SPECTRAL MANAGEMENT FOR IMPROVING PHOTOSYNTHETIC EFFICIENCY IN POLYHOUSE CULTIVATION OF VEGETABLES

By

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(2014-11-177)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"SPECTRAL MANAGEMENT FOR IMPROVING PHOTOSYNTHETIC EFFICIENCY IN POLYHOUSE CULTIVATION OF VEGETABLES"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Anjana

Anjana J Madhu

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ABBREVIATIONS

Chl-A : Chlorophyll-A

Chl-B : Chlorophyll-B

FLW : Flowering

IAA : Indole Acetic Acid

MTY : Maturity

PAR : Photosynthetically Active Radiation

PPFD : Photosynthetic Photon Flux Density

SLA : Specific Leaf Area

UV-A : Ultra Violet-A

UV-B : Ultra Violet-B

INTRODUCTION

1. INTRODUCTION

Light is an indispensible factor for the survival of photoautotrophic higher plants. The light environment varies incessantly, with both spatial and temporal fluctuations. The plants being sessile organisms they cannot choose their surroundings hence they modify their growth and development inorder to enhance their utilization of ambient light. Light as a signal regulates all aspects of development viz., from seed germination and seedling establishment, to mature plant architecture and the onset of reproduction. Plants monitor the quantity, spectral quality, periodicity and direction of light, and use this information to modulate all aspects of development. Such developmental plasticity is conferred by specialized families of information-transducing photoreceptors. Plants monitor changes in the ambient light environment using sensory photoreceptor families: the phototropins and cryptochromes, which absorb UV-A or blue light; the phytochromes, which sense red/far-red light; and the UV-B photoreceptors.

Productivity of all crops in the greenhouse was affected by light which in turn a limiting factor of photosynthetic productivity. Spectral quality can have dramatic effects on plant growth and development (Sims and Pearcy, 1992). The colored shade nets have been developed during the past decade to filter selected regions of the spectrum of sunlight, concomitantly with inducing light scattering. They are designed specifically to modify the incident radiation (spectrum, scattering and thermal components). Depending on the pigmentation of the plastic threads and the knitting design, these nets provide varying mixtures of natural, unmodified light, together with spectrally modified scattered light.

The photoselective nets represent a novel agro-technological concept. They offers combining the physical protection along with the differential filtration of the solar radiation. Thus they specifically promotes desired physiological responses that are light regulated. The shade nets are used to reduce the amount of sunlight reaching a crop or to shorten the photoperiod. Nettings, regardless of color, reduce radiation reaching crops underneath. The combination of light-scattering spectral manipulation can modify desirable plant growth characteristics. Tailoring illumination spectra enables one to control plant growth, development, and nutritional quality.

Vegetables are prominent as a part of healthy diet globally and play vital role in overcoming micronutrient deficiencies and providing opportunities of higher farm income. Vegetable cultivation absorbs a considerable amount of labour. India's share of the world vegetable market is around 14%. It produces 133.5 million tones of vegetables from an area of 7.9 million hectares. According to Ministry of Agriculture and Farmers Welfare (MoA&FW) statistics, the production of vegetables has increased from 58,532 thousand tonnes to 168,300 thousand tonnes during the period 1991-92 to 2014-15. In spite of all these achievements, India is very low against WHO standards (180 g/day/capita against 300 g/day capita recommended by FAO) in per capita consumption of vegetables .

Shade net can be commercially exploited for successful year round cultivation of high value thermo sensitive vegetables. Mainly 12 major varieties of vegetables and 6 minor varieties of fruits are cultivated in Kerala. The major vegetables cultivated in protected cultivation include salad cucumber, tomato, capsicum, leafy vegetables and yardlong bean. Among the major vegetables tomato, capsicum and cucumber are the high return giving and most extensively cultivated vegetables under green houses (Chandra *et al.*, 2000).

There are a number of different types of shade cloth available. Black and green are the most common colors. However, additional cooling is offered by white or aluminized shade cloth. Other colors such as red filters different wavelengths of light which may benefit specific crop. Shade cloths are also available in various percent shading. A percent shade between 20 % and 40% with ~30% being the most common recommendation for vegetables. Very little work has been done with shade cloth for field production of vegetables to analyse the physiological response of crops to shade nets.

Though poly house cultivation gives promising yield for vegetable production, the high variability in crops suggest that physiological aspects involved in the photo response of crops under photo selective nets should be well studied. Hence the present study was proposed with the following objective.

- To study the morphological and physiological responses of vegetables, viz. tomato, salad cucumber, capsicum and yard long bean exposed to spectral modification through different colored shade nets.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Sun is the sole source of energy which drives the life processes. Plants convert the solar energy to chemical form not only to nourish the dependent species but also for their nourishment. Virtually every aspect of plant life processes, from germination, reproduction and senescence, is affected by light (Smith, 2000). Sunlight consists of about 4% ultra violet radiation, 52% of infrared radiation and 44% of visible light.

Vegetables are abundant and fairly cheaper source of vitamins and minerals. Adding vegetables to diet gives taste, palatability & increases appetite. It also supply fiber for digestion and soothing constipation. They also provide valuable roughages which help in movement of food in intestine and also aids in neutralizing the acids produced during digestion of pretentious and fatty foods . Increasing population, coupled with global competition, other factors and cost of production made traditional method of vegetable production a overwhelming burden to farmers. To attain maximum productivity per unit area with assured quality is the need of the hour. Nikolaos and Constantinos, (2008) reported that protected cultivation helps in maintaining a favourable environment to plants and thus makes it possible to obtain maximum productivity.

The use of photoselective shade-netting is a looming approach in protected cultivation. The photoselective nets comprises of "colored-color nets" (Red, Yellow, Green, Blue) as well as "neutral-color nets" (Pearl, White and Grey). They absorbs spectral bands shorter, or longer than the visible range. Spectral manipulation can be achieved in a cheaper manner with photoselective nets as compared to supplemental lighting. Rajapakse and Shahak, (2007) found that the spectral manipulation is aimed at specifically promoting photomorphogenetic-physiological responses, while scattering improves light penetration into the inner canopy . There are numerous photoreceptors in plants, including phytochromes, cryptochromes and phototropins. They helps the higher plants respond to light quantity, quality, direction, and periodicity (Folta and Maruhnich, 2007). Perez *et al.* (2006) reported that the photoselective shade nets can provide environmental modification (humidity, shade, temperature), physical protection (birds, hail, insects, excessive radiation), and also affect the light quality by increasing the relative proportion of diffuse (scattered) light as well as absorb various spectral bands.

Photoselective netting was primarily tested in ornamental crops. Traditionally the ornamental crops were cultured under black shade nets. Shahak *et al.* (2004) found that black shade nets differ from color nets as they have no effect on light quality, they merely reduce light intensity. The red and yellow nets were found to specifically stimulate vegetative growth rate and vigour of foliage and cut-flower crops compared with black nets of the same shading factor (measured for PAR). The blue net caused dwarfing and the grey net specifically enhanced branching and bushiness, and also reduced leaf size and variegation (Oren-Shamir *et al.*, 2000 and Priel, 2001). The blue, yellow and red nets enriches/reduces the relative content of blue, yellow and red spectral bands of the transmitted light which results in specific effects. These effects are similar with the effects reported for photoselective films and artificial illumination (Rajapakse *et al.*, 1999; Kim *et al.*, 2004; Rajapakse and Shahak, 2007). The grey net has its distinct absorption in the IR range which might relate to the effects produced by the net.

2.1 WEATHER PARAMETERS

2.1.1 Photosynthetically Active Radiation (PAR)

Photosynthetically Active Radiation (PAR) is the light wavelength range that is best fit for photosynthesis to occur. Photosynthesis is a process that requires light energy and optimally occurs in the 400 to 700 nanometer (nm) range. The level of photosynthetically active radiation that an area receives is important. This is because different plants respond to different wavelengths of PAR . The amount of PAR inside the shade-house is one of the most significant parameters related to protected cultivations at any time of the year.

The black net treatments, which reduced photosynthetically active radiation (PAR) the most (47% and 54%), were the main effectors of vegetative growth-increasing internode, leaf and shoot lengths, and leaf widths compared with the no-net control. The other colored nets (gray, red, white) reduced PAR by 29% to 41% and had no effect on internode and shoot lengths had minor effects, on other vegetative parameters (increased leaf length- gray 50%, increased leaf width- all three at 50% and also gray at 35%) (Stamps, 2009) .

Orchid Research from Brazil on a number of Phalaenopsis cultivars and hybrids showed a fairly consistent pattern of enhanced foliage biomass production (fresh and dry weights) under blue netting despite reduced transmission of PAR compared with black and red nets (Leite *et al.*, 2008).

2.1.2 Global Radiation

Protected environment promotes the production of vegetables in off-season periods, allowing supply regulation and enhanced fruit quality. Protected cultivation also offers increased growth of crops with quality, yield and sanity due to excessive solar radiation attenuation and consequent decrease in internal temperature (Ilic *et al.*, 2012). Excessive internal warming and/or photosynthetically active radiation decrease may make weather changes promoted by protected environments adverse. A correct choice for protected environment cover material is a crucial issue for plant development since the solar radiation has decisive importance in all plant vital processes such as photosynthesis, respiration, photoperiod, tissue growth and flowering (Sapounas *et al.*, 2010).

The reflective shading nets offers additional effects. They are metalized with aluminium and endorse improved energy conservation and solar radiation reflection, resulting in lower summer temperatures and higher winter ones. These nets promote solar radiation diffusion, which increases energy efficiency captured by canopies and improve photosynthetic efficiency (Leite *et al.*, 2008 and Kittas, *et al.*, 2012).

2.1.3 Light Intensity

The light intensity plays an important role in process photosynthesis of specific environmental condition. The light intensity was found more in white shade net as well as in open field as compared to the green shade net house (Gupta *et al.*, 2015). Even if the accessory pigments are abundant plants grown under light-limited conditions have a lower quantum yield for CO_2 fixation (Hogewoning, 2010).

2.1.4 Temperature

The temperature of outside condition was more i.e. 4°C to 5°C than shade net house. Due to trapping of short wave radiation in shade net house under partially closed condition's the temperature in shade net house is less than outside condition and this is one of reason of getting maximum yield in shade net house (Gupta *et al.*, 2015).

Kittas *et al.* (2009) studied the effect of different shading screens on tomato crop microclimate, production and quality and observed similar values of air temperature and vapour pressure deficit under the shading nets and outside.

2.1.5 Relative Humidity

The relative humidity should be within the comfortable zone of plant to achieve satisfactory result. The high humidity reduces transpiration thus reducing water loss. Nimje *et al.* (2007) found that high humidity was needed for better yield due to their beneficial effect on flowering and fruiting also on parthanocarpic development of fruits. He also found that fruit yield of sweet pepper inside poly house was 2.27 times more than that of open cultivation.

Relative humidities under netting are often higher than outside as a result of trapping of water vapour being transpired by the crop and abridged mixing with drier air outside the netted area (Elad *et al.*, 2007), even though temperatures under the netting are higher than outside (Stamps, 1994).

2.2 PHENOLOGICAL OBSERVATIONS

In a study conducted in southern Italy using shade nets with shading factors from 20.4% to 26.9%. The numbers of flowers and inflorescences per shoot were lower in the net (viz., white, red, blue, and gray netting) than no-net treatments (Basile *et al.*, 2008). Earlier flowering of nine of ten *Phalaenopsis* cultivars and hybrids was recorded in red netting, in comparison with black and blue netting (all nominal 30% shade) (*Leite et al.*, 2008).

Elad *et al.* (2007) reported increased yields of two *Capsicum annuum* cultivars when grown under black (nominal 25% and 40% shade), blue (40% shade), blue–silver (40% shade), silver (40%), and white (25%) shade nets as compared with the no-net control. However, there were no differences in total yield when comparing black and white netting (both 25% nominal shade factor) and the only yield increase comparing 40% shade factor nets occurred for one cultivar (Louisiana) in which yields under silver netting were higher than under black or blue netting. Data from another experiment reported in that same paper showed that shade factors change over time and actual shade factors may differ considerably from nominal values. Shahak (2008) reported that 16% to 32% increase in production was observed in three cultivars of bell pepper cultivated under pearl and red compared with black netting.

2.3 BIOMETRIC OBSERVATIONS

The changes in the numbers of plant organs occurring through the initiation of new leaves, stems and fruit, abortion of leaves and fruit, and physiological development of numbers from one age class to the next decides the growth of plants (Jones *et al*., 1989).

Specific leaf area (SLA) values vary amongst species and depends on the quality of light .In environments with low light intensity plants increases the SLA and reduce the thickness of the leaf blade. Under shading conditions such alterations confer functional advantages (Buisson and Lee, 1993). Thus it is important to know how the anatomical and ultra-structural leaf changes are related with biomass production.

Stem elongation is known to be inhibited by blue light. Cosgrove and Green (1981) studied the mechanism of blue light mediated hypocotyl-elongation inhibition in cucumber (*Cucumis sativus* L.) and sunflower (*Helianthus annuus* L.) seedlings by measuring changes in turgor.

Andhale *et al*. (2014) confirmed that growth attributes viz., leaf area and dry matter/plant and important yield contributing characters viz., number of fruits/plant showed a significant increase of capsicum plants grown under green + white shade net colour compared to other shade net colours. Increase in attributes significantly increased the capsicum yield(113.19 t/ha) thus suggesting suitability of green + white shade net colour for capsicum cultivation.

Santana *et al.* (2012) reported that significant losses of commercial fruit by solar blight was observed in open crops. According to the authors, photo-selective (red and blue) shading net houses reached greater yield and higher fruit quality for sweet pepper hybrid compared with those obtained from open field.

Previous research has shown that photo-selective nets have a positive effect on fruit yield (in relation to full sun conditions) in some varieties of *Vaccinium corymbosum* L., depending on the colour and shade percentage used (Lobos *et al.*, 2012). In bell pepper cultivars grown in the Besor (semi-arid) region of Israel under 35% shading, the red, yellow, and pearl nets were found to markedly increase the productivity and improve the fruit quality (both pre- and postharvest) compared with the black nets commonly used (Fallik *et al.*, 2009). Growing fruit trees in stressed environments (high irradiances and temperatures) could reduce their photosynthetic rate, carbohydrate accumulation and fruit yields (Darnell and Birkhold, 1996).

2.4 ANATOMICAL FEATURES OF LEAF AND STEM

Plants adapt to different environmental conditions by altering the morphology and physiological functions through their reactions to the changes in spectrum of electromagnetic radiation to which they were exposed (Kasperbbauer and Hamilton, 1984). These alterations are pigment mediated such as phytochromes, which have absorption peaks in the red and blue/ultraviolet regions of the spectrum (Li *et al.*, 2000). These photoreceptors induce photomorphogenetic responses either *in vivo* or *in vitro* due to its ability to detect variations in light composition (Kim *et al.*, 2004) they also influence growth and development (Li *et al.*, 2000), morphology (Stuefer and Huber, 1998), leaf and stem anatomy (Schuerger *et al.*, 1997), distribution of photosynthetic products (Brown *et al*., 1995), photosynthetic efficiency (Kasperbbauer and Peaslee, 1973) and chemical composition (Macedo *et al.*, 2004).

Hogewoning, (2010) reported that red light alone caused physiological disorders associated with leaf development which was eliminated by adding a small amount of blue light.

2.5 PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS

Under light-saturated conditions, photosynthetic capacity can be affected by a variety of leaf characteristics. Oguchi *et al*. (2003) stated that photosynthetic rate decreases due to the physical restriction in intracellular space which limits the area for chloroplasts.

Legarrea *et al*. (2010) and Jang *et al*. (2014) stated that higher PAR resulted in higher SPAD values and higher chlorophyll concentration. The most important photoreceptors in photosynthesis are the chlorophylls. Two kinds of chlorophylls viz., Chl a and Chl b that vary in their abundance and absorption spectra are present in higher plants. Kriedemann, (2010) reported that the Chlorophyll a/b ratios in higher plants range from 3.3 to 4.2 in sun adapted species and as low as 2.2 for shade-adapted species. Carotenoids are known as accessory pigments also contribute to photosynthetic energy transduction. They are present in higher plants at one third the abundance of chlorophylls and absorb mainly in the blue and green parts of the PAR spectrum.

According to Pinto *et al*., 2007, shading plants receive more diffused light enriched in far-red (FR) light radiation which increases Chl *b* in relation with Chl *a*, enabling a more efficient photosynthetic apparatus under low-intensity light conditions.

Schwartz and Zeiger (1984) studied stomatal opening of two plant species under white light, blue, red light and darkness. He reported that stomatal apertures were higher under blue light than white and red light at all photon fluxes in both species. This response is in line with other studies of Travis and Mansfield (1981); Pamadasa (1982); Schwartz and Zeiger (1984). They found that activity of two photoreceptors correlates with the stomatal opening. First, a PAR-dependent receptor linked to the guard-cell chloroplast and 18 amino acid, second one specific to the blue-light-dependent system. They also observed that the low photon fluxes saturates the blue-light photo-system. Under light saturating conditions the rate of photosynthesis can be limited by intracellular CO2 concentration controlled by stomatal conductance and mesophyll conductance (Hogewoning, 2010 and Zeiger, 1990).

Lopez *et al*. (2007) who showed that the lycopene content of tomatoes grown under red and pearl frame nets were 51 and 37 μg g−1, respectively. The tomatoes grown in plastic houses integrated with red colour nets were detected with highest concentration of lycopene (64.9 μg g−1 f.w.), while lowest levels of lycopene was found in tomatoes grown in fields covered with pearl nets (46.7 μg g−1f.w) (Illic, 2015).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study entitled “Spectral management for improving photosynthetic efficiency in polyhouse cultivation of vegetables” was conducted with the main objective to study the morphological and physiological responses of vegetables, viz. tomato, salad cucumber, capsicum and yardlong bean exposed to spectral modification through different colored shade nets. The experiment was conducted at Pothencode and at the College of Agriculture, Vellayani during 2015 - 16. The details of materials used and methods adopted are presented in this chapter.

3.1 GENERAL DETAILS

3.1.1 Survey

A survey was conducted in 20 polyhouse units in Thiruvananthapuram district to know the adoption of shade nets by the farmers practicing polyhouse cultivation and for experiment.

3.1.2 Location

The field experiment was laid out at Pothencode in the field of Shri. Vishnu Nirmal. The geographical co-ordinates of the location of Pothencode are 8 37’ 38.1” N latitude and 76'54’ 01.3” E longitude at an altitude of 11m above mean sea level.

3.1.3 Season

The crops were raised in the poly house from November 2015 to March 2016.

3.2 EXPERIMENTAL DETAILS

The experimental unit (polyhouse of dimension 500m^2) was divided into five parts on an east-west direction roofed with photoselective and photo neutral shade nets of four different optical properties and one part without any shade net. Four different vegetables, viz. salad cucumber, yardlong bean, capsicum and tomato were grown under these shade nets.

3.2.1 Layout of the Experiment

The experiment was laid out in CRD with five treatments and four replications. A survey was conducted in 20 polyhouse units in Thiruvananthapuram district to know the adoption of shade nets by the farmers practicing polyhouse cultivation and for our experiment. The experimental unit (polyhouse of dimension $500m^2$) was divided into five parts on an east-west direction roofed with photo – selective (green and red) and neutral shade nets (white and black) of different optical properties and one part without any shade net (plate 1 and plate 2). The light interception by nets were analysed using spectro radiometer at University of Agricultural Science, Bangalore (plate 3) Four different crops, viz. salad cucumber, yardlong bean, capsicum and tomato were grown under these shade nets. Raising of crops and management were made as per the farmer's practices already following.

3.3 OBSERVATIONS RECORDED

3.3.1 Weather parameters

All the weather parameters viz. Photosynthetically Active Radiation, global radiation, light intensity, temperature, humidity were observed under both conditions from 9.00 am to 12.00 pm which is considered as the biologically active photoperiod for inducing the physiological process.

3.3.1.1 Photosynthetically Active Radiation (PAR)

Photosynthetically Active Radiation (PAR) was observed using the instrument light meter with quantum sensor Model Licor -250. The intensity of PAR is referred as PPFD (Photosynthetic Photon Flux Density) which is expressed in unit $\mu mol m^{-2} s^{-1}$.

Plate 1. View of experimental plot

Plate 2. Veiw of experimental unit with photoselective and photo neutral netting

Plate 3. Analysing interception of light by shade nets with spectro radiometer

3.3.1.2 Global Radiation

The global radiation was measured by using radiometer, which is expressed in Wm^{-2}.

3.3.1.3 Light Intensity

Light intensity inside the poly house was measured using photometer and expressed in lux.

3.3.1.4 Temperature

Maximum temperature inside the poly house was recorded using a sensor in a thermohygrometer. It was expressed as ^{0}C.

3.3.1.5 Relative Humidity

Relative humidity inside the poly house was observed throughout the crop period using a sensor in a thermohygrometer. It was expressed in percentage.

3.3.2 Phenological observations

3.3.2.1 Pollen sterility

Pollen sterility of yardlong bean, capsicum and tomato flowers were analysed using acetocarmine dye method and expressed in percentage. Fresh pollen was collected in the field from recently opened anther and brought into the laboratory. The test consist to the addition of dye on pollen and observation under photonic microscope (Leica). The pollen sterility was scored according to staining level (pollen with bold red colour as viable and colourless as sterile). The percentage of pollen sterility was determined as the ratio of the number of sterile grains to the total grains number.

3.3.2.2 Days to first Flowering

Number of days was counted from the date of sowing to the date when first flower opened and the values expressed as days to flowering.

3.3.2.3 Days to first Fruiting.

The number of days taken from sowing to first tender fruit stage was recorded and the values expressed as days to first fruiting.

3.3.2.4 Days of Fruiting to Maturity.

The number of days taken to mature the tender fruit was counted and expressed as days of fruiting to maturity.

3.3.3 Biometric observations

3.3.3.1 Number of leaves at first flowering

The number of leaves during first flowering was recorded and expressed as number.

3.3.3.2 Specific leaf area

From each plant, fully expanded third leaf (from main stem apex) was collected. Leaflets were separated, petioles were discarded and area was measured. Leaflets were dried at 80^0C for 2 days and the dry weight was taken. SLA was calculated using the formula.

$$SLA(cm^2 / g) = \frac{leaf\ area}{dry\ weight}$$

3.3.3.3 Internode Length

The length between nodes was measured in all the selected plants as internodal length and expressed in cm.

3.3.3.4 Setting percent

Number of fruits present per inflorescence after two weeks of flowering was recorded. Percentage fruit set was calculated from the no of flowers produced.

3.3.3.5 Root weight

The roots of plants were cut at the base level and washed free of adhering soil with low jet of water. The roots were then oven dried and dry weight was recorded.

3.3.3.6 Shoot Weight

Shoot weight was measured by weighing the above ground part of the plants in a weighing balance.

3.3.3.7 Root Shoot Ratio

Ratio of weights of dried roots and shoots of sample plants were calculated and mean value arrived.

3.3.3.8 Dry matter production

The sum of root and shoot dry weights were taken as the total dry matter production as g.

3.3.3.9 Yeild

Weight of all fruits harvested from selected plants was recorded and the total worked out and expressed in grams/plant.

3.3.3.10 Sex ratio in cucumber

The male flowers to female flowers was recorded since gynoecious parthenocarpic hybrid salad cucumber was used for cultivation.

3.3.4 Anatomical features of petiole, leaf and stem

Fresh petiole, leaf and stem were collected from selected plants. Hand sections of the petiole, leaf and stem were taken with a sharp blade. The sections were then stained with 1 % saffranine stain and viewed under microscope (35X) (leica) and photographed.

3.3.5 Physiological and biochemical parameters

3.3.5.1 Photosynthetic rate

The photosynthetic rate was measured during the period from 9am-11am at which the photosynthesis will be at its peak. Photosynthetic rate was measured by using photosynthetic system (CIRAS-3SW) at the Department of Plant Physiology and expressed in $\mu molm^{-2}s^{-1}$.

3.3.5.2 Pigment composition

Estimation of Chlorophyll and Carotenoids

Chlorophyll content of leaf samples were estimated as per the procedure described by Arnon (1949). A weighed quantity of leaf sample (0.5g) was taken from fully expanded third leaf and cut it into small bits. These bits were put in test tubes and incubated overnight at room temperature, after pouring 10 ml DMSO: 80% acetone mixture (1:1 v/v). The coloured solution was decanted into a measuring cylinder and made up to 25 ml with the DMSO-acetone mixture. The absorbance was measured at 663, 645, 480 and 510nm. The chlorophyll content was measured by substituting the absorbance values in the given formulae.

$$Chla = (12.7 \times A_{663} - 2.69 \times A_{645}) \times \frac{V}{1000} \times \frac{1}{fresh\,weight}$$

$$Chlb = (22.9 \times A_{645} - 4.68 \times A_{663}) \times \frac{V}{1000} \times \frac{1}{fresh\,weight}$$

$$TotalChl(a+b) = (8.02 \times A_{663} - 20.2 \times A_{645}) \times \frac{V}{1000} \times \frac{1}{fresh\,weight}$$

$$Carotenoid = \left(\frac{7.6 \times A_{480} - 1.49 \times A_{510} \times V}{w \times 1000} \right)$$

3.3.5.3 Stomatal charecteristics

Stomatal Conductance

Stomatal conductance was measured using the SAI-1 Porometer of company Delta T Devices and expressed as mmoles $m^{-2}s^{-1}$.

Stomatal Frequency and Stomatal Index

Stomatal count refers to the number of stomata per unit area of leaf. A thick mixture of thermocol and xylene was prepared and this was smeared on both the surfaces of leaves and allowed to dry. It was peeled gently after drying and the peel was observed under microscope and counted using a 40X objective and 10X eyepiece. The field of the microscope was measured using a stage micrometre and stomatal frequency per unit area was calculated.

$$Stomatal\ frequency = \frac{No\,of\ stomata}{Area\,of\ the\,microscopic\ field}$$

Stomatal index is the percentage which indicates the nuber of stomata present to the total number of epidermal cells, each stomata being counted as one cell. Stomatal index was calculated by using the following equation .

Stomatal Index, I = (No of stomata per unit area) / (No of stomata per unit area + No of epidermal cells per unit area)

3.3.5.4 Transpiration rate

Transpiration rate was measured using the SAI-1 Porometer of company Delta T Devices and expressed as mmoles $m^{-2}s^{-1}$.

3.3.5.5 Total soluble protein

The total soluble protein of leaf samples were estimated using simple protein dye binding assay of Bradford (1976) using bovine serum albumin (BSA) as the standard. One hundred milligram of CBB 250 was dissolved in 50 ml of 95% ethanol. To this 100 ml of 85% (w/v) orthophosphoric acid was added. The resulting solution was diluted to a final volume of 200 ml with distilled water. 0.1g of leaf samples were taken from third fully opened leaves and was ground to a thin paste and soluble protein was extracted with 10 ml of phosphate buffer (pH 7.8). The extract was centrifuged at 5000 rpm for 10 minutes. To the 20µl of the supernatant a known volume (5 ml) of diluted dye binding solution was added. The solution was mixed well and allowed to develop a blue colour for at least 5 min but no longer than 30 min and the absorbance was measured at 596 nm. The protein content was calculated using the BSA standard in the range of (10-100µg). The protein content was expressed as mg/g FW.

3.3.5.6 Phenol content

Quantification of phenols was done by Folin-Ciocalteau method (Mayr *et al.*, 1995). Phenol was estimated from 0.5g of leaf samples and reflexed in 10 ml 80%

methanol for 20 min. The tissue was ground thoroughly in a mortar with pestle and filtered through a double layered cheese cloth. The filtrate was subjected to centrifugation at 1000 rpm for 10 min. The supernatant was collected and made to a known volume using 80% methanol. 0.1 ml aliquot was drawn to a test tube and made up to 3 ml using 80% methanol. To this, 0.5 ml of Folin-Ciocalteau reagent and 2 ml 20% Na_2CO_3 were added. It was kept in a boiling water bath for 5 min till a white precipitate was formed and was then again centrifuged at 5000 rpm for 5 min. The absorbance of the clear supernatant was read at 650 nm against the blank. Standard curve was prepared using different concentrations of catechol and expressed in catechol equivalents as microgram per gram leaf tissue on fresh weight basis.

3.3.5.7 Crude fibre content

Crude fibre of pod was estimated by the acid- alkali treatment and expressed as percentage as per the procedure outlined by Sadasivam and Manickam (1996).

3.3.5.8 Crude protein content

Crude protein content of pod of sample plants were calculated by multiplying the nitrogen content of the plant by the factor 6.25 (Simpson *et al.*, 1965).

3.3.5.9 Carbohydrate

Total carbohydrate content was estimated by anthrone method (Hedge and Hofreiter, 1962). Leaf samples of 100 mg each were weighed out from all the selected plants and hydrolysed with 5 ml of 2.5 N hydrochloric acid (HCl) in a boiling water bath. The hydrolyzate was neutralized with solid sodium carbonate until the effervescence ceased. The volume was made up to 100 ml and centrifuged at 5000 rpm for 15 minutes. From the supernatant 0.5 ml aliquot was taken and made up to one ml by adding distilled water. To this 4 ml anthrone reagent was added and heated for eight minutes in a boiling water bath. This was cooled rapidly and the absorbance was measured at 630 nm in a spectrophotometer. Amount of carbohydrate present was calculated from standard graph prepared using glucose and expressed in terms of milligrams of glucose equivalent per gram of leaf tissue on fresh weight basis.

3.3.5.10 Bio assay of IAA

Bioassay of IAA was done with wheat coleoptiles. Coleoptiles of germinated wheat were taken and incubated in plant extract prepared as follows. 0.1 g sample was taken and then extracted using 80% ethanol and the supernatant was collected after centrifugation. 1ml of the extract was diluted to 10 ml. to this 0.5 cm long coleoptiles were incubated. Distilled water was taken as control. The quantity of IAA was calculated by plotting a standard curve of IAA.

3.3.5.11 Lycopene content of tomato

Lycopene content of the fruits was estimated at the full ripe stage by the following method of Srivastava and Kumar (1994).

Reagents

Acetone, petroleum ether (40-60 degree Celsius),anhydrous sodium sulphate and five percent sodium sulphate.

Procedure

Tomato fruits were crushed with the help of pestle and mortar and pulped it well to a smooth consistency in a blender. Five to ten grams of this pulp was weighed and the pulp was extracted repeatedly with acetone using pestle and mortar until the residue become colourless. The acetone extracts were pooled and transferred to a separating funnel containing about 20 ml petroleum ether and gently mixed. About

5% sodium sulphate solution washed and shaken the separating funnel gently. Volume of petroleum ether might be reduced during the process because of its evaporation and so 20 ml more of petroleum ether was added to the separating funnel for the clear separation of two layers. Most of the colour was noticed in the upper petroleum ether layer. The two phases were separated and the lower aqueous phase was re-extracted with additional 20 ml petroleum ether until the aqueous phase was coloureless. The petroleum ether extracts was pooled and washed once with little distilled water. The washed petroleum extracts containing carotenoids was poured into a brown bottle containing about ten gram anhydrous sodium sulphate and kept it aside for 30 minutes. The petroleum ether extracts was decanted into a 100ml volumetric flask through a funnel containing cotton wool. Sodium sulphate slurry was washed with petroleum ether until it was colourless and the washings were transferred to the volumetric flask. The volume was made up and absorbance was measured in a spectrophotometer at 503 nm using petroleum ether as blank.

$$\text{Lycopene(mg/100g)} = \frac{31.206 \times \text{Absorbance}}{\text{Weight of sample}}$$

3.3.5.12 Vitamin C content of tomato & capsicum

The ascorbic acid content in plants was estimated volumetrically by the method explained by Sadasivam and Manickam (2009). Working standard solution of 5ml containing 100µg/ml of ascorbic acid was pipetted out into a 100 ml conical flask. 4% oxalic acid was added to it and titrated against 2,6-dichlorophenol indophenol dye (V_1 ml). End point was noted on appearance of pink colour which persisted for a few minutes. The sample (0.5g) was weighed and ground in a mortar with pestle using 15ml 4% oxalic acid.

The homogenate was filtered through a double layered cheese cloth. The filtrate was made up to a known volume and centrifuged at 10,000 rpm for 10 min. The supernatant was collected and made up to 25ml using oxalic acid. 5.0 ml aliquot was pipetted into a conical flask to which 10ml of 4% oxalic acid was added. This was titrated against dichlorophenol indophenol (DCPIP) solution, until the appearance of pink colour (V_2 ml). The amount of ascorbic acid is calculated as follows:

$$Ascorbic\,acid = \frac{0.5mg}{V_1 ml} \times \frac{V_2}{5ml} \times \frac{100}{weight\ of\ sample}$$

RESULTS

4. RESULTS

The main objective of the study entitled "Spectral management for improving photosynthetic efficiency in polyhouse cultivation of vegetables" was to study the morphological and physiological responses of vegetables, viz. tomato, salad cucumber, capsicum and yardlong bean exposed to spectral modification through different colored shade nets. The main findings of the experiments and results are presented here.

4.1 WEATHER PARAMETERS

4.1.1 Photosynthetically Active Radiation

The influence of spectral quality on Photosynthetically Active Radiation on different shade nets is depicted in Table 1. There was not much difference in the values since the experimental polyhouse was a single unit.

4.1.2 Global radiation

The values obtained for global radiation are given in Table 2. The influence of spectral quality on global radiation in poly house was not much pronounced.

4.1.3 Light Intensity

Influence of spectral quality on light intensity is depicted in Table 3. The part without shade net shows higher light intensity than the parts with shade nets.

4.1.4 Temperature

The temperature values recorded are shown in Table 4. There was not much difference under shade nets. The temperature ranges from 35-40 C.

4.1.5 Relative Humidity

Relative humidity inside the polyhouse ranges from 73-89% .The values of relative humidity are shown in Table 5.

4.2 PHENOLOGICAL OBSERVATIONS

4.2.1 Pollen sterility

The pollens of all the crops are found to be viable under different spectral condition (Plate 4, Plate 5, Plate 6).

4.2.2 Days to first Flowering

The mean values of number of days to first flowering are shown in Table 6. The mean number value ranges from 27-35 days. The earliness to flowering was observed under open condition for salad cucumber (27), capsicum (31) & tomato (29) and for the yardlong long bean (28) it was under black net.

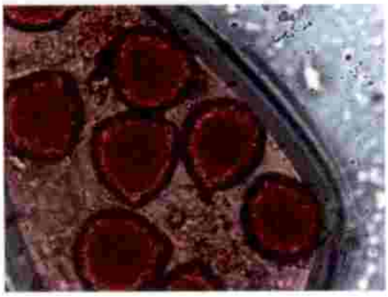
4.2.3 Days to first Fruiting

The influence of spectral quality on days to first fruiting is presented in Table 7. The earliness to fruiting was observed under open condition for salad cucumber (32), capsicum (51) and tomato (35). Yardlong bean (32) showed earliness to flowering under black net.

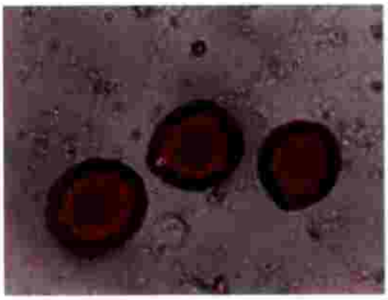
4.2.4 Days of Fruiting to Maturity

The mean values of days of fruiting to maturity are given in Table 8. The earliness to fruiting to maturity for salad cucumber (36), capsicum (74) and tomato (53) were observed under open condition. In case of yardlong bean earliness of fruiting to maturity was observed under black net (39).

4(a) Green



4(b) Red



4(c) White

4(d) Black

4(e) Open

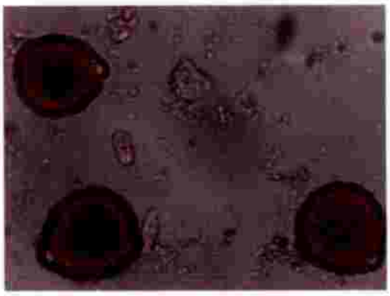
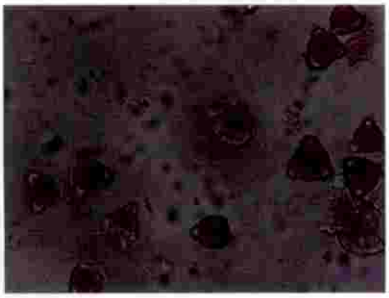


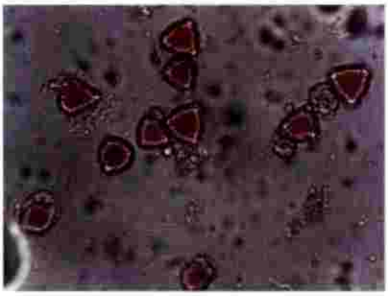
Plate 4. Influence of spectrally varying shade nets on pollens of yardlong bean

5(a) Green



5(b) Red

5(c) White



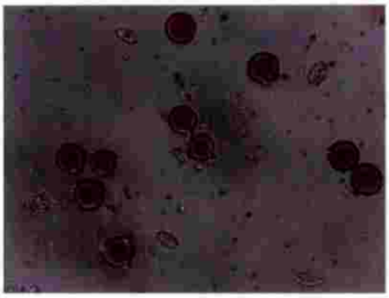
5(d) Black

5(e) Open

Plate 5. Influence of spectrally varying shade nets on pollens of capsicum

6(a) Green

6(b) Red



6(c) White

6(d) Black

6(e) Open

Plate 6. Influence of spectrally varying shade nets on pollens of tomato

Table 1. Influence of spectrally varying shade nets on Photosynthetically Active Radiation (μmolm^{-2}s^{-1}).

	Photosynthetically Active Radiation (μmolm^{-2}s^{-1})				
Months/Weeks	**Green**	**Red**	**White**	**Black**	**Open**
December					
1st week	336	359	229	328	270
2nd week	355	352	241	323	254
3rd week	354	349	231	270	248
4th week	355	339	333	254	274
January					
1st week	335	312	411	332	293
2nd week	340	293	413	324	292
3rd week	393	329	415	329	289
4th week	194	328	162	153	556
February					
1st week	326	321	310	408	785
2nd week	324	336	366	424	780
3rd week	336	340	402	337	580
4th week	335	339	405	327	573

Table 2. Influence of spectrally varying shade nets on global radiation (Wm^{-2}).

	Global radiation (Wm^{-2}).				
Months/Weeks	**Green**	**Red**	**White**	**Black**	**Open**
December					
1st week	265	233	172	225	190
2nd week	296	325	242	170	225
3rd week	330	305	235	192	345
4th week	305	248	170	167	240
January					
1st week	263	215	185	132	176
2nd week	161	198	132	120	185
3rd week	213	183	165	162	235
4th week	208	179	153	105	162
February					
1st week	269	224	213	146	201
2nd week	275	309	340	253	305
3rd week	397	271	285	245	434
4th week	350	220	225	199	344

Table 3. Influence of spectrally varying shade nets on light intensity (lux).

	Light intensity (lux)				
Months/weeks	**Green**	**Red**	**White**	**Black**	**Open**
December					
1st week	13500	7900	11500	9600	18400
2nd week	13100	7700	11500	9400	18100
3rd week	13000	7800	12000	9700	18300
4th week	13200	7800	11400	9500	18100
January					
1st week	9900	6400	9000	8900	14000
2nd week	10000	6600	9300	8700	14500
3rd week	9700	6700	9500	8600	14600
4th week	9800	6100	9100	8800	14200
February					
1st week	13300	11500	14500	15100	16700
2nd week	13200	11400	14600	15700	16500
3rd week	13400	11200	14800	15300	16400
4th week	13000	11700	14000	15400	16800

Table 4. Influence of spectrally varying shade nets on temperature (°C).

	Temperature (°C).				
Months/weeks	**Green**	**Red**	**White**	**Black**	**Open**
December					
1st week	37.00	40.00	38.30	38.00	38.50
2nd week	37.00	37.00	36.00	38.20	38.00
3rd week	35.00	36.00	39.00	37.00	39.20
4th week	39.00	38.00	37.60	37.90	37.80
January					
1st week	36.00	37.80	37.60	38.80	38.80
2nd week	38.00	38.00	39.20	38.60	37.90
3rd week	37.40	37.00	38.70	38.70	38.00
4th week	38.00	36.90	39.00	38.70	37.50
February					
1st week	38.00	38.00	39.00	38.90	37.00
2nd week	37.50	37.90	39.90	36.50	38.00
3rd week	38.20	37.00	38.50	36.00	39.00
4th week	39.00	39.00	38.00	37.00	38.40

Table 5. Influence of spectrally varying shade nets on relative humidity (%).

	Relative Humidity (%).				
Months/weeks	**Green**	**Red**	**White**	**Black**	**Open**
December					
1st week	73.27	80.43	83.83	85.06	84.40
2nd week	76.41	83.17	85.37	89.65	84.07
3rd week	85.90	88.35	83.06	85.00	83.89
4th week	73.47	81.21	84.61	84.85	84.57
January					
1st week	82.60	84.59	84.75	81.06	81.37
2nd week	84.51	80.41	82.63	83.10	87.46
3rd week	84.82	83.28	87.15	88.90	80.34
4th week	84.26	80.63	83.45	80.40	84.51
February					
1st week	81.95	80.78	84.51	84.75	82.60
2nd week	81.90	84.46	80.34	82.63	85.51
3rd week	89.86	88.62	83.84	87.15	84.82
4th week	82.29	83.33	87.46	83.45	84.26

Table 6. Influence of spectrally varying shade nets on days to first flowering

Shade Nets	Salad Cucumber	Yardlong Bean	Capsicum	Tomato
Green	28.50	29.75	35.00	30.50
Red	31.00	30.50	32.50	29.75
White	31.00	31.25	33.00	28.50
Black	29.50	27.50	35.50	31.50
Open	27.00	30.75	30.50	28.50
CD(0.05)	2.39	2.34	2.42	2.22

Table 7. Influence of spectrally varying shade nets on days to first fruiting

Shade Nets	Salad Cucumber	Yardlong Bean	Capsicum	Tomato
Green	33.50	33.75	55.00	36.50
Red	36.00	34.50	52.50	35.75
White	36.00	35.25	53.00	34.50
Black	34.50	31.50	55.50	37.50
Open	32.00	35.00	50.50	34.50
CD(0.05)	2.39	2.31	2.42	2.22

4.3 BIOMETRIC OBSERVATIONS

4.3.1 Number of leaves at first flowering

The mean values of number of leaves at first flowering is depicted in Table 9. The range of number of leaves at first flowering for salad cucumber is from 32 – 42 days, for yardlong bean and capsicum it ranges from 13-26 days and for tomato it ranges from 52-66 days. The highest number of leaves at first flowering for salad cucumber (42) and yardlong bean (21) were observed under white shade net and for capsicum (26) and tomato (66) under red shade net.

4.3.2 Specific leaf area

The influence of spectrally varying shade nets on specific leaf area is presented in Table 10. Specific Leaf Area was significantly higher under red net for salad cucumber (979.52cm^{2}g^{-1}), capsicum (564.21cm^{2}g^{-1}). Yard longbean recorded highest SLA under green net. The lowest mean value for SLA was observed under open condition (without shade net) for all the four crops.

4.3.3 Internode length

The internode length was taken at 30 days interval. The mean values for internode elongation in salad cucumber, yardlong bean, capsicum and tomato are presented in Table 11, Table 12, Table 13, and Table 14 respectiveley. The highest mean value of internode elongation was observed under black shade net for all the selected plants. Open condition or without shade condition shown a drastic decrease in internode elongation.

4.3.4 Setting %

Setting percent is one of the preffered character which contributes to yield. Higher setting percent was observed under red net for capsicum (80.9%) and tomato (81.8%), white net for salad cucumber (85.4%) and green for yardlong bean (89.3%). Table 15 shows the mean values of influence of spectrally varying shade nets on setting percent.

4.3.5 Root weight

The variation of root weight of different vegetables due to the influence of spectrally varying shade nets is presented in Table 16. The red net grown salad cucumber (2.17g) plants shown highest root weight. Open condition favoured maximum root growth for yardlong bean (2.25g) and capsicum (2.87 g). Tomato grown under black net had a maximum root weight of 6.8g.

4.3.6 Shoot weight

The shoot weight under green net was highest for salad cucumber (65g). Under black net highest shoot weight was observed for yardlong bean (86g). Capsicum grown without shade condition scored highest shoot weight. Maximum shoot weight for tomato (441g) was obtained under white shade net. Influence of spectrally varying shade nets on shoot weight of salad cucumber, yardlong bean, capsicum and tomato are depicted on Table 17.

4.3.7 Root shoot ratio

Table 18 shows the variation in root shoot ratio due to difference in spectral quality of shade nets on selected vegetables. Highest root shoot ratio for salad cucumber (0.044) was obtained under white net. Yardlong bean has highest root shoot ratio under without shade condition. Green net grown capsicum plants has highest root shoot ratio of 0.044. Tomato plants grown under black shade net has a maximum root shoot ratio of 0.016.

Table 8. Influence of spectrally varying shade nets on days of fruiting to maturity

Shade Nets	Salad Cucumber	Yardlong Bean	Capsicum	Tomato
Green	37.50	40.75	78.00	54.50
Red	40.00	41.50	75.50	53.75
White	40.00	42.25	76.00	52.50
Black	38.50	38.50	78.50	55.50
Open	36.00	41.75	73.50	52.50
CD(0.05)	2.39	2.34	2.42	2.22

Table 9. Influence of spectrally varying shade nets on number of leaves at first flowering

Shade Nets	Salad Cucumber	Yardlong Bean	Capsicum	Tomato
Green	37.50	20.25	20.75	60.00
Red	35.00	17.25	25.25	66.00
White	41.50	20.50	23.00	58.50
Black	35.50	13.50	18.50	62.00
Open	32.25	14.50	20.25	52.75
CD(0.05)	2.39	3.49	2.61	3.05

Table 10. Influence of spectrally varying shade nets on specific leaf area (cm^2/g).

	Specific Leaf Area (cm^2/g)			
Shade Nets	**Salad Cucumber**	**Yardlong Bean**	**Capsicum**	**Tomato**
Green	643.33	517.75	484.19	559.00
Red	979.52	480.52	564.21	561.18
White	867.15	379.91	445.93	458.40
Black	759.86	378.41	514.30	580.77
Open	622.94	357.57	425.96	540.63
CD(0.05)	11.17	9.55	16.20	5.93

4.3.8 Dry matter production

Maximum dry matter production was obtained under red shade net for yardlong bean (382.13g) and capsicum (399.01g). Salad cucumber grown under open condition has the highest dry matter production. Highest dry matter production for tomato (2160.19g) was obtained under white shade net. Table 19 presents dry matter production of different vegetables under the influence of spectrally varying shade nets.

4.3.9 Yeild

The maximum yield for capsicum (0.967kg) and tomato (1.472kg) was obtained under red shade net. Influence of spectral quality on yield of different crops is depicted in Table 20. Salad cucumber (3.648kg) has maximum yield under white shade net. Green shade net contributed maximum yield for yardlong bean (1.268kg).

4.3.10 Sex ratio in cucumber

No male flowers were observed since a gynoecious parthenocarpic hybrid salad cucumber was used for cultivation.

Table 11. Influence of spectrally varying shade nets on internode elongation of salad cucumber (cm)

	Internode Length of Salad Cucumber(cm)			
Shade Nets	**1st Month**	**2nd Month**	**3rd Month**	**Mean**
Green	14.37	15.00	19.25	16.32
Red	14.75	14.87	19.12	16.25
White	12.75	16.75	21.75	17.08
Black	13.12	17.75	22.75	17.87
Open	10.87	15.12	19.62	15.20
CD(0.05)	1.48	1.36	1.78	

Table 12. Influence of spectrally varying shade nets on internode elongation of Yardlong bean(cm).

	Internode Length of yardlong bean (cm)			
Shade Nets	**1st Month**	**2nd Month**	**3rd Month**	**Mean**
Green	32.25	37.00	39.37	36.21
Red	30.75	35.75	38.25	34.92
White	29.50	34.50	37.00	33.67
Black	33.25	37.75	40.25	37.08
Open	28.50	33.50	36.00	32.67
CD(0.05)	2.46	2.62	2.62	

Table 13. Influence of spectrally varying shade nets on internode elongation of capsicum(cm).

	Internode Length of Capsicum(cm)			
Shade Nets	**1st Month**	**2nd Month**	**3rd Month**	**Mean**
Green	10.12	10.75	11.25	10.71
Red	9.37	9.87	10.25	9.83
White	8.50	9.37	10.00	9.29
Black	8.87	10.12	10.75	9.91
Open	7.25	9.00	9.75	8.67
CD(0.05)	1.01	0.97	1.02	

Table 14. Influence of spectrally varying shade nets on internode length of tomato(cm)

	Internode Length of Tomato (cm)			
Shade Nets	**1st Month**	**2nd Month**	**3rd Month**	**Mean**
Green	13.25	15.25	17.75	15.42
Red	14.12	16.75	19.25	16.71
White	13.12	16	18.5	15.87
Black	15.87	16.12	18.62	16.87
Open	12.75	15.12	17.62	15.16
CD(0.05)	1.8	1.09	1.09	

Table 15. Influence of spectrally varying shade nets on setting percent (%) of salad cucumber, yardlong bean, capsicum and tomato

	Setting percent (%)			
Shade Nets	**Salad Cucumber**	**Yardlong Bean**	**Capsicum**	**Tomato**
Green	84.895	89.350	71.615	77.300
Red	80.275	80.105	80.995	81.805
White	85.405	83.520	79.565	68.900
Black	76.610	72.085	66.435	69.420
Open	78.395	74.215	74.125	67.290
CD(0.05)	5.826	3.594	3.923	4.758

Table 16. Influence of spectrally varying shade nets on root weight (g) of salad cucumber, yardlong bean, capsicum and tomato

	Mean Root Weight (g)			
Shade Nets	**Salad Cucumber** $n = 37$	**Yardlong Bean** $n = 25$	**Capsicum** $n = 25$	**Tomato** $n = 25$
Green	1.67	1.32	1.75	2.50
Red	2.17	0.80	1.87	3.48
White	2.03	0.75	1.49	6.80
Black	1.15	0.38	1.91	2.69
Open	0.77	2.25	2.87	0.94

Table 17. Influence of spectrally varying shade nets on shoot weight (g) of salad cucumber, yardlong bean, capsicum and tomato

	Mean Shoot Weight (g)			
Shade Nets	**Salad Cucumber** n = 37	**Yardlong Bean** n = 25	**Capsicum** n = 25	**Tomato** n = 25
Green	65	76	39	351
Red	64	68	52	289
White	46	52	42	441
Black	41	86	58	161
Open	64	60	70	107

Table 18. Influence of spectrally varying shade nets on root shoot ratio of salad cucumber, yardlong bean, capsicum and tomato

Shade Nets	**Salad Cucumber**	**Yardlong Bean**	**Capsicum**	**Tomato**
Green	0.025	0.017	0.044	0.007
Red	0.033	0.011	0.035	0.012
White	0.044	0.014	0.035	0.015
Black	0.028	0.004	0.032	0.016
Open	0.012	0.037	0.041	0.008

Table 19. Influence of spectrally varying shade nets on dry matter production of salad cucumber, yardlong bean, capsicum and tomato(g).

	Mean Dry Matter Production (g)			
Shade Nets	**Salad Cucumber** $n = 37$	**Yardlong Bean** $n = 25$	**Capsicum** $n = 25$	**Tomato** $n = 25$
Green	621.4	324.2	313.25	2102.68
Red	666.3	382.13	399.01	1462.32
White	548.4	250.23	209.3	2160.19
Black	563.3	315.52	294.16	889.21
Open	872.4	190.25	282.08	908.46

Table 20. Influence of spectrally varying shade nets on yield of salad cucumber, yardlong bean, capsicum and tomato

	Mean Yeild (kg/plant)			
Shade Nets	**Salad Cucumber** $n = 37$	**Yardlong Bean** $n = 25$	**Capsicum** $n = 25$	**Tomato** $n = 25$
Green	3.478	1.268	0.959	1.426
Red	3.536	1.16	0.967	1.472
White	3.648	1.138	0.964	1.396
Black	2.754	0.763	0.57	1.16
Open	3.451	1.058	0.556	1.08

4.4 ANATOMICAL STUDY OF PETIOLE, LEAF AND STEM

4.4.1 Anatomical study of petiole in salad cucumber

The petiole anatomy of salad cucumber (Plate 7) grown under white net showed good arrangement of vascular bundles, green net grown salad cucumber has not so developed structure (Plate 7 c).

4.4.2 Anatomical study of petiole in yardlong bean

Vascular bundles are arranged well in green shade net grown yardlong bean (Plate 8 a).

4.4.3 Anatomical study of petiole in capsicum

Eratic distribution of cells was seen in anatomy of green net grown capsicum while well aarranged in red net (Plate 9 b).

4.4.4 Anatomical study of petiole in tomato

Red net grown tomato offers good arrangement which synchronize with the photosynthetic rate, while eratic distribution was seen in open condition (Plate 10 e) .

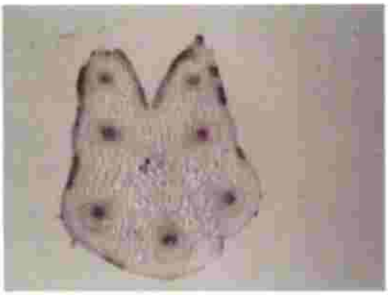
4.4.5 Anatomical study of leaf in salad cucumber

The distribution of trichomes was found to be higher in white net which offers more boundary layer resisitance (Plate 11 c).

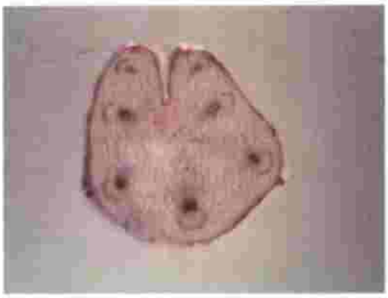
4.4.6 Anatomical study of leaf in yardlong bean

Well distributed vascular bundles was seen in green which is in match with the yield (Plate 12a).

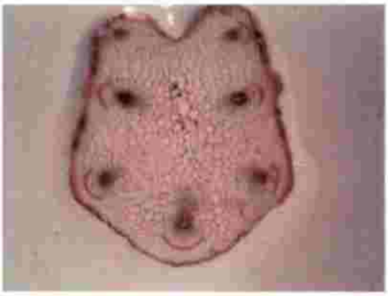
7(a) Green



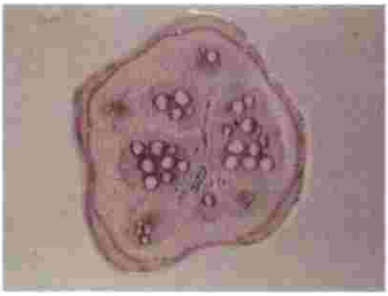
7(b) Red



7(c) White



7(d) Black



7(e) Open

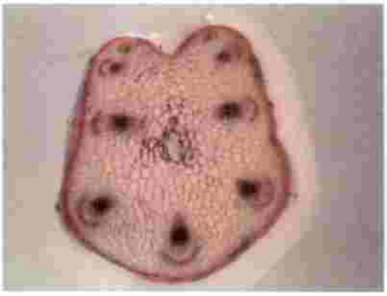
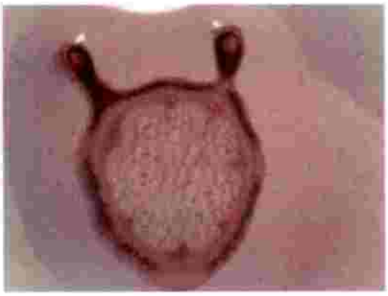
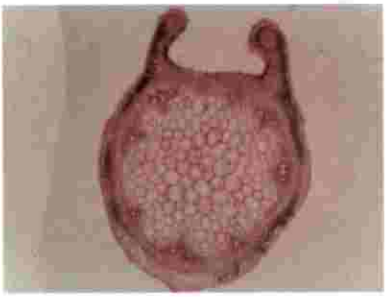


Plate 7. Influence of spectrally varying shade nets on petiole anatomy of salad cucumber

8(a) Green

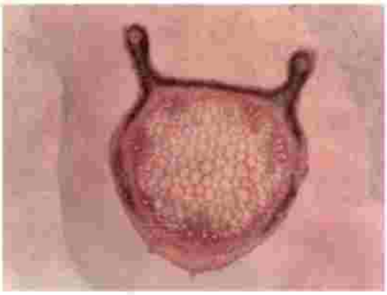


8(b) Red



8(c) White

8(d) Black



8(e) Open

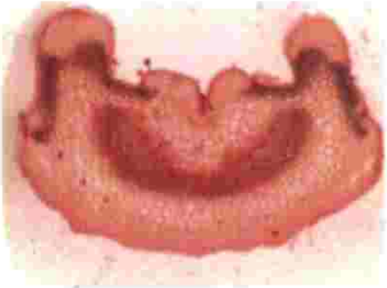
Plate 8. Influence of spectrally varying shade nets on petiole anatomy of yardlong bean

9(a) Green

9(b) Red

9(c) White

9(d) Black

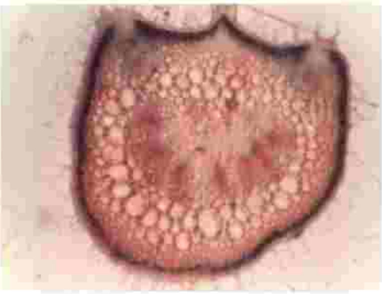


9(e) Open

Plate 9. Influence of spectrally varying shade nets on petiole anatomy of capsicum

10(a) Green 10(b) Red

10(c) White



10(d) Black 10(e)Open

Plate 10. Influence of spectrally varying shade nets on petiole anatomy of tomato

4.4.7 Anatomical study of leaf in capsicum

Vascular bundles distribution was higher in red which is in sink with the photosynthetic rate (Plate 13b).

4.4.8 Anatomical study of leaf in tomato

Black net grown tomato showed less arrangement of vascular bundles which leads to low translocation (Plate 14 d).

4.4.9 Anatomical study of stem in salad cucumber

Pholem is well developed and organised. Tightly packed xylem was observed in white net while in case of black the diameter of conducting vessels was high (Plate 15c and Plate 15 d).

4.4.10 Anatomical study of stem in yardlong bean

More arranged pith cells was seen in stem anatomy of green net grown yardlong bean, while white net has pith cells with more diameter (Plate16 a and Plate 16 c).

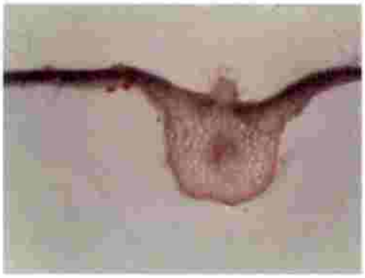
4.4.11 Anatomical study of stem in capsicum

In red net grown capsicum stem anatomy, the vascular bundles are concentrated and tightly packed (Plate 17 b).

4.4.12 Anatomical study of stem in tomato

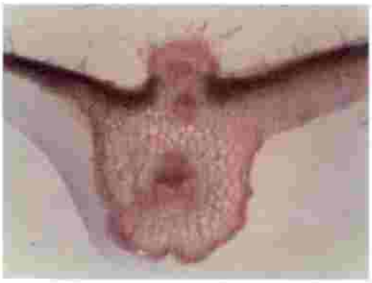
Arranged vascular bundles are seen in anatomy red net grown tomato, while scatterd arrangement in open (Plate 18 b and Plate 18 e).

11(a) Green

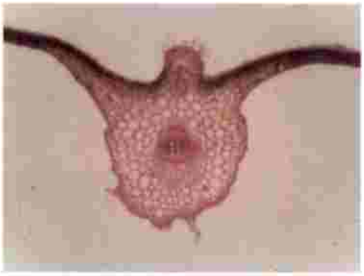


11(b) Red

11(c)White



11(d) Black



11(e) Open

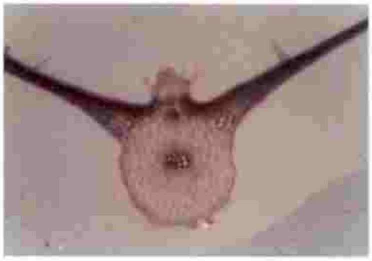
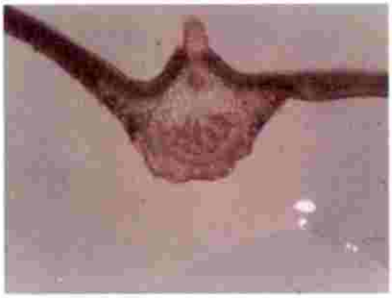


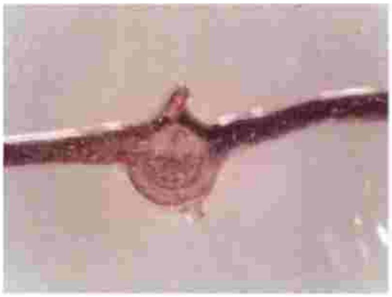
Plate 11. Influence of spectrally varying shade nets on leaf anatomy of salad cucumber

12(a) Green



12(b) Red

12(c) White



12(d)Black

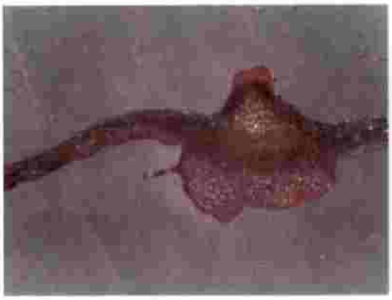
12(e) Open

Plate 12. Influence of spectrally varying shade nets on leaf anatomy of yard long bean

13(a) Green

13(b) Red

13(c) White



13(d) Black

13(e) Open

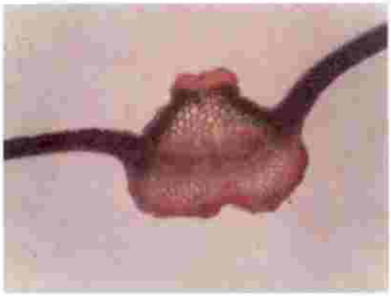
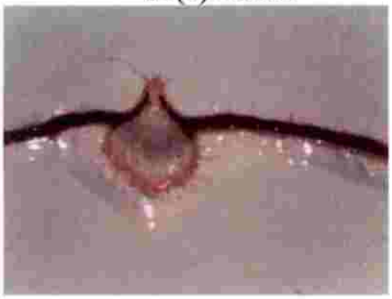
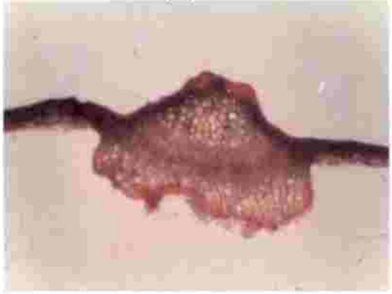


Plate 13. Influence of spectrally varying shade nets on leaf anatomy of capsicum

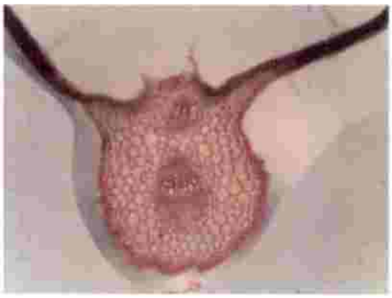
14(a) Green



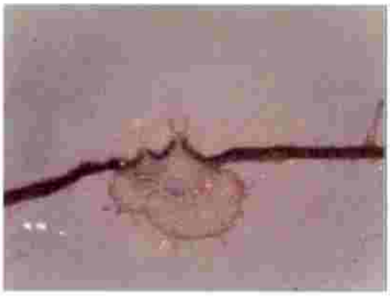
14(b) Red



14(c) White



14(d) Black



14(e) Open

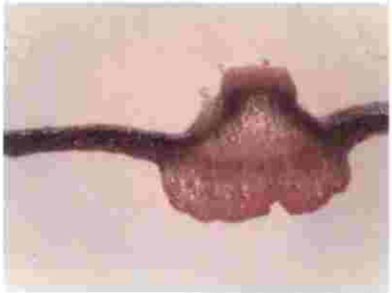
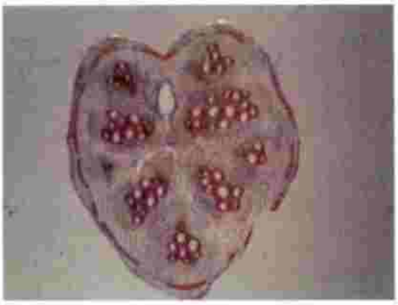
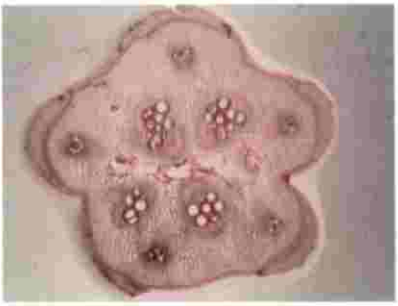


Plate 14. Influence of spectrally varying shade nets on leaf anatomy of tomato

15(a) Green

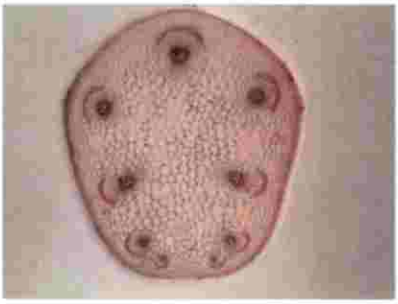


15(b) Red



15(c) White

15(d) Black



15(e) Open

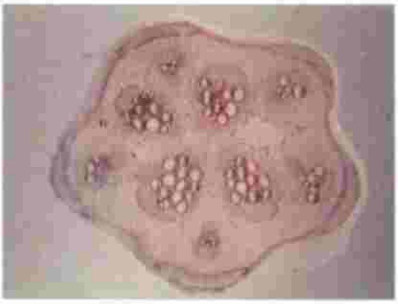
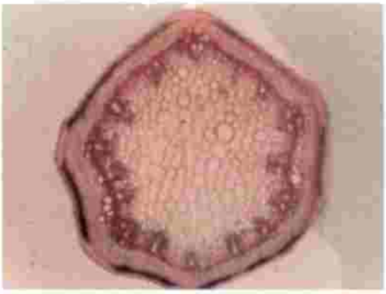


Plate 15. Influence of spectrally varying shade nets on stem anatomy of salad cucumber

16(a) Green

16(b) Red

16(c) White



16(d) Black

16(e) Open

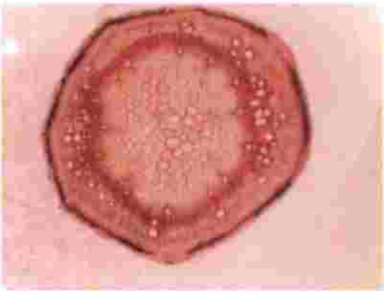
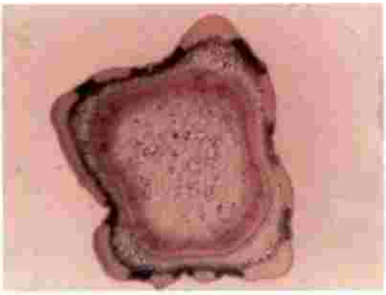
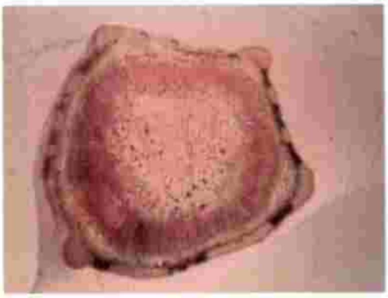


Plate 16. Influence of spectrally varying shade nets on stem anatomy of yard long bean

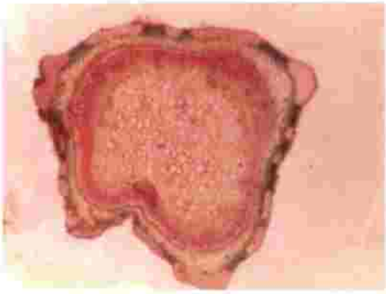
17(a) Green



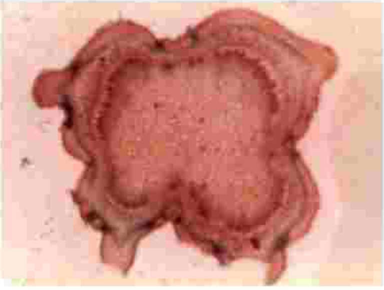
17(b) Red



17(c) White



17(d) Black



17(e) Open

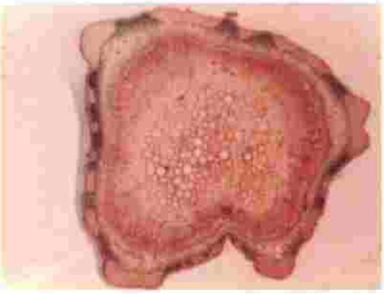
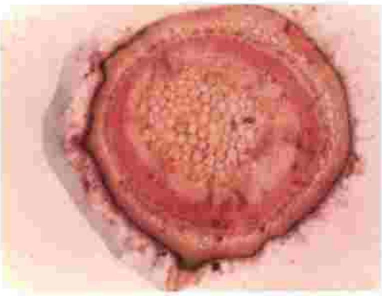


Plate 17. Influence of spectrally varying shade nets on stem anatomy of capsicum

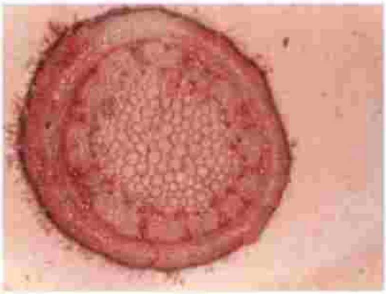
18(a) Green

18(b) Red

18(c) White



18(d) Black



18(e) Open

Plate 18. Influence of spectrally varying shade nets on stem anatomy of tomato

4.5 PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS

4.5.1 Photosynthetic rate

Mean values of photosynthetic rate are presented in Table 21. Photosynthetic rate was significantly high under red shade net for salad cucumber (33.62μmolm^{-2}s^{-1}) capsicum (20.67μmolm-^{2}s-^{1}) and tomato (30.35μmolm-^{2} s-^{1}). Highest photosynthetic rate for yardlong bean (31.5 μmolm-^{2}s^{-1}) was observed under green shade net.

4.5.2 Pigment composition

Table 22, 23, 24 and 25 shows the influence of spectrally varying shade nets on different pigment components of salad cucumber, yardlong bean, capsicum and tomato.

Chlorophyll a

During flowering (1.05 mg g^{-1}) and maturity stage (0.72 mg g^{-1}) highest value recorded for black net grown salad cucumber. For yardlong bean maximum value of chlorophyll a content recorded under white net at flowering(0.70 mg g^{-1}) and maturity (0.63 mg g^{-1}). Capsicum plants recorded highest mean value under green net at flowering stage (1.30 mg g^{-1}) and under open condition at maturity stage(0.95 mg g^{-1}). Red net grown tomato plants recorded highest mean value at flowering stage (0.75 mg g^{-1}) and at maturity stage (1.58 mg g^{-1}) open condition recorded the highest mean.

Chlorophyll b

During flowering (0.67 mg g^{-1}) and maturity stage (0.14 mg g^{-1}) highest mean value recorded for black net grown salad cucumber. For yardlong bean maximum value of chlorophyll a content recorded under open condition at flowering (0.25 mg g^{-1}) and under red net at maturity (0.17 mg g^{-1}).

Capsicum plants recorded highest mean value under red net at flowering stage (0.22 mg g^{-1}) and under open condition at maturity stage (0.95 mg g^{-1}). Red net grown tomato plants recorded highest mean value at flowering stage (0.26 mg g^{-1}) and at maturity stage (0.48 mg g^{-1}) open condition recorded the highest mean.

Total chlorophyll

During flowering (1.71 mg g^{-1}) and maturity stage (0.86 mg g^{-1}) highest mean value recorded for black net grown salad cucumber. For yardlong bean maximum value of chlorophyll content recorded under white net at flowering(0.81 mg g^{-1}) and maturity (0.78 mg g^{-1}). Capsicum plants recorded highest mean value under white net at flowering stage (1.61 mg g^{-1}) and under open condition at maturity stage (0.16 mg g^{-1}). Red net grown tomato plants recorded highest mean value at flowering stage (0.99 mg g^{-1}) and at maturity stage (2.07 mg g^{-1}) open condition recorded the highest mean.

Carotenoid

During flowering (0.84 mg g^{-1}) and maturity stage (0.78 mg g^{-1}) highest mean value recorded for black net grown salad cucumber. For yardlong bean maximum value of carotenoid content recorded under white net at flowering(0.63 mg g^{-1}) and maturity (0.63 mg g^{-1}). Capsicum plants recorded highest mean value under without shade net at flowering stage (0.69 mg g^{-1}) and at maturity stage (0.95 mg g^{-1}). Black net grown tomato plants recorded highest mean value at flowering stage (0.45 mg g^{-1}) and at maturity stage (1.39 mg g^{-1}) open condition recorded the highest mean.

4.5.3 Stomatal charecteristics

4.5.3.1 Stomatal conductance

Highest mean value of stomatal conductance was found under red net for yardlong bean (489.75 milli molesM^{-2}s-^{1}) and tomato (729.50 milli molesm-^{2}s-^{1}). For salad cucumber (887.50 milli molesM^{-2}s-^{1}) highest mean value of stomatal conductance was recorded under white net and black for capsicum (517.00 milli moles M^{-2}s-^{1}). The mean values of stomatal conductance are presented in Table 26.

Table 21. Influence of spectrally varying shade nets on photosynthetic rate of salad cucumber, yardlong bean, capsicum and tomato (µmolm-^{2}s^{-1}).

	Photosynthetic Rate(µmolm-^{2}s^{-1})			
Shade Nets	**Salad Cucumber**	**Yardlong Bean**	**Capsicum**	**Tomato**
Green	19.12	31.52	17.35	12.15
Red	33.62	12.05	20.67	30.35
White	25.20	14.92	14.87	15.40
Black	18.47	9.62	15.22	14.12
Open	7.55	22.45	2.02	7.82
CD(0.05)	2.48	10.16	9.95	7.66

Table 22. Influence of spectrally varying shade nets on pigment composition of salad cucumber(mg g-^{1}).

Shade Nets	Pigment Composition of Salad Cucumber (mg g-^{1})							
	Flowering				Maturity			
	Chl A	Chl B	Total Chl	Carotenoids	Chl A	Chl B	Total Chl	Carotenoids
Green	0.87	0.63	1.50	0.79	0.37	0.05	0.42	0.35
Red	0.76	0.42	1.18	0.76	0.41	0.09	0.50	0.55
White	1.02	0.65	1.67	0.82	0.65	0.13	0.77	0.68
Black	1.05	0.67	1.71	0.84	0.72	0.14	0.86	0.78
Open	0.7	0.34	1.04	0.76	0.69	0.1	0.77	0.74
CD(0.05)	0.05	0.06	0.06	0.05	0.19	0.03	0.21	0.09

Table 23. Influence of spectrally varying shade nets on pigment composition of yardlong bean(mg g-^{1}).

Shade Nets	Pigment Composition of Yardlong Bean (mg g-^{1})							
	Flowering				Maturity			
	Chl A	Chl B	Total Chl	Carotenoids	Chl A	Chl B	Total Chl	Carotenoids
Green	0.49	0.18	0.58	0.45	0.40	0.11	0.50	0.47
Red	0.63	0.23	0.77	0.57	0.51	0.17	0.69	0.56
White	0.70	0.24	0.81	0.63	0.63	0.16	0.78	0.63
Black	0.60	0.22	0.73	0.52	0.59	0.11	0.71	0.52
Open	0.58	0.25	0.72	0.25	0.5	0.13	0.63	0.57
CD(0.05)	0.02	0.02	0.03	0.03	0.12	0.04	0.08	0.04

Table 24. Influence of spectrally varying shade nets on pigment composition of capsicum(mg g-^{1}).

Shade Nets	Pigment Composition of Capsicum (mg g-^{1})							
	Flowering				Maturity			
	Chl A	Chl B	Total Chl	Carotenoids	Chl A	Chl B	Total Chl	Carotenoids
Green	1.30	0.28	1.58	0.67	0.76	0.14	0.89	0.82
Red	1.15	0.39	1.54	0.68	0.90	0.14	1.04	0.83
White	1.25	0.35	1.61	0.69	0.82	0.12	0.95	0.77
Black	1.01	0.33	1.32	0.64	0.75	0.22	0.96	0.79
Open	1.15	0.34	1.48	0.69	0.95	0.22	1.16	0.95
CD(0.05)	0.07	0.04	0.05	0.01	0.06	0.04	0.04	0.07

Table 25. Influence of spectrally varying shade nets on pigment composition of tomato(mg g-^{1}).

Shade Nets	Pigment Composition of Tomato (mg g-^{1})							
	Flowering				Maturity			
	Chl A	Chl B	Total Chl	Carotenoids	Chl A	Chl B	Total Chl	Carotenoids
Green	0.68	0.14	0.83	0.34	1.05	0.20	1.25	1.00
Red	0.75	0.26	0.99	0.33	1.25	0.22	1.47	1.17
White	0.71	0.16	0.87	0.48	1.12	0.24	1.35	1.13
Black	0.70	0.15	0.85	0.49	1.25	0.34	1.59	1.3
Open	0.67	0.10	0.77	0.36	1.58	0.48	2.07	1.39
CD(0.05)	0.001	0.001	0.002	6.987	0.003	0.009	0.004	0.157

Table 26. Influence of spectrally varying shade nets on stomatal conductance (milli molesm-^{2}s-^{1}) of salad cucumber, yardlong bean, capsicum and tomato

	Stomatal Conductance (milli molesm-^{2}s-^{1})			
Shade Nets	Salad Cucumber	Yardlong Bean	Capsicum	Tomato
Green	164.00	441.75	316.00	510.25
Red	335.50	489.75	504.50	729.50
White	887.50	139.75	142.75	247.50
Black	534.25	249.00	517.00	269.50
Open	233.50	153.75	258.25	78.00
CD(0.05)	68.74	66.69	85.99	71.16

4.5.3.2 Stomtal frequency and Stomatal Index

Stomatal frequency and Stomatal index were two important aspects of stomata which will influence the transpiration behavior of crop. Table 27, Table 28, Tabe 29, Table 30 shows the influence of spectrally varying shade nets on stomatal frequency and stomatal index of different vegetables.

Adaxial stomatal index of the salad cucumber plants grown under green shade net (22.76) was found with highest mean value while adaxial stomatal frequency was highest under black net (15.10 no cm^{-2}). Highest mean value of abaxial stomatal index (22.43) and stomatal frequency (826.82 no cm^{-2}) was observed under black net.

Under open condition (without shade net condition), yardlong bean plants recorded with highest mean value of abaxial stomatal frequency (1270.58 no cm^{-2}) and adaxial stomatal index (22.49) and stomatal frequency (737.43 no cm^{-2}). Highest mean value of abaxial index (21.49) was found under white net.

Capsicum plants with highest mean value of adaxial stomatal frequency (379.88 no cm^{-2}) was observed under green net while highest mean value of adaxial stomatal index (21.40) and abaxial stomatal index (20.61) and frequency (916.20 no cm^{-2}) under open condition.

Both adaxial (603.36 no cm^{-2}) and abaxial (1050.27 no cm^{-2}) stomatal frequency was recorded the highest mean value under without shade condition for tomato while abaxial (21.50) and adaxial (21.50) stomatal index was highest under white net.

4.5.4 Transpiration rate

Effect of spectrally varying shade nets on transpiration rate of different vegetables are presented in Table 31. Stomatal movements provides the leaf with the oppurtunity to change the partial pressure of CO_2 at the site of carboxylation and rate of transpiration. Highest mean value of transpiration rate was recorded under green net for yardlong bean (2.420 milli moles $H_2O\ m^{-2}\ s^{-1}$) and tomato(2.895 milli moles $H_2O\ m^{-2}\ s^{-1}$) while under white net for salad cucumber (3.765 milli moles $H_2O\ m^{-2}\ s^{-1}$) and capsicum (2.575 milli moles $H_2O\ m^{-2}\ s^{-1}$) .

Table 27. Influence of spectrally varying shade nets on stomtal frequency (no cm^{-2}) and stomatal index of salad cucumber

Shade Nets	Stomtal Frequency (no cm^{-2}) and Stomatal Index of Salad Cucumber			
	Adaxial		Abaxial	
	S.I	S.F	S.I	S.F
Green	22.76	379.88	21.74	815.64
Red	17.72	335.20	14.30	770.95
White	14.19	201.11	15.23	424.58
Black	15.10	335.20	16.16	692.73
Open	15.57	424.58	22.43	826.82
CD(0.05)	3.27	86.94	2.98	78.72

Table 28. Influence of spectrally varying shade nets on stomtal frequency (no cm^{-2}) and stomatal index of yardlong bean

Shade Nets	Stomtal Frequency (no cm^{-2}) and Stomatal Index of Yardlong Bean			
	Adaxial		Abaxial	
	S.I	S.F	S.I	S.F
Green	15.13	513.96	14.44	1200.00
Red	15.35	245.81	14.44	1105.88
White	17.66	290.51	21.49	964.71
Black	14.79	379.88	14.32	1058.83
Open	22.49	737.43	14.52	1270.58
CD(0.05)	3.25	86.94	3.05	100.28

Table 29. Influence of spectrally varying shade nets on stomtal frequency (no cm^{-2}) and stomatal index of capsicum

Shade Nets	Stomtal Frequency (no cm^{-2}) and Stomatal Index of Capsicum			
	Adaxial		Abaxial	
	S.I	S.F	S.I	S.F
Green	15.35	379.88	16.49	603.36
Red	15.48	201.11	14.12	692.73
White	14.19	156.43	14.72	737.43
Black	17.85	245.81	15.82	474.86
Open	21.40	290.51	20.61	916.20
CD(0.05)	3.13	86.94	2.51	84.62

Table 30. Influence of spectrally varying shade nets on stomtal frequency (no cm^{-2}) and stomatal index of tomato

Shade Nets	Stomtal Frequency (no cm^{-2}) and Stomatal Index of tomato			
	Adaxial		Abaxial	
	S.I	S.F	S.I	S.F
Green	14.63	379.88	15.65	916.20
Red	15.62	335.20	14.31	826.82
White	21.50	245.81	21.50	737.43
Black	17.63	513.96	14.70	871.50
Open	14.87	603.36	16.57	1050.27
CD(0.05)	2.75	86.94	2.81	86.94

Table 31. Influence of spectrally varying shade nets on transpiration rate (milli moles H_2O m^{-2} s-1) of salad cucumber, yardlong bean, capsicum, tomato

	Transpiration Rate (milli moles H_2O m^{-2} s-1)			
Shade Nets	**Salad Cucumber**	**Yardlong Bean**	**Capsicum**	**Tomato**
Green	1.095	2.42	2.275	2.895
Red	3.235	1.505	0.735	1.235
White	3.765	0.885	2.575	1.535
Black	2.81	0.655	1.055	0.295
Open	3.075	1.78	1.46	2.825
CD(0.05)	1.245	1.01	1.128	0.933

4.5.5 Total soluble protein

The mean values obtained for total soluble protein recorded are shown in Table 32. Red net grown tomato plants showed highest mean value at flowering (2.38 mg g^{-1}) and maturity stage (2.48 mg g^{-1}). Salad cucumber recorded highest mean value under red net at flowering stage (0.76 mg g^{-1}) and at maturity stage (2.05 mg g^{-1}) under white net. Maximum total soluble protein content at flowering stage (2.25 mg g^{-1}) for yardlong bean was found under without shade condition and under black net at maturity stage (2.26 mg g^{-1}). Capsicum grown under white net recorded highest mean value at flowering stage (2.82 mg g^{-1}) while under without shade condition at maturity (2.33 mg g^{-1}) .

4.5.6 Phenol content

Highest mean value of phenol content at flowering stage was observed under black net for salad cucumber and capsicum. Without shade net condition contributed maximum phenol content at flowering and maturity stage for capsicum and salad cucumber. Influence of spectrally varying shade nets on phenol content of different vegetables are shown in Table 33. Yardlong bean showed maximum phenol content grown under green shade net. Tomato plants grown under white shade net showed highest mean value of phenol content.

4.5.7 Fibre content of pod

The fibre content of pod of yardlong bean showed significant variation with the influence of spectrally varying shade nets which is presented in Table 34. Highest mean value of fibre content(19.22) was observed in plants grown under without shade net condition.

Table 32. Influence of spectrally varying shade nets on total soluble protein (mg g^{-1}) content of salad cucumber, yardlong bean, capsicum, tomato

	Total Soluble Protein (mg g^{-1})							
Shade Nets	Salad Cucumber		Yardlong Bean		Capsicum		Tomato	
	FLW	MTY	FLW	MTY	FLW	MTY	FLW	MTY
Green	0.62	1.06	2.17	2.19	2.76	2.20	2.27	2.28
Red	0.76	1.19	2.13	2.11	2.68	2.18	2.38	2.48
White	0.34	2.05	1.81	2.13	2.82	1.69	2.30	2.42
Black	0.21	1.31	2.12	2.26	2.78	2.17	2.33	2.46
Open	0.07	1.68	2.25	2.19	2.67	2.33	2.25	2.43
CD(0.05)	0.04	0.02	0.11	0.08	0.09	0.1	0.07	0.08

Table 33. Influence of spectrally varying shade nets on phenol content (mg g^{-1}) of salad cucumber, yardlong bean, capsicum, tomato

	Phenol Content (mg g^{-1})							
Shade Nets	Salad Cucumber		Yardlong Bean		Capsicum		Tomato	
	FLW	MTY	FLW	MTY	FLW	MTY	FLW	MTY
Green	0.91	0.44	7.39	7.00	2.96	0.82	1.53	1.07
Red	0.71	0.36	5.67	5.63	4.88	0.77	1.38	0.84
White	0.88	0.22	5.56	5.55	4.92	0.81	2.18	1.38
Black	1.50	0.25	4.19	4.08	2.97	0.84	1.51	0.96
Open	0.89	0.86	4.22	4.23	5.40	0.84	1.42	0.94
CD(0.05)	0.02	0.05	0.13	0.34	0.19	0.03	0.12	0.16

Table 34. Influence of spectrally varying shade nets on fibre content of pod of yardlong bean(%).

Shade Nets	Fibre content of Yardlong Bean (%)
Green	5.65
Red	10.27
White	10.72
Black	5.97
Open	19.22
CD(0.05)	1

4.5.8 Crude protein

Highest mean value of crude protein(64.75) was recorded under white shade net grown yardlong bean pods. The variation of crude protein content of pod of yardlong bean is depicted in Table 35.

4.5.9 Carbohydrate

The total carbohydrate content showed significant variation with the influence of spectrally varying shade nets in different vegetables (Table 36). At flowering stage the salad cucumber plants grown under red shade net showed maximum total carbohydrate content (1.31 mg g^{-1}). Green shade net grown cucumber plants showed maximum total carbohydrate content (2.59 mg g^{-1}) at maturity stage. Yardlong bean, capsicum and tomato showed maximum total carbohydrate content at both flowering and maturity stage under open condition (without shade net).

4.5.10 IAA content

There was no significant diference in the IAA content in the leaves of salad cucumber and yardlong bean. The influence of spectrally varying shade nets on IAA content of capsicum and tomato vary slightly. Table 37 shows the mean values of IAA content of salad cucumber, yardlong bean, capsicum and tomato under under the influence of spectral quality.

4.5.11 Lycopene content of tomato

Lycopene content of tomato varied significantly under the influence of spectrally varying shade nets as presented in Table 38. Highest mean value (37.90 mg $100g^{-1}$) was shown by tomato plants grown under white shade net. Lowest mean value (15.16 mg $100g^{-1}$) was shown by plants grown under red shade net.

Table 35. Influence of spectrally varying shade nets on crude protein content of pod of yardlong bean

Shade Nets	Crude Protein of YardlongBean (%)
Green	57.40
Red	50.75
White	64.75
Black	53.20
Open	57.92
CD(0.05)	2.01

Table 36. Influence of spectrally varying shade nets on carbohydrate (mg g^{-1}) content of salad cucumber, yardlong bean, capsicum, tomato

	Carbohydrate (mg g^{-1})							
Shade Nets	Salad Cucumber		Yardlong Bean		Capsicum		Tomato	
	FLW	MTY	FLW	MTY	FLW	MTY	FLW	MTY
Green	1.1	2.59	1.82	1.83	0.77	1.26	1.51	2.31
Red	1.31	2.47	1.25	1.49	0.73	1.18	1.39	1.87
White	0.44	2.2	1.49	1.5	0.71	1.41	1.37	2.22
Black	1.11	2.44	1.22	1.72	0.83	1.15	1.57	2.26
Open	1.15	2.4	1.9	2.16	0.84	1.55	1.66	3.25
CD(0.05)	0.1	0.11	0.11	0.24	0.06	0.07	0.03	0.05

Table 37. Influence of spectrally varying shade nets on IAA content of salad cucumber, yardlong bean, capsicum, tomato(mg g^{-1}).

	IAA Content (mg g^{-1})			
Shade Nets	Salad Cucumber	Yardlong Bean	Capsicum	Tomato
Green	0.017	0.018	0.017	0.014
Red	0.015	0.012	0.012	0.012
White	0.012	0.015	0.017	0.017
Black	0.017	0.018	0.012	0.017
Open	0.012	0.015	0.018	0.014
CD(0.05)	N.S	N.S	0.006	0.003

4.5.12 Vitamin C content of tomato

Influence of spectrally varying shade nets on vitamin C content of tomato is presented in Table 39. Highest content of vitamin C (20.93 mg $100g^{-1}$) content was recorded in tomato plants grown under white shade net. Lowest mean value (10.81 mg $100g^{-1}$) was shown by plants grown under red shade net.

4.5.13 Vitamin C content of capsicum

Table 40. shows the influence of spectrally varying shade nets on vitamin C content of capsicum. Content of ascorbic acid was highest in capsicum (106.87 mg $100g^{-1}$) under without shade condition. The lowest mean value of ascorbic acid (51.25 mg $100g^{-1}$) was found under red shade net.

Table 38. Influence of spectrally varying shade nets on lycopene content (mg100g^{-1}) of tomato

Shade Nets	Lycopene content of tomato (mg100g^{-1})
Green	16.01
Red	15.16
White	37.90
Black	31.00
Open	30.30
CD(0.05)	3.17

Table 39. Influence of spectrally varying shade nets on vitamin C content (mg100g^{-1}) of tomato

Shade Nets	Vitamin C content of tomato (mg100g^{-1})
Green	12.43
Red	10.81
White	20.93
Black	14.81
Open	18.62
CD(0.05)	2.59

Table 40. Influence of spectrally varying shade nets on vitamin C content (mg100g^{-1}) of capsicum

Shade Nets	Vitamin C content of capsicum (mg100g^{-1})
Green	96.25
Red	51.25
White	66.87
Black	58.12
Open	106.87
CD(0.05)	10.21

DISCUSSION

5. DISCUSSION

The present investigation entitled "Spectral management for improving photosynthetic efficiency in polyhouse cultivation of vegetables" was carried out to study the influence of spectral management in photosynthetic efficiency in polyhouse cultivation of vegetables. The study also envisaged to understand the morphological and physiological responses of vegetables, viz. tomato, salad cucumber, capsicum and yard long bean exposed to spectral modification through different colored shade nets. The experiment was conducted at Department of Plant Physiology and at farmer's field at Pothencode .

Greenhouse covering materials transmit either all wavelengths or designed to absorb certain wavelengths changing the composition of solar spectrum based on the specific material and color (Rajapakse *et al*., 1999). When the cover of a greenhouse is designed to change the spectral quality of transmitted light, the aim is often to modify plant morphology to affect flowering time. Spectral quality influences plant growth and development.

Protected cultivation with spectral management is a novel technology which ushers quatum jump in production and also weather proofing. Spectral management can be achieved by two ways either by supplemental lighting or by use of shade nets. Considering the investment, shade nets are more popular. The use of shade nets is becoming very popular due to the increase in global temperatures. Netting is frequently used to protect agricultural crops from excessive solar radiation, improving the thermal climate (Kittas *et al*., 2009), sheltering from wind and hail and exclusion of bird and insect transmitted virus diseases (Teitel *et al*., 2008).

Even though the shade nets have high popularity and wide availability in markets, neither the consumers nor the producers have a clear idea in selecting a shade net for specific application (Al-Helal and Abdel-Ghany, 2010). There is no research report available on this aspect. Hence an experiment was proposed to generate the basic information on which colored shade net is suitable for our crop of interest in Kerala and how the spectral quality modifies development and photomorphogenic processes in crops of our interest.

To understand the physiological parameters that influence the photosynthetic efficiency in poly house conditions, the four crops were raised in naturaly ventilated poly house, which was equally divided into five parts. Similar cultural and management practices were given under both conditions. Various morphological, physiological, phenological and yield related characters were recorded and the results obtained are discussed in this chapter.

5.1 WEATHER PARAMETERS

The presence of shade nets can cause a change in the weather inside the polyhouse. These changes may include temperature, humidity, vapour pressure deficit etc. Each of these change have direct relation with the growth and development of the plant. Many researchers have studied about the effect of green house environment on the growth, development and productivity of crops (Challa and Schapendoruk, 1984; Bakker *et al.*,1987; Ellis *et al.*, 1990; Pearson, 1992).

Temperature plays vital role in vegetative growth. The temperature of polyhouse condition was higher i.e. 4°C to 5°C than outside. It was found that the temperature under each shade net was more or less similar since it's a single polyhouse unit (Fig. 1).

Humidity directly affects the growth of plant in shade net house. The absolute humidity of inside air rises with sun since the stomatal opening increase transpiration and will affect the plant growth. For most of the crops, the range of relative humidity is between 5% to 80%. In our study the humidity ranges from 73-89%. There was not much variation within different shade nets. The relative humidity is very less outside the shade net house as compare to inside the shade net house due to the winter season. Kong *et al*. (2013) found that pearl screen increased transmittance of long-wave band light and light intensity within plant canopy. The air temperature and humidity under pearl and black screen treatments had no significant difference.

All shade nets reduced PAR compared with uncovered sites but there were differences between colors. Observed PAR values ($\mu mol \cdot m^{-2}s^{-1}$) were reduced under black net and least under red net with green and white nets intermediate (Fig. 2). These results are consistent with previous reports of Stamps and Chandler, (2008) where PAR was reduced less by 70% red netting compared with 70% black or 70% blue netting in unreplicated structure.

Both diminished light intensity and higher than the optimum level affects the growth. Diminished light intensity slows down photosynthesis and hence the growth, while higher than optimal light intensities slows down growth because of injury to the chloroplasts.

5.2 PHENOLOGICAL OBSERVATIONS & BIOMETRIC OBSERVATIONS

The photoselective responses include fruit-set, harvest time (early or late maturation), and fruit yield, size, color (Shahak *et al*., 2004 ; Rajapakse and Shahak, 2007; and Shahak, 2008). The plants were able to grow faster under high temperature, which promotes the earliness but decreases the total yield. The earliness to flowering, fruiting and maturity was observed in vegetables grown without shade condition but prolonged growth was observed under shaded condition. Higher yield for tomato and capsicum was obtained under red net.

Fig. 1 Influence of spectrally varying shade nets on Temperature° C

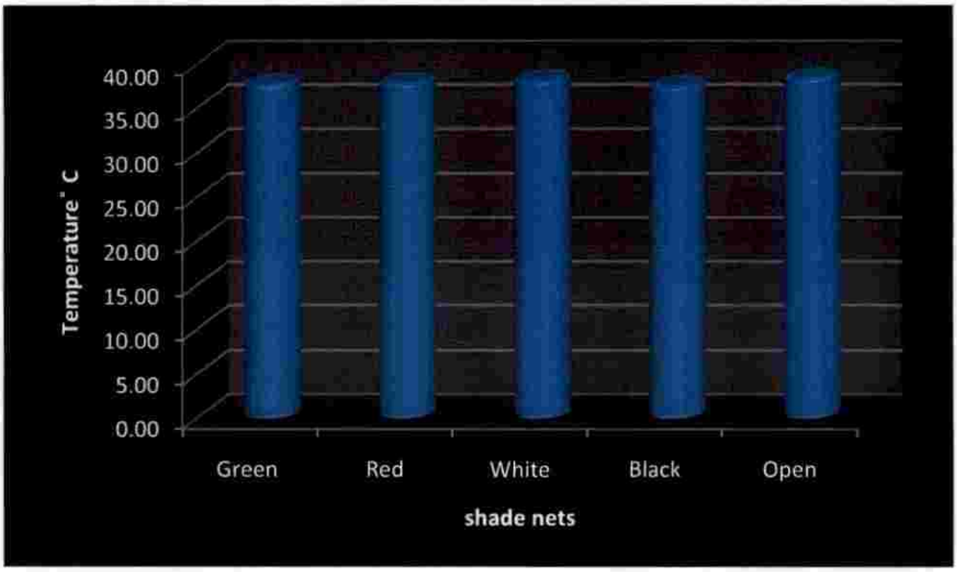
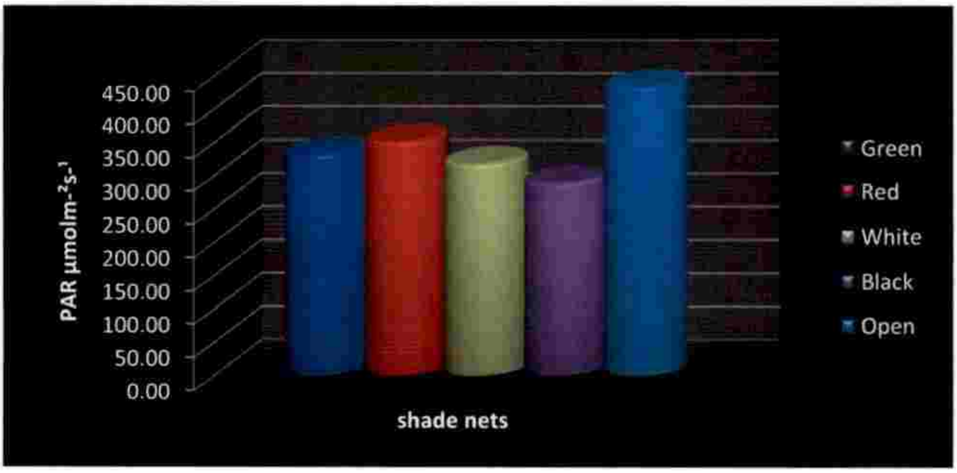


Fig. 2 Influence of spectrally varying shade nets on Photosynthetically Active Radiation (µmolm^{-2}s^{-1}).



The internode length, number of leaves & specific leaf area were influenced by growing environment. For plants grown under shade nets the reduction in leaf thickness is seen. In our study also SLA of salad cucumber, tomato and capsicum was found to be higher under red shade net and in case of yardlong bean it was found higher under green shade net (Fig.3). In salad cucumber, yardlong bean, capsicum and tomato the internode length, number of leaves, specific leaf area were highest under shade nets than open condition. Increase in intermodal length is a phytochrom mediated shade avoidance response in plants (Taiz and Zeiger, 2014). This may be due to enhanced photosynthesis and respiration due to favourable micro climatic conditions under the shade nets. This agrees with results of Ramesh and Arumugam, (2010) on vegetables grown under poly house.

Ferreira *et al.* (2012) reported that phenological characteristics such as leaf number and leaf area index of sweet pepper was affected by attenuation of photosynthetically active radiation by reflective shading net. Gupta *et al.* (2015) reported that the height and number of leaves of spinach were more in green shade net as compared to the white shade net due to favorable microclimate under in green shade net.

In this experiment highest yield was obtained under the shade nets of red, white and green than black and open condition. Similarly Illic *et al.* (2012) in his study found that increased total yield was obtained in tomato plants grown under red and pearl nets with 40% shade.

Shahak, (2008) explained the highest yield under shade nets, since the nets are composed of holes. The holes along with the translucent photo- selective threads will convert the natural, unmodified light into mixtures of diffused and spectrally modified light.

5.2 ANATOMICAL STUDIES OF PETIOLE, LEAF AND STEM

In this study the variation in anatomy of vegetables exposed to spectral management through different shade nets was examined. Lee *et al.* (2000) reported that variation in leaf structure may affect plant function in at least three ways. Leaf anatomy, particularly stomatal density and the extent and shape of mesophyll air spaces, affects resistance to gas exchange and may limit photosynthetic assimilation. Second, pigment content and distribution, influenced by anatomical changes, determine the efficiency of light capture by leaves and influence photosynthesis. Finally, leaf toughness may reduce a plant's susceptibility to herbivory, increase its longevity, and enhance the plant's carbon balance.

The anatomical studies of petiole, leaf and stem of salad cucumber, yardlong bean, capsicum and tomato revealed that the leaf structure may contribute to photosynthesis and yield. The influence of spectral quality on anatomical chances was crop specific.

5.3 PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS

The physiological parameters indicate the efficiency of the plant in terms of yield. In the present study, Photosynthetic rate was significantly higher under red shade net for salad cucumber (33.62 μmol $m^{-2}s^{-1}$), capsicum (20.67μmol $m^{-2}s^{-1}$) and tomato (30.35 μmol $m^{-2}s^{-1}$) (Fig. 4). More scattering of light was offered by red shade net which in turn gives more diffused light results in increased absorption of photosynthetically active radiation. Highest mean value of photosynthetic rate for

Fig. 3 Influence of spectrally varying shade nets on specific leaf area (cm^2/g) of salad cucumber, yardlong bean, capsicum and tomato

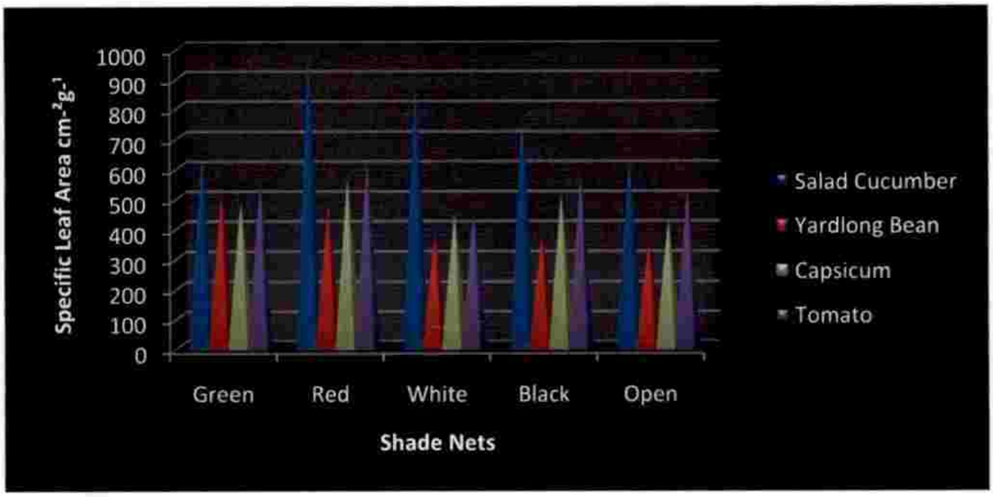
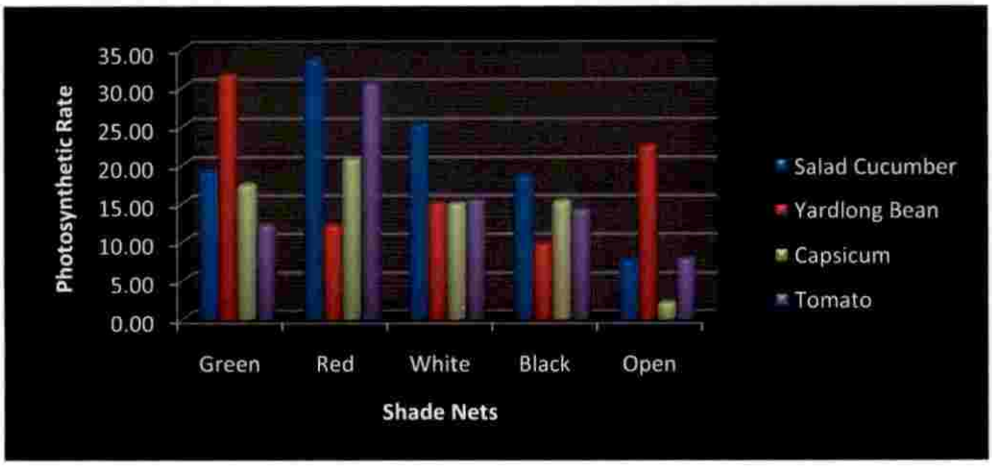


Fig. 4 Influence of spectrally varying shade nets on photosynthetic rate ($\mu molm^{-2}s^{-1}$) of salad cucumber, yardlong bean, capsicum and tomato



yardlong bean (31.52 μmol $m^{-2}s^{-1}$) was observed under green shade net .Similar results were recorded by Shahak *et al.* (2004); Elad *et al.* (2007) and Shahak, (2008).

Light mostly causes alterations in the stomatal movements of plants. Givnish and Vermeij (1976) stated that potential increases in photosynthesis resulting from greater stomatal conductance must be weighed against the costs associated with increased transpiration, such as increased root allocation, decreased mesophyll photosynthetic capacity, and shortened season of photosynthetic activity .

Talbott *et al*. (2006) remarked that stomatal opening was stimulated by blue and red light where as the green light inhibited the opening. Lee *et al*. (2007) found that the stomatal number and size was increased by white light, while blue light reduced the above parameters. From our study it was observed that the stomatal conductance was higher under shade nets than without shade condition.

The pigment composition followed a different trend in salad cucumber, yardlong bean, capsicum and tomato. In case of salad cucumber the pigment compostion was more under black shade net. Yardlong bean has most of its pigments concentrated under white shade net. Pigment composition of tomato and capsicum at maturity stage was found to be higher under without shade condition (Fig. 5 and Fig. 6). This difference in pigment composition may be due to the crop variability.

Ghasemzadeh *et al*. (2010) reported that phenolic biosynthesis requires light and is also enhanced by light. Yardlong bean had highest phenolic content under green shade net and for capsicum under open condition and for tomato under white shade net. Variation in phenolic compounds is also due to crop specificity.

Most of the quality traits show a continuous variation, strongly influenced by environmental conditions. Stronger light irradiance (both intensity and duration)

Fig. 5 Influence of spectrally varying shade nets on pigment composition of capsicum (mg g^{-1})

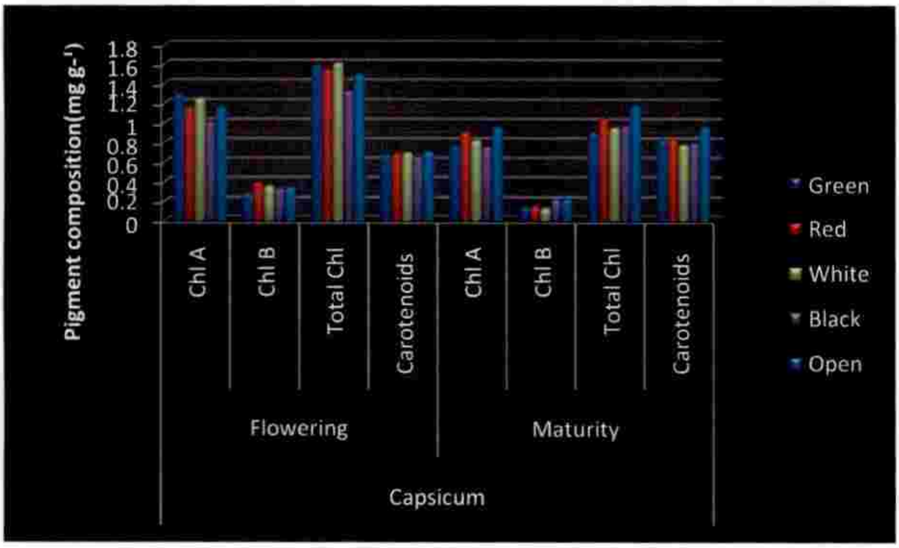
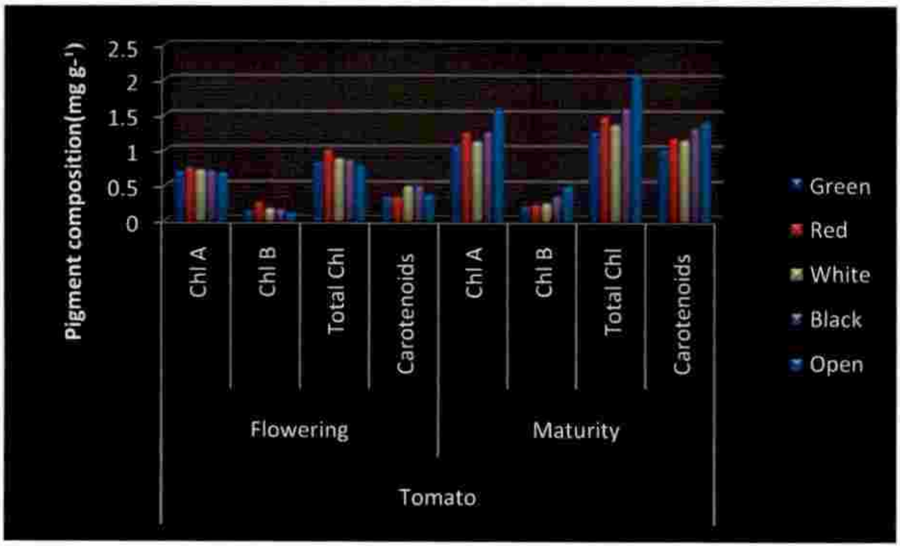


Fig. 6 Influence of spectrally varying shade nets on pigment composition of tomato (mg g^{-1})



influence the fruit growth, development, and fruit quality due to increase in the transportation of photo-assimilates to the fruit. Illic (2015) found that the tomatoes grown in plastic houses integrated with red colour nets was detected with highest concentration of lycopene (64.9 μg g^{-1} f.w.), while tomatoes grown in fields covered with pearl nets had the lowest levels of lycopene (46.7 μg g^{-1}f.w.). In our study highest lycopene content was observed in tomato plants grown under white shade net (37.90 mg $100g^{-1}$) while lowest under red shade net (15.16 mg $100g^{-1}$). Brandt *et al.* (2006), reported that the synthesis of lycopene was inhibited in fruits exposed to excessive sunlight.

In the present study ascorbic acid was found to be highest under white shade net and without shade net condition for tomato (20.93 mg/100g) and capsicum (106.81 mg/100g) respectively. Lee and Kader (2000) stated that ascorbic acid content was shown to increase in the presence of higher light intensity in fresh produce and this explains the higher ascorbic acid content obtained in tomatoes produced under the white net and without shade condition.

SUMMARY

SUMMARY

Polyhouse cultivation incorporated with photo selective netting is an emerging approach in Kerala. Light under the shade net is both spectrally modified and scattered. The spectral modification promotes physiological responses. The scattering improves the penetration of the spectrally modified light into the inner plant canopy. Different wave length of light influence specific physiological process. In this context, the study entitled "Spectral management for improving photosynthetic efficiency in polyhouse cultivation of vegetables" was conducted .

Cultivation in polyhouse enhanced with shade nets provides a new scope for commercial vegetable production. Hence the present study was proposed to understand the basic physiological mechanism on productivity of poly house crops using salad cucumber, yard long bean, capsicum and tomato as a test crops. The proposed study will generate basic information on the aptness of colored shade net over our crops in Kerala. This will in turn tells us how spectral quality modifies the development and photomorphogenic processes in crops of our interest. The study was conducted at the Department of Plant Physiology, College of Agriculture, Vellayani to understand the spectral management for improving the photosynthetic efficiency in polyhouse cultivation of vegetables. The crop was raised in farmer's poly house at Pothencode in Thiruvananthapuram district. A survey was conducted in 20 polyhouse units in Thiruvananthapuram district to know the adoption of shade nets by the farmers practicing polyhouse cultivation. The experiment was done in a polyhouse of dimension 500m^2, which was divided into five parts on an east-west direction roofed with two photoselective and two neutral shade nets of four different optical properties and one part without any shade net. The light interception by shade nets were analysed using spectro radiometer at University of Agricultural Science, Bangalore. The green net reduced 59.9%, white net reduced 55.14% and red net reduced 41.05%

of red light compared to open. Four different crops, viz. salad cucumber, yardlong bean, capsicum and tomato were grown under these shade nets.

The salient findings of the study are :

- Weather paramaters doesnot show much variation as all the shade net partitions were under the same polyhouse unit.
- Photosynthetically Active Radiation, global radiation and light intensity were slightly higher in the part without shade nets.
- The pollens of all the crops are found to be viable under different spectral condition.
- Earliness to flowering, fruiting and maturity was observed under no shade net condition for salad cucumber, capsicum and tomato, for yardlong bean under it was black shade net.
- The biometric characters were higher in shaded condition than in open shade condition.
- The anatomical studies of the stem, leaf and petiole revealed that spectral management doesn't show a drastic variation but showed some effect with photosynthesis and yield.

Spectrally varying shade nets photo selectively screen sunlight and can be utilized as a low cost technology in protected cultivation. Spectral quality has significant influence on plant growth and development. Crop suitability was also observed with different shade nets. From our present study photosynthetic efficiency was observed higher in red shade net. In general red net was suitable for capsicum and tomato, white net for salald cucumber and green for yardlong bean. The benefits of polyhouse technology and spectral management is immence.

The polyhouse technology is still in its initial stage in Kerala and combined efforts are required from all concerned agencies to bring it at par with the global standards. Economically viable and feasible technology suitable for the kerala agro climatic and geographical conditions is needed.

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SPECTRAL MANAGEMENT FOR IMPROVING PHOTOSYNTHETIC EFFICIENCY IN POLYHOUSE CULTIVATION OF VEGETABLES

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ABSTRACT OF THE THESIS

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ABSTRACT

Plant growth is influenced by both the quality and intensity of light. The transmittance of light by different shade nets are unique. Hence the spectral quality of light vary under each coloured net. Different wave length of light influence specific physiological process. In this context, the study entitled "Spectral management for improving photosynthetic efficiency in polyhouse cultivation of vegetables" was conducted at the Dept of Plant Physiology, College of Agriculture, Vellayani and at Pothencode, Thiruvananthapuram during 2014- 2016. The main objective was to study the morphological and physiological responses of vegetables, viz. tomato, salad cucumber, capsicum and yard long bean exposed to spectral modification through different colored shade nets.

A survey was conducted in 20 polyhouse units in Thiruvananthapuram district to know the adoption of shade nets by the farmers practicing polyhouse cultivation. The experiment was done in a polyhouse of dimension 500m^2, which was divided into five parts on an east-west direction roofed with two photoselective and two neutral shade nets of four different optical properties and one part without any shade net. The light interception by shade nets were analysed using spectro radiometer at University of Agricultural Science, Bangalore. The green net reduced 59.9%, white net reduced 55.14% and red net reduced 41.05% of red light compared to open. Four different crops, viz. salad cucumber, yardlong bean, capsicum and tomato were grown under these shade nets. Weather parameters such as Photosynthetically Active Radiation (PAR), global radiation and temperature were recorded but didnot show much variation. The pollen viability was not altered by spectral variation. Earliness to flowering, fruiting and fruit maturity was observed in open condition for salad cucumber and capsicum.

The number of leaves at first flowering was higher in white net for salad cucumber and yardlong bean while it was higher in red net for capsicum and tomato. Specific Leaf Area was significantly higher under red net for salad cucumber (979.52cm^{2}g^{-1}), capsicum (564.21cm^{2}g^{-1}) and tomato (631.18 cm^{2}g^{-1}). The same trend was followed in case of photosynthetic rate also. The internode elongation was found to be minimum in open condition for all the four crops. The leaf anatomy of salad cucumber grown under white net showed higher vascular thickness.

Setting percentage was higher in white and green shade nets for salad cucumber (85.40%) and yardlong bean (89.35%) respectively where as red net was suitable for capsicum (80.99%) and tomato (81.80%). Higher shoot weight and root weight were observed under white shade net for tomato. Root shoot ratio and total dry matter content was higher in capsicum grown under red shade net. Transpiration rate of yardlong bean and tomato plants grown under green shade net was higher while higher transpiration rate of salad cucumber and capsicum was observed under white shade net. The pigment composition of salad cucumber was higher under black shade net. Abaxial stomatal frequency in all the four crops was higher in open condition. Total soluble protein content of tomato and salad cucumber at flowering stage was higher under red shade net. Higher carbohydrate content was observed under open condition in case of yardlong bean, capsicum and tomato. Phenol content increased in tomato plant grown under white shade net. There was no significant variation in IAA. Higher crude protein was observed in yardlong bean grown under white shade net while the crude fibre was higher under open condition. Ascorbic acid was higher in capsicum grown under open condition while for tomato it was under white shade net.

Spectral modifications through shade nets altered morphological and physiological responses of salad cucumber, yardlong bean, capsicum and tomato. Varietal suitability was observed in different shade nets. Photosynthetic efficiency was also influenced by shade nets and reflected in the yield of selected crops. Red net was suitable for capsicum and tomato while white net was ideal for salald cucumber and green for yardlong bean.