increase leaf photosynthesis rates, plant growth and development, fruit yield and quality of greenhouse product (Hendriks 1992).

2.3.1 High Pressure Sodium (HPS)

In greenhouse horticulture High Pressure Sodium (HPS) lamps are the most commonly used supplemental light. For commercial plant production HPS-lamps proves to be excellent light source due to high electric efficiency, long operating time and wide spectrum of light. HPS-lamps are operated at a high temperature (>200°C). In addition to photosynthetically active radiation (PAR) it also emits long-wave heat (infrared) radiation, which influences plant temperature as well as greenhouse climate. Since, HPS-lamps emit radiation in a broad band spectrum, including heat it cannot be applied at close distance to the leaves. To avoid too high temperatures in greenhouse there should be available sufficient ventilation or cooling capacity (Opdam et al. 2005). Due to lack of irradiance in 400-500 nm range HPS lights is neither considered optimal nor efficient for plant growth (Brazaitytė et al. 2009), and this low level of blue light is not optimal for plant growth. HPS emits the peak emission yellow that is 590 nm. HPS lamps spectral composition is fixed and rather different from solar light.

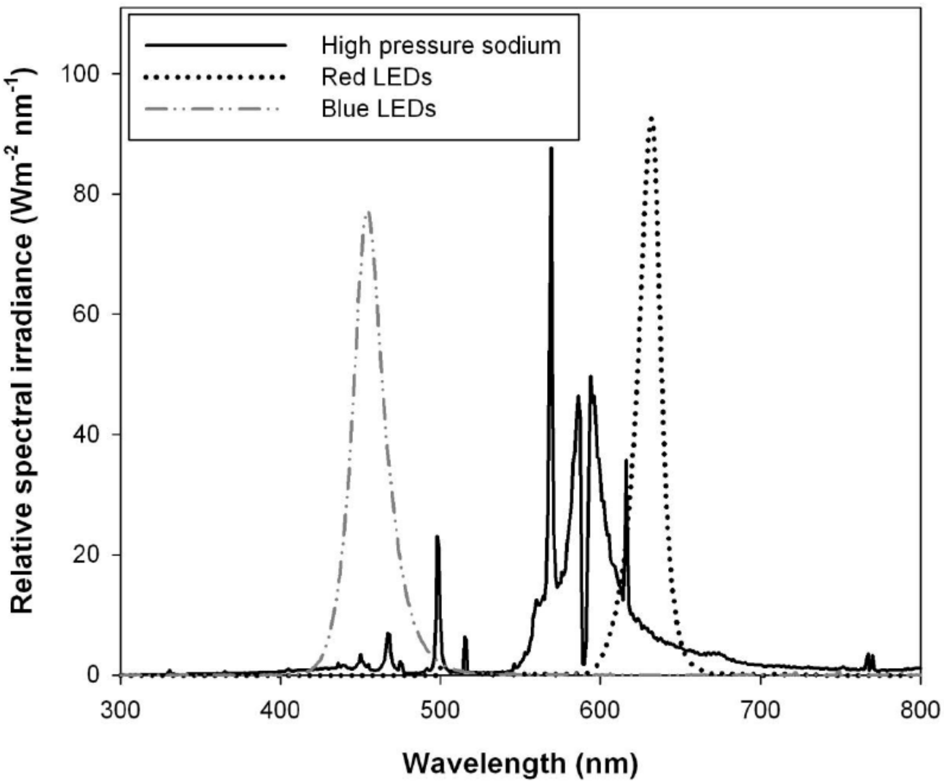

Figure. 2 Spectral distribution of High Pressure Sodium, Red LEDs and Blue LEDs.

2.3.2 Light Emitting Diodes (LEDs)

A new type of light sources based on Light Emitting Diodes (LEDs), has emerged in the greenhouse production which spectral composition can be manipulated to meet the desired morphology and photosynthesis. LEDs emit radiation in a narrow wavelength band dependent on their wavelength (Van Ieperen & Trouwborst 2008). LED's covers the PAR spectrum (400-700 nm) and the exact wavelength depends on the properties of semiconductor materials. LEDs have maximum emission wavelength from UV-C (~250nm) to infrared (~1000nm) (Bourget 2008). LEDs allow wavelengths to match to plant photoreceptors to influence plant morphology and composition due to capability of true spectral control (Morrow 2008).

The LEDs technology is evolving at rapid pace in electrical use efficiency. The blue LEDs that were only 11% efficient in converting electrical energy into photon energy in 2006 were able to be 49 % electrical use efficient in 2011 (Mitchell et al. 2012). The photosynthetic efficiency of red LEDs is expected to be double of HPS lambs by the year 2020 (Pinho et al. 2012). LEDs are safer for user and environment along with energy saving and functionality. LEDs do not contain hazardous materials, no fragile glass envelope to break and no high touch temperature. Since LEDs do no emit radiant heat it can be placed closed to plants.

To replace the HPS with LED technology is still relatively expensive. However it is possible to combine the spectra of conventional light source with LED wavelength. It optimizes different physiological process like growth, flowering and photosynthetic efficiency with optimized spectral quality and creates economically efficient lighting system. LEDs and florescent lamp were combined (Li & Kubota 2009) as well as LEDs were combined with HPS lambs (Ménard et al. 2006) for positive growth and metabolic effect.

2.3.3 Intercanopy Lighting

"Intercanopy lighting" a recently developed supplementary lighting technique have been set up for high-wire grown vegetable production in greenhouses in several countries, e.g. Iceland (Gunnlaugsson & Adalsteinsson 2006), Finland(Hovi et al. 2004), Netherland (Heuvelink et al. 2006), and Norway (Pettersen et al. 2010). In intercanopy lighting, some of the lamps are placed lower between the plants rows instead of above the canopy for more and even distribution of artificial light throughout the canopy. The yield of cucumber, tomato and sweet pepper has been shown to increase due to intercanopy lighting (Gunnlaugsson & Adalsteinsson 2005; Hovi et al. 2004; Pettersen et al. 2010) but no increase in yield was found in some studies with improved fruit quality (Gunnlaugsson & Adalsteinsson 2005; Heuvelink et al. 2006; Trouwborst et al. 2010) .

2.4 Quality

Climatic factors influence the product qualities of most greenhouse horticultural crops. Physiological process as well as internal quality of crops is influenced by environmental factor in greenhouses. Change in climate condition in the greenhouse affects the taste such as sugars, acids and flavor substances as well as vitamins and secondary plant compounds (Gruda 2005).

The external and internal quality of different vegetable crops has been improved and the yield increased due to use of supplemental light in greenhouses. As a result of supplemental light higher percentage of first class fruit, higher dry matter content and skin chlorophyll in cucumber

(Hao & Papadopoulos 1999), increased head firmness of lettuce (Gaudreau et al. 1994) and higher sugar content and ascorbic acid concentration in tomato (Dorais & Gosselin 2002) have been reported.

Fruit skin chlorophyll content is an important quality factor in cucumber which strongly influences the keeping quality. The location of fruit in the canopy (Lin & Ehret 1991) and fruit greenness during harvest (Klieber et al. 1993) are related to the post harvest shelf life of cucumber. Good light penetration into the canopy results in darker fruit and a longer shelf life of cucumber (Klieber et al. 1993). Lower chlorophyll concentrations are observed in cucumber grown under low light condition and are easily turned yellow during shelf life stored at 13°C (Lin & Jolliffe 1994). Low ratio of Red (R) to Far-red (FR) light is associated with low chlorophyll content (Miller & Zalik 1965). Slow degradation of chlorophyll during senescence is also associated with Red light (Okada et al. 1992). Extension of shelf life and enhancement of fruit colour is reported by higher nutrient concentration and fruit thinning (Lin & Ehret 1991).

In horticultural crops one of the most important nutritional quality factors is vitamin C, including ascorbic acid and dehydroascorbic acid. Vitamin C content in fruits and vegetables are influenced by different pre harvest (climatic condition and cultural practice) and post harvest (maturity at harvest, harvesting technique and postharvest handling) factor as well as genotypic differences. Chemical composition of horticultural crops is strongly influenced by light and average temperature. L-ascorbic acid (AA) is synthesized from sugar supplied through photosynthesis in plants. The amount of AA formed in plants is definitely influenced by the amount and intensity of light during growing season. On the same plant vitamin C content in fruit exposed to maximum sunlight outside is higher than the shaded fruit inside the canopy (Lee & Kadar 200).

Cucumbers are affected by shading which results on decrease in fresh and dry fruit weight due to reduce distribution of photosynthate to fruit. Increased irradiance and decreased temperature is known to have increased dry matter content in cucumber (Marcelis 1993). Use of covering materials in green houses causes loss of light. Cucumbers harvested from glasshouses contain higher fruit dry matter than those harvested from either acrylic or double-inflated polethylene houses. Increase in dry matter in glasshouse might be due to higher solar irradiance at upper parts of canopy and slightly low temperature (Hao & Papadopoulos 1999).

3. EXPERIMENTS

3.1 Introduction

The experiment was conducted in greenhouses at **Solbergs Gartneri As** and Fruit Laboratory of Norwegian University of Life Sciences (UMB), Norway. Cucumber were grown and provided by Solberg and then stored and analysed at UMB. For this research project, seeds of the cucumber cultivars Odeon were seeded in winter 2012 and Samona in autumn 2012. The postharvest experiment and quality analysis of cucumber was done only from cucumber harvested in winter. The set point of temperature was maintained at 22 °C while the plants were grown. The average day and night temperature were 23.5°C and 18°C respectively. The relative air humidity was maintained at 80% with CO_2 at 900 to 1000 ppm.

During winter production, cucumbers were harvest from 1st week of February to the 3rd week of April. For quality analysis, cucumbers were harvested in three different harvesting periods. First (Early) harvest was done the 3rd week of February, second (Mid) harvest was done the 2nd week of March whereas the third (Last) harvest was done the last week of March.

3.2 Material and Methods

3.2.1 Experimental Setup

The growing experiment was conducted with four different light treatments. Each treatment consisted of four rows of cucumbers of 36 m long and 192cm row to row.

Table1. Additional lights due to different light treatments

Treatment	Light	Additional light
Control (Top- lighting)	85 W/m^2	-
Philips (Top-lighting + Philips 114W interc)	85 + 23.13W/m^2	27%
Valoya 144W (Top-lighting + Valoya 144W interc)	85 + 41.66W/m^2	49%
Valoya 192W (Top-lighting + Valoya 192W interc)	85 + 55.55W/m^2	65%

The HPS top lighting was 85W/m^2 for 19.5 h/day. The interlighting was on for 19 h/day. The interlighting for cucumber was provided by two light sources: Philips and Valoya. Of Valoya two light strength of bulb 144 W and 192 W were used. The Philips light strength of bulb was 114 W. The Philips light tubes are lighted directly to the sides, while the Valoya are lighted out with an angel of 120°. The Philips LED was 95 cm above growing bags (GB) in one row and 120 cm above GB in another row. During harvest cucumber of the two Philips LED treatments were mixed. The Valoya LED was 150 cm above GB.

The Philips modules that provide 114W adds 23.13W/m^2 that is 27% addition lights to the HPS Top Lighting. Whereas Valoya 144W adds 41.66W/m^2 and Valoya 192W adds 55.55W/m^2 that is 49% and 65% addition respectively to the HPS top lighting.

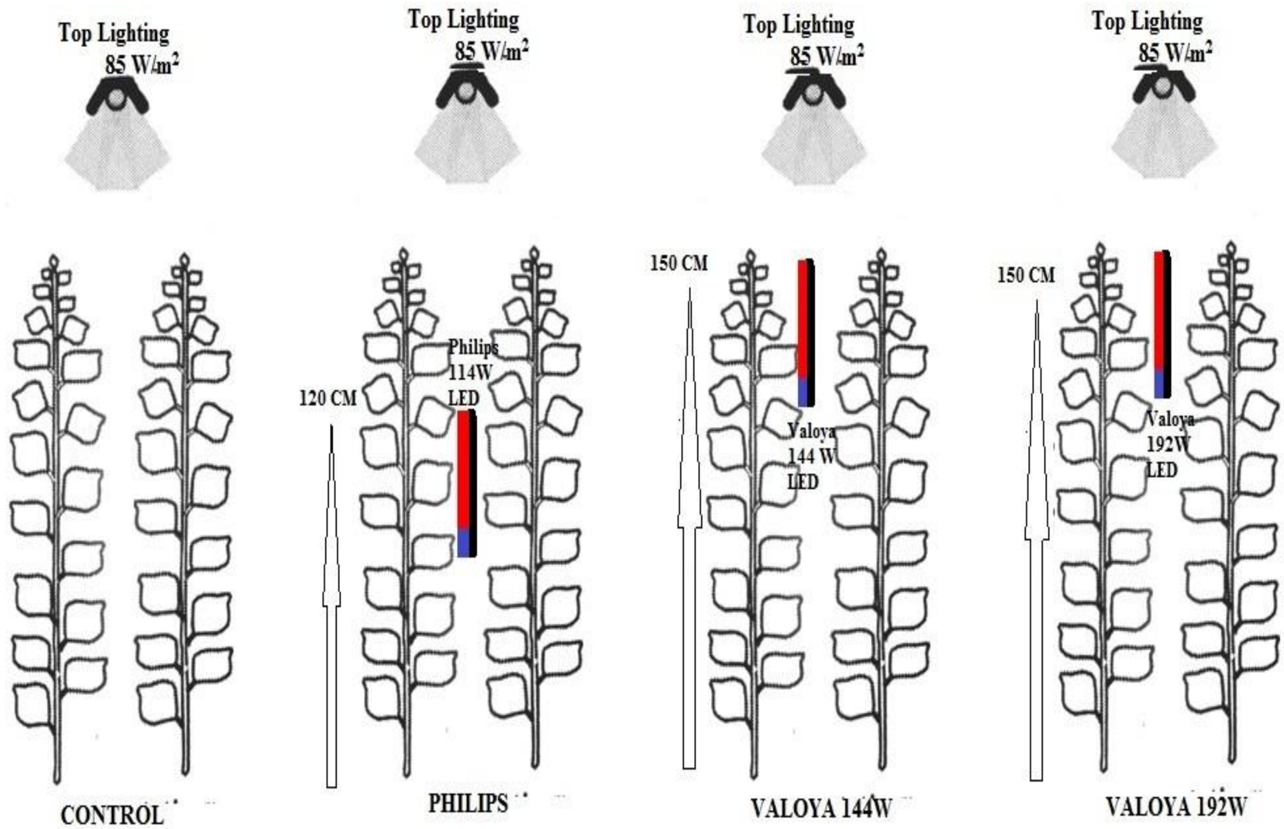

Figure 3. Schematic representation of the control and interlighting treatment.

3.2.2 RECORDING

The light distribution and intensity were measured for each treatment during daylight (Figure 4) and at night (Figure 5). The yields were recorded by Solberg for each treatment during the 10 weeks harvesting period. It was recorded by taking numbers of pieces and weight on both sides of the rows.

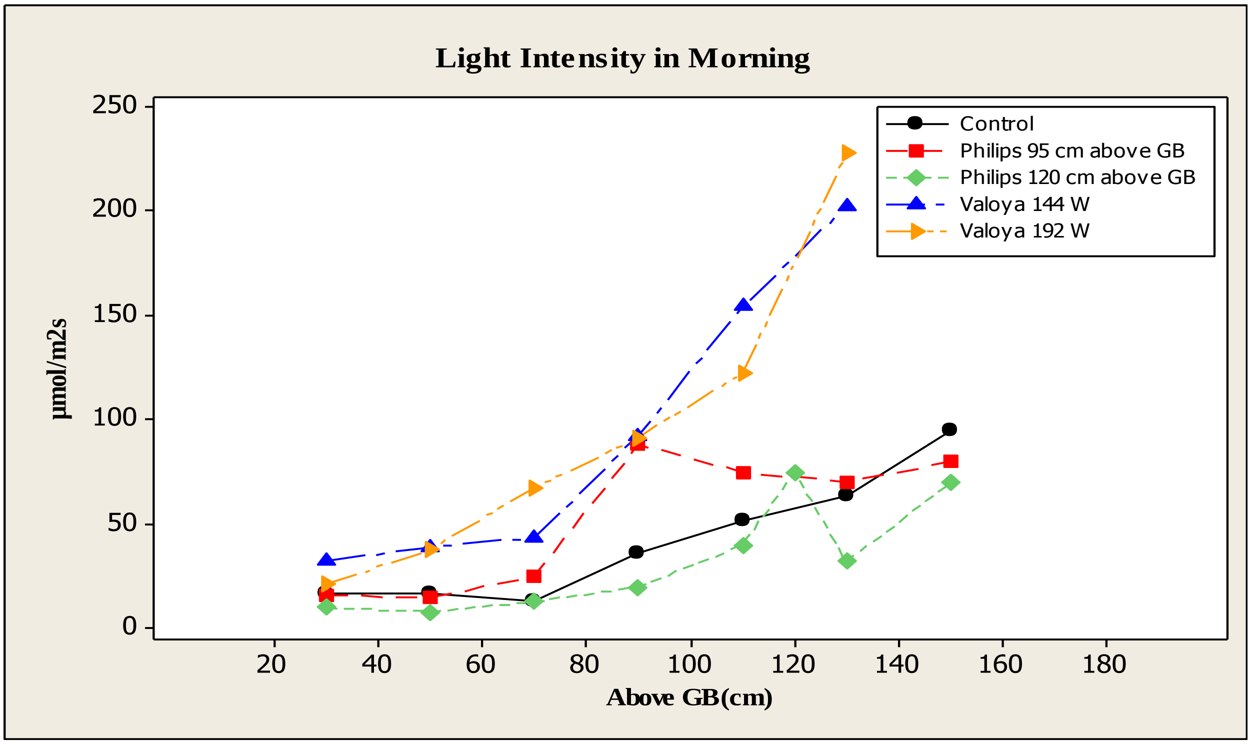

Figure 4. Light distribution and intensity in different height of plants with natural light.

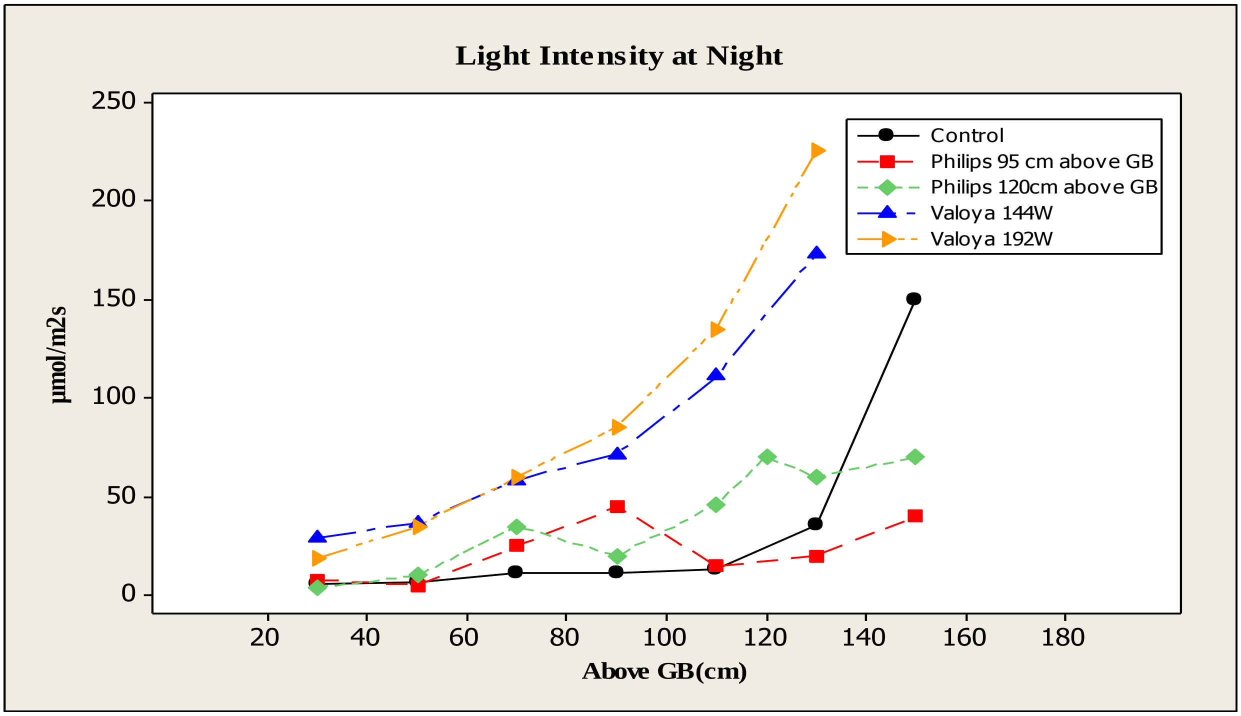

Figure 5. Light distribution and intensity in different height of plants without natural light.

3.2.3 Spectral Distribution of LEDs

The spectral distributions of LEDs were provided by the manufacturing company.

The Philips LEDs contains 95 % deep red light (R; peak wavelength at about 660nm) and 5 % blue light (B; peak wavelength at 445nm).

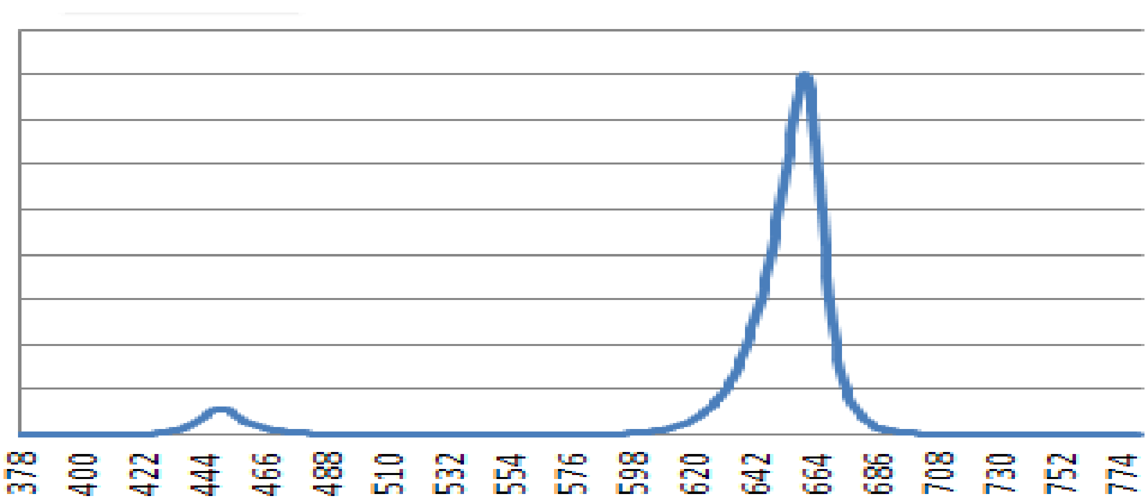

Figure 6. Spectral distribution of Philips LEDs.

The spectral distribution of Valoya LEDs starts from 400nm to 800nm. The percentage of wavelength areas out of 400-800nm of Valoya LEDs are 6.4% (400- 450 nm), 5.3% (450-500nm), 6.5% (500-550nm), 9.7% (550-600nm), 23.1% (600-650nm), 31.1% (650-700nm), 14.1% (700-750nm) and 3.8% (750-800nm). The R:FR was 2.7

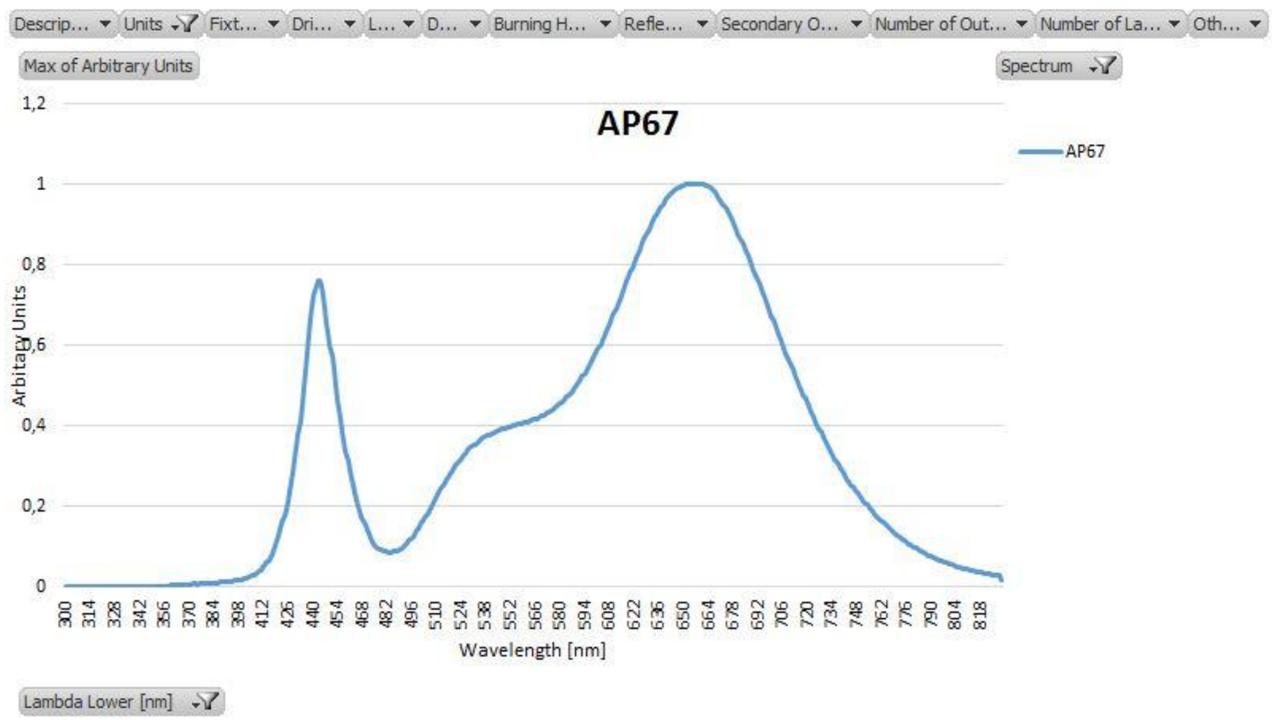

Figure 7. Spectral distribution of Valoya 144W and Valoya 192 W LEDs.

3.2.4 Cucumber Analysis

Cucumbers were harvested for quality analyses and storage three times during the growth period. Forty five cucumbers were harvested each time from each treatment. A total of 135 cucumbers were harvested from each treatment. The cucumbers were sealed and marked at harvest. Out of 45 cucumbers, nine cucumbers were used for non-destructive chlorophyll analysis by the multiplex. The cucumbers (3x4) were then stored for two weeks and four weeks. The cucumbers were individually wrapped in plastic film and stored at 13°C and 90-95% RH. Cucumber for further quality analyses were collected and frozen at -20 ^{0}C. The same procedures were repeated after two and four weeks of storage.

3.2.4.1 Colour /chlorophyll (Multiplex)

Nine cucumbers from each treatment were used for non-destructive measurements of chlorophyll. Colour measurement by the multiplex was done at harvest at three places on individual cucumbers. The company plastic film was removed before measuring. All the cucumbers were measured. The measurements were repeated once a week up to 4 weeks of storage. But due to the use of incorrect standard during measuring, the data is not presented and the result is not discussed.

3.2.4.2 Water loss

Nine cucumbers were used to determine the water loss during storage. The weights of company sealed cucumbers were recorded after harvest and every week up to four weeks of storage. The other nine cucumber used for multiplex and placed in plastic bags was also weighted to determine water loss during storage. Those nine cucumber used in multiplex were wrapped in ordinary plastic.

3.2.4.3 Sample Preparation

The frozen cucumber samples were thawed overnight at room temperature. The cucumber samples were then homogenized using a food processor (BRAUN,Germany). The homogenized samples were filtered (125 mm, Whatman GmbH, Dassel, Germany). The filtrate/juice was collected in conical flasks. Then the juice was used for analysis of soluble solids, titrable acidity and pH.

3.2.4.4 Dry Matter

Approximately 6 grams of the homogenized sample were dried for 24 h at 104^{o}C. The weight of sample was recorded after drying for 24 hours. The dry matter percentages were calculated as follow:

$$\%\ \text{Dry matter} = \frac{[(\text{Dry weight of sample + cup}) - \text{weight of cup}]}{\text{Fresh weight of sample}} \times 100$$

3.2.4.5 Soluble Solids

Digital refractometer was used (Atago Palett PR-100, Japan) for this measurement. The refractometer was calibrated using distilled water. Then 2-3 drops of cucumber juice was placed on the sensor of the refractometer and the content of soluble solids was recorded. Soluble solid is given as %.

3.2.4.6 Titratable Acids

The acidity was measured by titration. Automatic titrator (Methrom 716 DMS Titrino and 730 Sample changer, Herisau, Switzerland) was used for measurement of titratable acid. 10 ml of filtrate was diluted with 50 ml of distilled water and sodium hydroxide (0,1N) was added until a pH of 8.1 was obtained. Then titratable acidity was calculated as a percentage of citric acid.

3.2.4.7 pH

pH meter (691 pH Meter, Metrohm, Swiss)was used to measure the pH. The pH meter was calibrated by using Titrisol with pH value of 4.

3.2.4.8 Vitamin C

For analyses of L-ascorbic acid 50 g of frozen material was made up to 150 g by adding 1% oxalic acid and homogenized for 1 min. The homogenate was then filtered (Whatman ®113V Wet and Strengthened Ø 125mm filter). The samples were then filtered through an activated sep-pak C18 cartridge (waters) and a Millipore filter (0.45 µm) before injection. 5ml of methanol and 5ml of ultrapure water was used to activate the sep-pak filter. The separation was conducted on a 250 x 4.6mm Zorbax SBC18 5 µm column (Agilent Technologies, Oslo, Norway). The mobile-phase was 0.05 M KH_2PO_4 for isocratic elution at 25ºC. The flow was 1 ml min^{-1}. The injection volume was 5 µl and the run time was set to 5 min. L-ascorbic acid was measured at 254 nm (Williams et al., 1973).

3.2.4.9 Chlorophyll

The fruit peel of frozen cucumber was taken out by using peeler. Then it was homogenized and grinded with liquid nitrogen. The 2 g sample was placed in 50ml centrifuge tube and 10 ml of aqueous 80% acetone was added. After that the sample was stored at 4ºC for 12 hours in darkness. The extract was filtered (Whatman No.2 filter paper) at 4ºC in darkness. 1 ml of filtered solution was mixed with 9 ml of 80% acetone. The absorbance for 1ml of 80% acetone was measured as blank and control at 645 nm and 663 nm. The absorbance was then set to zero. Then the absorbance of the solution was measured at 645 nm (Chl b) and 663 nm (Chl a). The chlorophyll concentration was calculated by absorbance at each wavelength per gram of sample.

3.2.5 Data Analysis

Analyses of variance (ANOVA) were performed to collected data with general linear model (GLM) procedure by using Minitab 16. Mean comparisons were performed at p=0.05 with Tukey`s pairwise comparison test. For graphical presentation sigma plot was used.

3.3 Results

3.3.1 Cucumber Production Analysis

3.3.1.1 Production per m^2

There was a small increase in the production per m^2 in terms of number of pieces of cucumber by use of interlighting compared to control during winter as well as autumn. The production was increased by 8.24%, 16.29% and 15.35% by Philips, Valoya 144W and 192W respectively per m^2 during winter. The production per m^2 was increased by 6.49%, 7.71% and 8.58% for Philips, Valoya 144W and 192W respectively during autumn (Figure 8).

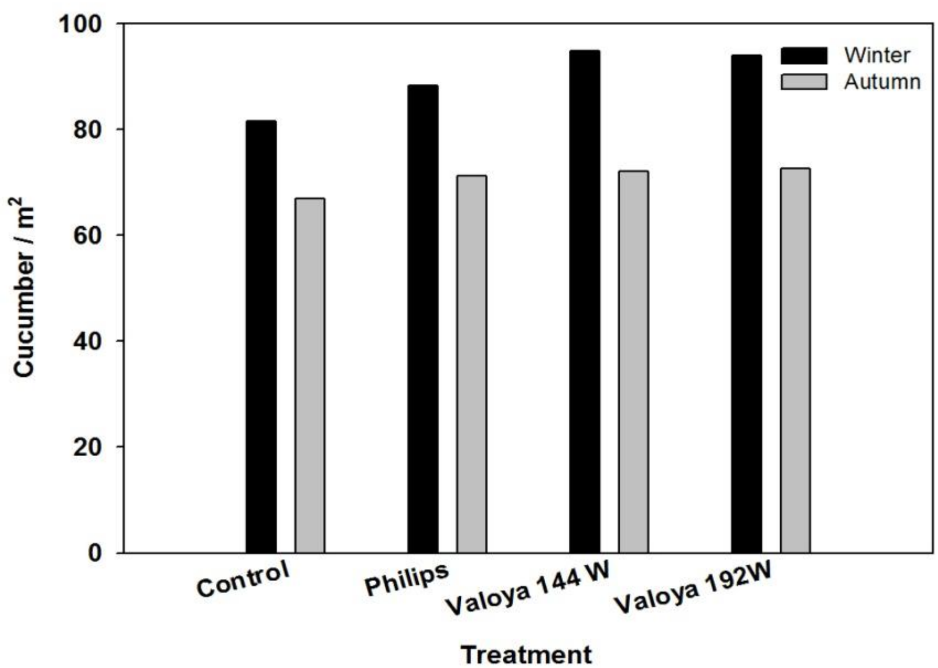

Figure 8. Effect of intercanopy lighting during winter (3rd Feb to 24th Apr) and autumn (10th Aug to 21st Oct) on number of pieces of cucumber harvested per m^2

In terms of kg the production was increased by 11.33%, 20.12% and 20.3% for Philips, Valoya 144W and 192W respectively per m^2 during winter (Figure 9).

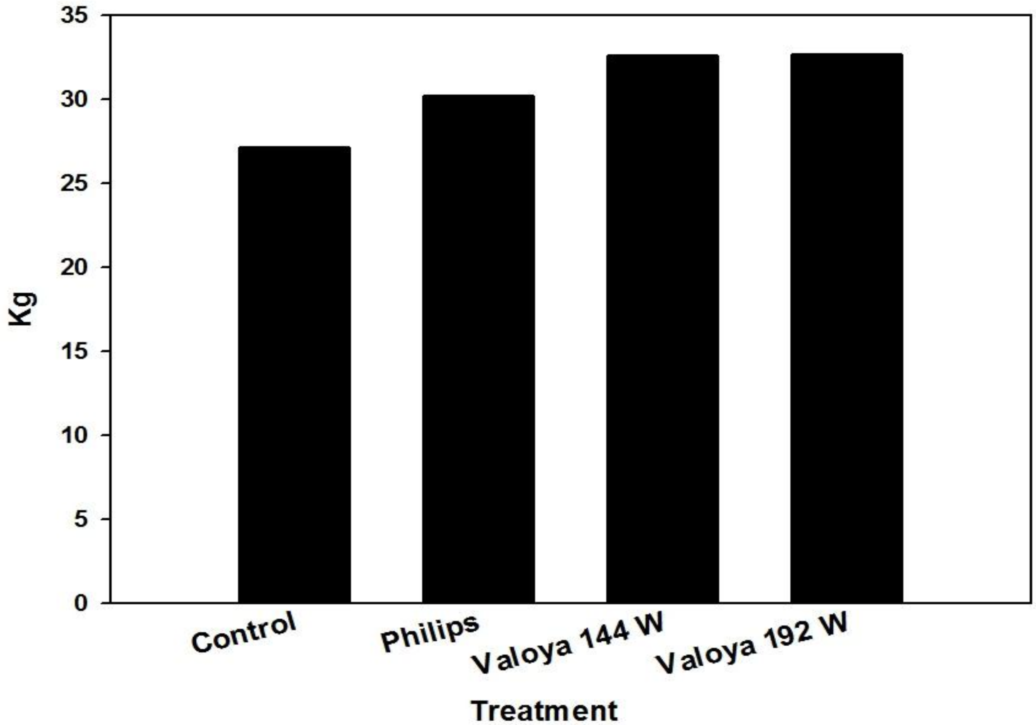

Figure 9. Effect of intercanopy lighting during winter (3rd Feb to 24th Apr) on production of cucumber per m^2

3.3.1.2 Production at Different Week

The light source influenced on yield, and top lighting with interlighting resulted in slightly higher yield compared to only top lighting during both winter and autumn production. There was small increase in production in terms of number of pieces as well as Kg from the beginning of harvest to the end (Figure 10).

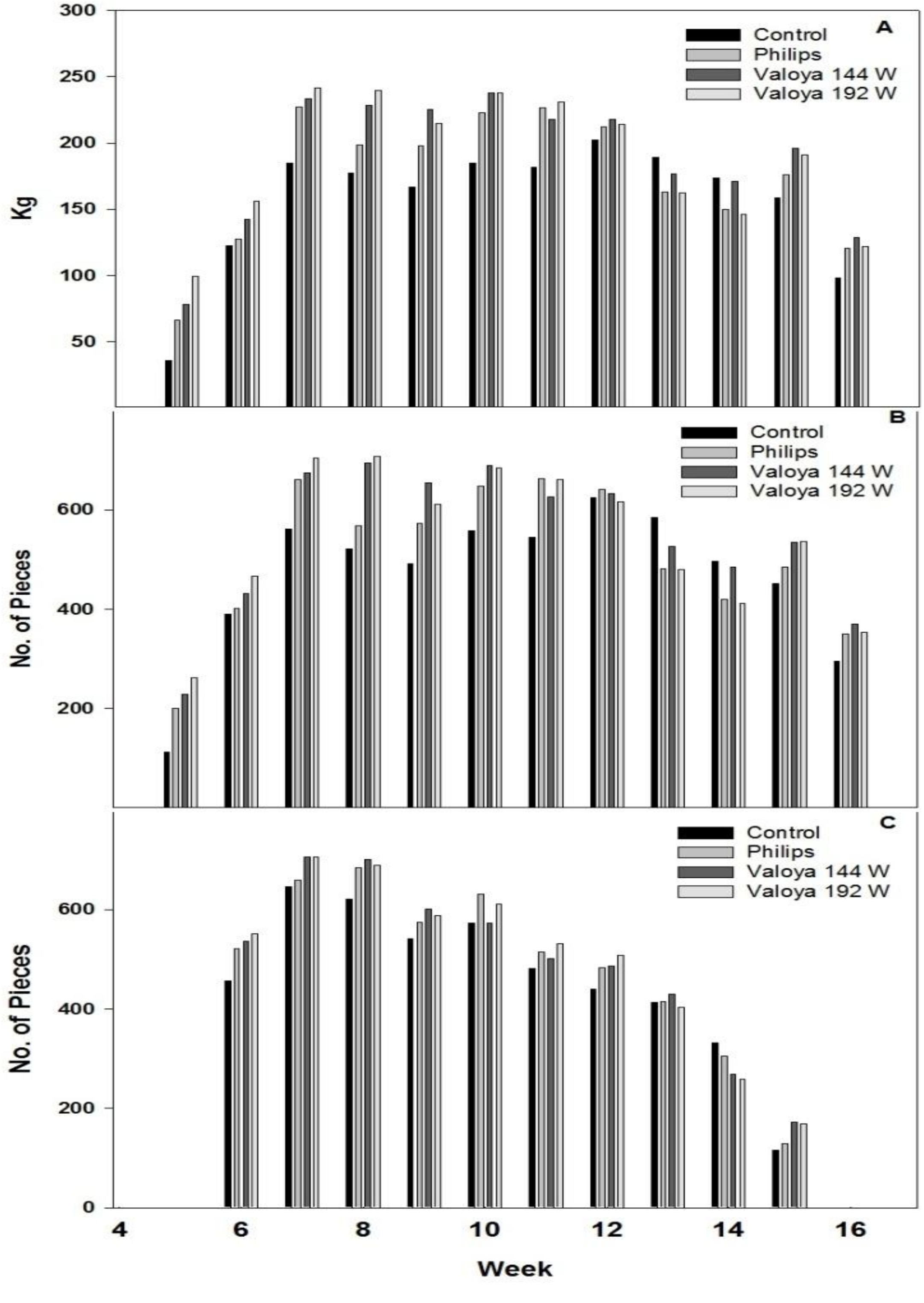

Figure 10. Effect of intercanopy lighting on production (A) and number of pieces (B) of cucumber harvested during winter (3rd Feb to 24th Apr) and number of pieces (C) of cucumber harvested during autumn (10th Aug to 21st Oct) on different weeks.

3.3.1.3 Production per week and light requirement

The use of interlighting within a canopy had small increase in the yield per week per m^2. Additional light within a canopy showed positive effect on the production. The light per kg cucumber production was reduced to some extent with additional light within the canopy by Philips LEDs and Valoya 114W LEDs. But Valoya 192W LEDs showed negative effect and light per kg was increased then the top lighting (Table 2).

Table 2. Effect of different light treatments on cucumber fruit yield and light requirement per kg production. Data represent eleven weeks of harvest.

Treatment	Yield ($Kg/week/m^2$)	Light per kg (mol/kg)
Control (Top- lighting)	2.47	72.31
Philips (Top-lighting + Philips 114W interc)	2.74	69.55
Valoya 144W (Top-lighting + Valoya 144W interc)	2.96	67.62
Valoya 192W (Top-lighting + Valoya 192W interc)	2.97	77.64

3.3.2 Cucumber Quality Analysis

Table 3. Effect of different light treatment and Harvest stage on different quality parameters Solube solids, Titratable acids, dry matter, and chlorophyll contain in cucumber harvested from 3rd Feb to 24th Apr.

Treatment	Levels	% dry matter	Soluble solids	% acidity	pH	Vitamin C	Chlorophyll
Light		**	**	**	**	**	NS
	Control	2.77 ±0.05 b	2.55 ±0.03 b	0.08 ±0.002 b	5.72 ±0.02 b	4.16 ±0.12 b	2.25 ±0.30 a
	Philips	2.95 ±0.06 a	2.64 ±0.04 a	0.09 ±0.002 a	5.77 ±0.02 a	4.60 ±0.19 ab	2.30 ±0.21 a
	Valoya 144 W	2.92 ±0.05 a	2.56 ±0.04 b	0.08 ±0.002 c	5.78 ±0.02 a	4.30 ±0.12 ab	2.20 ±0.20 a
	Valoya 192 W	2.98 ±0.06 a	2.61 ±0.05 ab	0.07 ±0.002 c	5.77 ±0.02 a	4.73 ±0.23 a	2.44 ±0.18 a
Harvest		**	**	**	**	**	NS
	Early	2.76 ±0.04 b	2.50 ±0.02 b	0.09 ±0.002 a	5.72 ±0.02 b	4.26 ±0.12 b	2.31 ±0.23 a
	Mid	2.79 ±0.03 b	2.47 ±0.03 b	0.09 ±0.002 a	5.74 ±0.01 b	4.15 ±0.12 b	2.28 ±0.17 a
	Late	3.16 ±0.04 a	2.80 ±0.04 a	0.08 ±0.002 b	5.82 ±0.02 a	4.93 ±0.18 a	2.28 ±0.18 a
Storage		**	**	**	**	NS	NS
	At Harvest	3.15±0.04 a	2.73±0.04 a	0.08±0.002 b	5.86±0.02 a	4.32±0.18 a	2.44±0.23 a
	2 Week	2.85±0.04 b	2.63 ±0.03 b	0.09±0.002 a	5.74±0.01 b	4.60±0.14 a	2.24±0.16 a
	4 Week	2.72±0.03 c	2.41 ±0.03 c	0.09±0.001 a	5.69±0.01 c	4.42±0.13 a	2.18±0.18 a

** Significiantly Difference

3.3.2.1 Dry Matter

The dry matter content of both interlighting Philips and Valoya was significantly ($p<0.05$) higher than Control. Furthermore, there was no significant difference in percentage of dry matter content between Philips and Valoya. Moreover, the dry matter content between time of harvest was significantly different ($p<0.05$). Late harvested cucumbers had higher dry matter content than the early and mid harvested cucumbers (Table 3). There were also significant differences in dry matter content during storage. The freshly harvested cucumbers content higher dry matter than cucumber stored for two and four weeks. The four week stored cucumbers contain least dry matter (Figure 11).

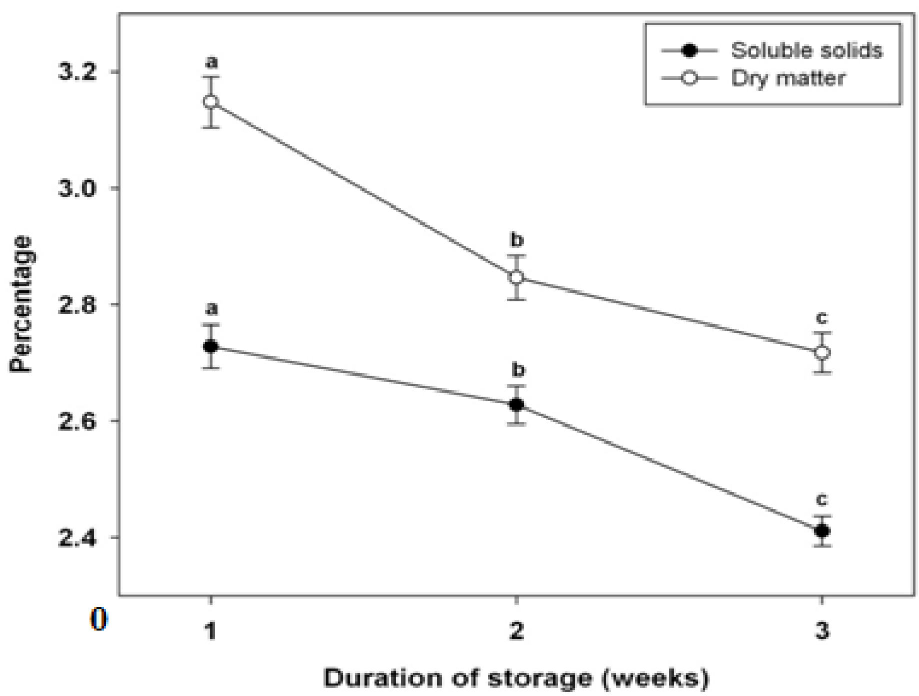

Figure 11. Effect of duration of storage on soluble solid and dry matter contain of cucumber at initial stage (1), 2 week after harvest (2) and 4 weeks after harvest (3). Error bar indicate the standard error of mean and significant differences between duration of storage is denoted by different letters (P=0.05)

3.3.2.2 Soluble Solids

Significant difference ($p<0.05$) of soluble solids were observed between different treatment and harvest. Philips gave significantly higher soluble solids than control and Valoya lighting. There was no significant difference between Control and Valoya 144W. In case of harvest, late harvest had significantly ($p<0.05$) higher soluble solids than early and mid harvest. There were no differences in soluble solids content in early and mid harvested cucumber (Table 3). There was a significant decrease in soluble solids content during storage. It was higher at the initial stage but decreased during storage (Table 3). The highest soluble solids content were observed for Valoya 192W at the late harvest (Figure 12).

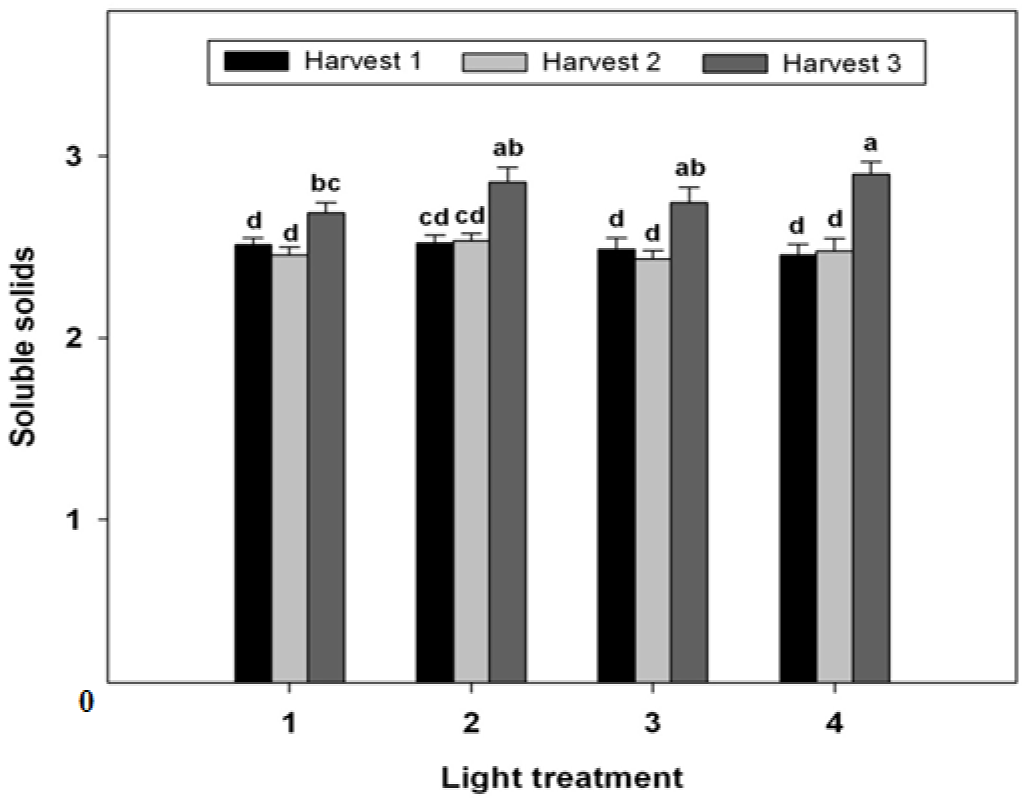

Figure 12. Effect of intercanopy lighting Control (1), Philips (2), Valoya 144W (3) and Valoya 192W (4) and harvest stages early (1), mid (2) and late harvest (3) on Soluble solids (%) contain in cucumber. Error bar indicate the standard error of mean and significant differences between treatments is denoted by different letters (P=0.05)

3.3.2.3 Titrable Acid

The titrable acid in cucumbers was significantly ($p<0.05$) higher in Philips lighting compared to Control and Valoya. Moreover, titrable acid in Valoya 144W had no significant difference with Valoya 192W. There was significant difference ($p<0.05$) in titrable acid between the different harvest. The late harvest had less titrable acid than early and mid harvest. There were no significant differences between early and mid harvest (Table 3). There was increase in titrable acid during storage. It was lower at initial stage but increased after two and four week of storage (Figure 13).

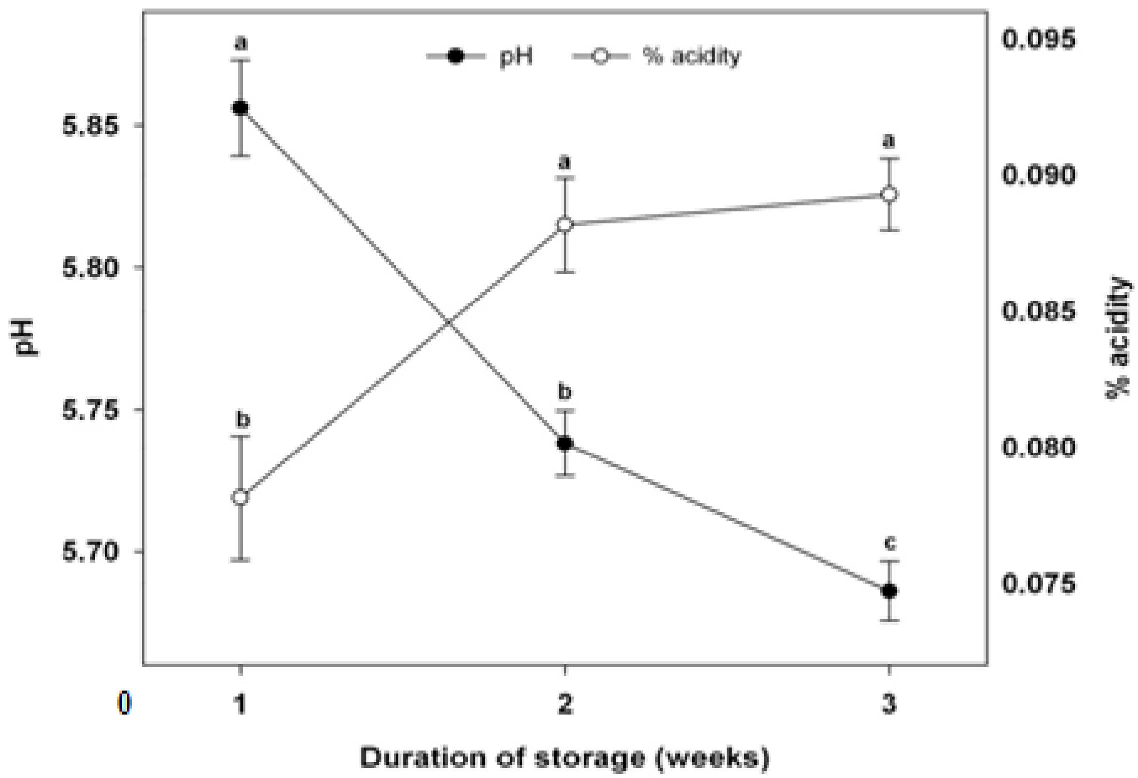

Figure 13. Effect of storage on pH and Titratable acids contain of cucumber at initial stage (1), 2 week after harvest (2) and 4 weeks after harvest (3). Error bar indicate the standard error of mean and significant differences between treatments is denoted by different letters (P=0.05).

3.3.2.4 pH

In the experiment, pH content of Control was significantly ($p<0.05$) lower compared to cucumbers grown with interlighting, and there was no significant difference in pH between Philips and Valoya (Figure 14A). Along with this, the pH content of late harvest was also significantly ($p<0.05$) higher compared to the pH value of early and mid harvest (Figure 14B). There was also significant different in pH content during storage. The cucumbers of initial stage contain higher pH than stored for two and four weeks (Figure 13).

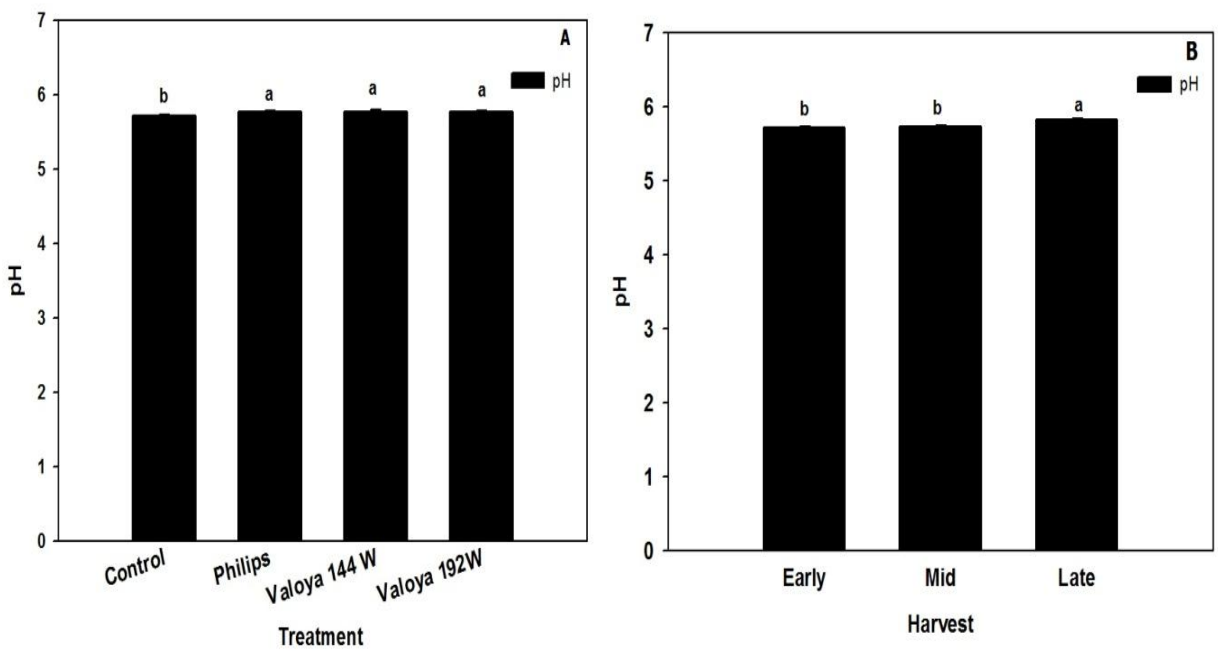

Figure 14. Effect of different intercanopy lighting (A) and harvest period (B) on pH content in cucumber. Error bar indicate the standard error of mean and significant differences between treatments is denoted by different letters (P=0.05)

3.3.2.5 Vitamin C

The Vitamin C content of Valoya 192W was significantly ($p<0.05$) higher than Control. Furthermore, there was no significant difference in Vitamin C content between Philips and Valoya lighting (Figure 15A). Control had the lowest Vitamin C content between all four treatments. Moreover, the vitamin C content between the harvest period was significantly different ($p<0.05$). Late harvest had higher vitamin C. There were no significant differences between early and mid harvest (Figure 15B).

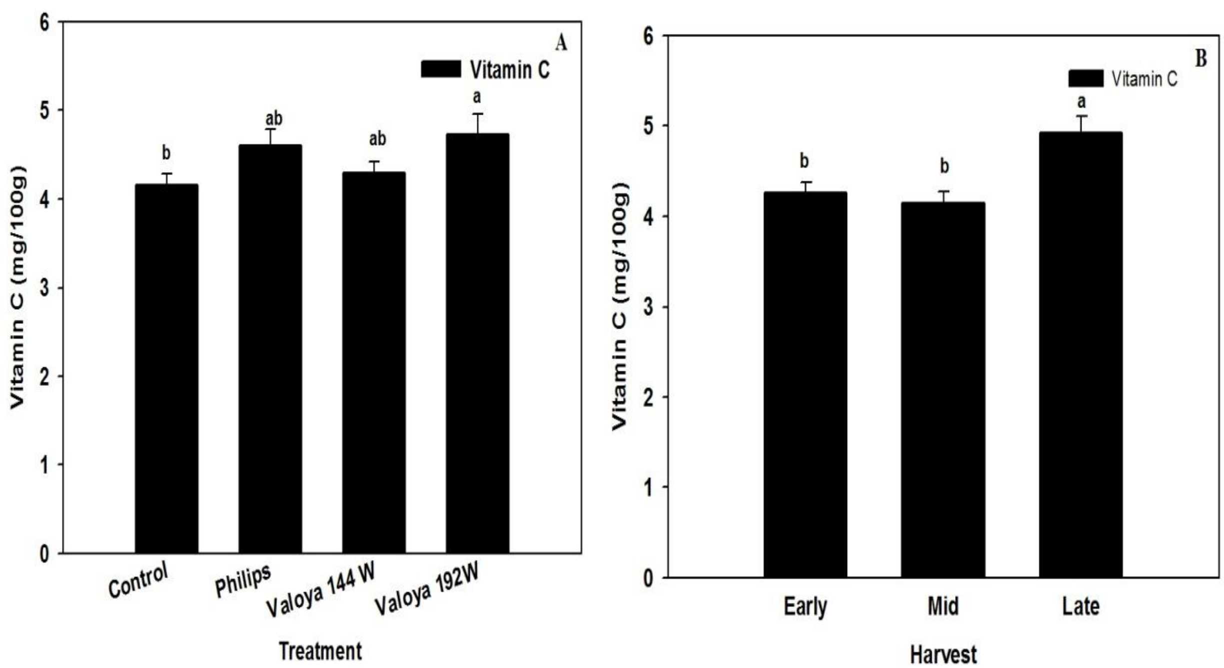

Figure 15. Effect of different intercanopy lighting (A) and harvest period (B) on Vitamin C content in cucumber. Error bar indicate the standard error of mean and significant differences between treatments is denoted by different letters (P=0.05)

3.3.2.6 Chlorophyll

There were no significant differences in the chlorophyll content between the treatment and within the harvesting period. The light sources did not influence the chlorophyll content of cucumber (Table 3). There were also no any significant differences in the chlorophyll content due to storage.

3.3.2.7 Water Loss

The loss of water from cucumber during storage was recorded once a week. There were no significant differences in the water loss of cucumbers between different treatments. There was a significant difference in water loss due to time of harvest. The mid harvest had higher amount of water loss and the late harvest had least water loss (Figure 16).There was also significant differences in water loss due to company sealed plastic and ordinary plastic. Water loss was higher in company sealed plastic (Figure 17).

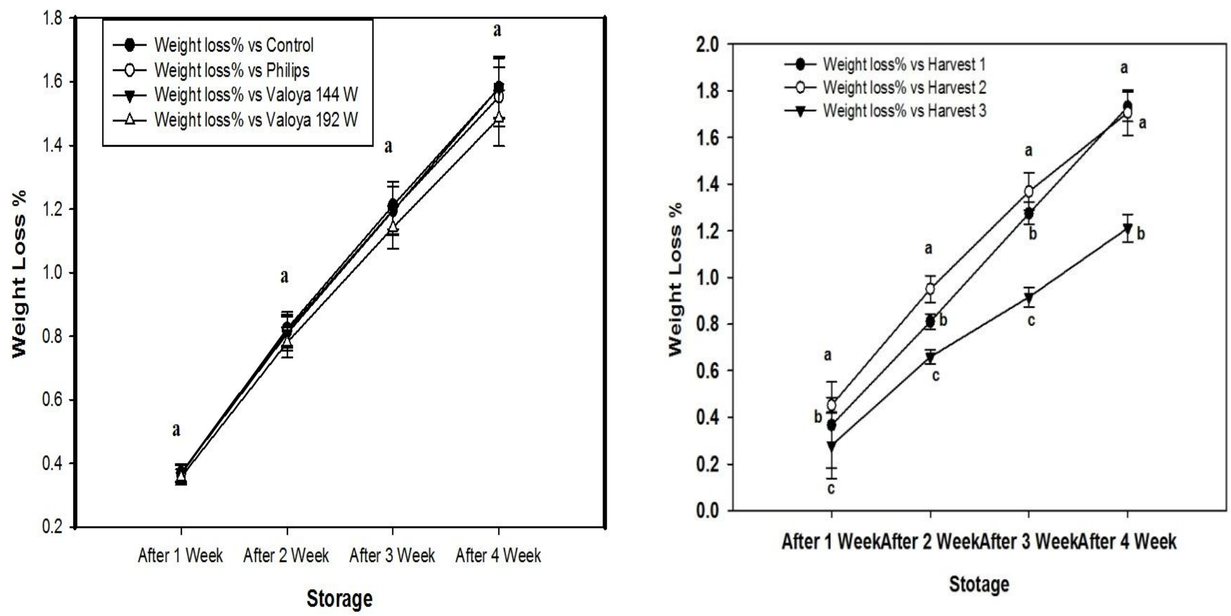

Figure 16. Effect of intercanopy lighting at different stage of storage on weight loss % of cucumber. Error bar indicate the standard error of mean and significant differences between treatments is denoted by different letters (P=0.05)

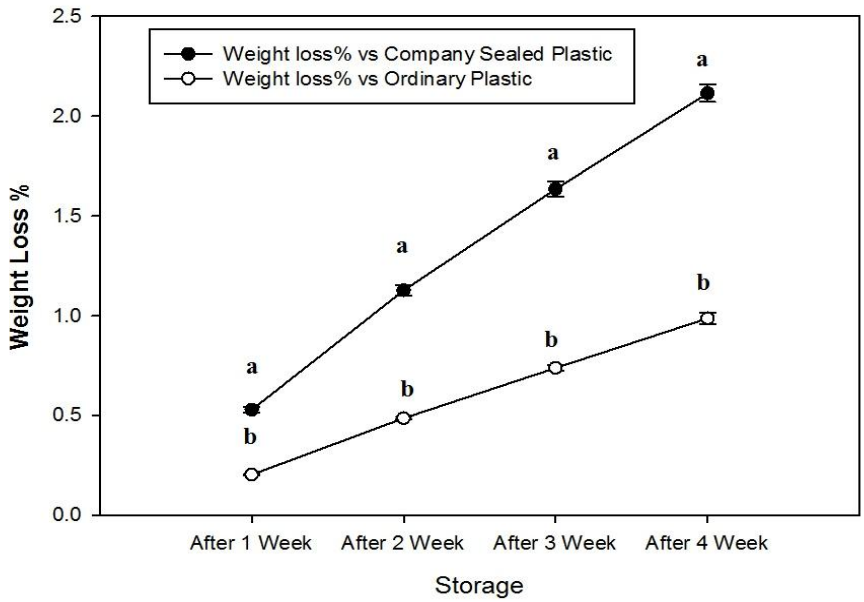

Figure 17. Effect of company sealed plastic and ordinary plastic at different storage stages on weight loss% of cucumber. Error bar indicate the standard error of mean and different letters corresponding to specific storage period indicate significant differences at P=0.05

4. DISCUSSION

4.1 Cucumber Production

In the present study, interlighting with different LEDs light proved to be efficient lighting method since; it increased the productivity of cucumber per m^2 in term of weight as well as fruit number. Although the harvest was started of all the treatments from same day, there was increase in fruit number and weight with interlighting from the beginning till end of harvest. Thus it shows that it is possible to enhance the cucumber productivity by distribution of irradiation more evenly throughout the canopy. Pervious report has shown that intercanopy lighting had increase fruit yield of cucumber, tomato and sweet pepper upto 15 % (Gunnlaugsson & Adalsteinsson 2006; Hovi et al. 2004; Pettersen et al. 2010).

Increase in the yield of cucumber was probably due to increased irradiance and higher temperature within a canopy of intercanopy lighting (Marcelis 1993). In this experiment, more uniform distribution of irradiation is made over the canopy and irradiation is increased near the plants rows. Fruit production is accelerated through higher growth rate with greater number of fruit growing at same time due to increased irradiance (Marcelis 1993). The rate of development of individual fruit is accelerated by increased irradiance and higher air temperature and therefore increases the early yield which was observed in the experiment.

There was distinct variation in the yield of cucumber due to season with intercanopy lighting. It may be due to varying amount of natural light. Plants benefit more from interlighting in low natural light condition. A similar trend was reported earlier for cucumber (Hovi et al. 2004). The use of supplementary lighting in cucumber cultivation is only recommended in low light condition (Hao & Papadopoulos 1999). In winter environmental condition in greenhouses are easier to control due to lower outdoor temperature. Thus the growth condition are closer to optimum than in the summer and light inside the canopy can be used more effectively, which make interlighting more profitable in winter.

Photosynthetic capacity (P_{max}) of overhead lighted plants decreases significantly from the upper to the lower part of the canopy, whereas in intracanopy lighting plants this decrease was significantly reduced (Pettersen et al. 2010) . Thus distributing the light more evenly in the canopy can improve photosynthesis in the lower part and subsequently increase the canopy assimilation and it could enable higher yield.

Marcelis et al. 2006 stated that increment of 1% light in greenhouses results in increase of yield by 0.5 to 1%. But to contrast there was only 8%, 16% and 15% increament in yield with addition of 27%, 49% and 65% interlighting within a canopy respectively. However the light required per kg cucumber production was decrease with additional light of 27% and 49%. But additional 65% interlighting showed negative effect on light required per kg. Excess additional light may have negative effect on fruit production.

Morphology, physiology, photosynthesis efficacy and flowering capabilities of plants are affected by the different wavelengths of the light spectrum (Menard et al. 2006). Most wavelengths have been shown to have positive and negative aspects. Addition of red and blue light through intercanopy lighting has significant effect on plant biomass and photosynthesis. Cryptochromes and phototropins are specifically blue light sensitive, whereas phytochromes are more sensitive to red than to blue light.

4.2 Cucumber Quality

Fruit colour is an important quality factor in cucumber. High red/far red (R/FR) ratio and light intensity is related with high chlorophyll content in peel and shelf life of greenhouse grown cucumber (Klieber et al. 1993; Lin & Jolliffe 1994). Cucumbers grown under a high light intensity (Lin & Jolliffe 1994) and intercanopy lighting (Hovi-Pekkanen & Tahvonen 2008) have higher chlorophyll content with darker green coloring of fruits indicating a potential longer shelf life and post-harvest quality of the fruits. The higher amount of light, especially in the lower part of the canopy during intercanopy lighting was the reason for the improvement of post harvest quality of fruit. The R/FR ratio has also an effect on fruit colour, in addition to light intensity (Kasperbauer 1971). In the present study top lighting was done by HPS lamps which have high ratio of R/FR. The interlighting was done with addition of Red and Blue lights. The Philips LEDs contain 95% deep red and 5% blue light. The Valoya LEDs contain higher red light and had R/Fr ratio 2.7 Consequently, the R/FR ratio was probably increased in intercanopy, especially near the developing fruits. But in contrast to other finding there were no significance differences in the chlorophyll content in intercanopy lighting to toplighting.

Interlighting had a significant effect on the dry matter concentration. Increased dry matter concentration in cucumber is known to be due to higher irradiation and decreased temperature (Marcelis 1993). In the present study, due to interlighting there was equal distribution of irradiation throughout the canopy which results in increase in the dry matter concentration in fruit.

Vitamin C is the most important vitamin in fruits and vegetables for human nutrition. Light and average temperature influences the chemical composition of horticultural crops (Klein &Perry 1982). Genotypic differences, preharvest climatic conditions and cultural practices, maturity and harvesting methods and postharvest handling procedures influences the content of vitamin C in fruits and vegetables. Higher amount of Vitamin C is obtained in fruit exposed to maximum sunlight. Lower AA content on plant tissues is observed on plants grown under lower the light intensity. In our result with only top lighting cucumber should the least Vitamin C content whereas the cucumber grown under excess additional light showed significantly higher vitamin C. Due to higher irradiation within a canopy in intercanopy lighting there was significant higher concentration of Vitamin C.

There were significant differences between the treatment in soluble solids content and titrable acid. It might be due to variation in light intensity between the treatments. pH content is almost reverses of acid content. There was significantly lower pH content in control than interlighting.

There were significant differences in the quality of cucumber due to time of harvest. The late harvest content higher dry matter, soluble solid, titrable acid and vitamin C than early and mid harvest. It might be due to varying amount of natural light during growing period. The average daily light integral during early harvest was 8.62 mol/m^2 and during mid harvest it was 19.11 mol/m^2 whereas during late harvest it was 30.4 mol/m^2.

Storing cucumbers for long period had significant increase the titrable acidity content as supported by other research (Artes et al. 1999). Storing cucumbers for long period has significant decreased the pH content and soluble solid which contrast the result found by other research (Artes et al. 1999). Decrease in soluble solid and pH might be due to deterioration of fruit characteristics and change in organic acids content during storage. There were no significant differences in Vitamin C and chlorophyll content during cucumber storage as supported by other research (Lin & Jolliffe 1994).

There were no significant differences in water loss of cucumbers between the treatments. Whereas water loss due to company sealed plastic was higher than the ordinary plastic. This might be due to the multiple layer of ordinary plastic. The cucumbers wrapped by ordinary plastic were wrapped by mutiple layer whereas company sealed plastic was single layer.

5. CONCLUSION

Interlighting with LEDs lamps had positive effect on production and quality of cucumber in greenhouse production. Improving the light condition within the canopy in high and densely cultivated crops seems to have potential for increasing yield and improving fruit quality. There was an increase in the yield due to interlighting from start of the harvest to the end without negative effect on fruit quality. Interlighting significantly increases the amount of light in the lower part of canopy. The results indicate that interlighting is a suitable method for greenhouse cucumber cultivation especially in lower natural light condition. There was less effect on yield increment due to interlighting during summer. So, during higher natural light condition when the amount of natural light is enough for photosynthesis in upper part of canopy the interlighting LEDs lamps can be used alone to reduce electricity consumption. However, further studies can be performed on effect of additional interlighting without top lighting.

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