PHOTOSYNTHETIC EFFICIENCY AND PRODUCTIVITY OF GYNOECIOUS PARTHENOCARPIC CUCUMBER IN NATURALLY VENTILATED POLY HOUSE

By

GAYATHRI RAJASEKHARAN

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"PHOTOSYNTHETIC EFFICIENCY AND PRODUCTIVITY OF GYNOECIOUS PARTHENOCARPIC CUCUMBER IN NATURALLY VENTILATED POLY HOUSE"** 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.

Vellanikkara

Date: 25-08-2015

Gayathri Rajasekharan

(2013-11-164)

CERTIFICATE

Certified that this thesis entitled **"PHOTOSYNTHETIC EFFICIENCY AND PRODUCTIVITY OF GYNOECIOUS PARTHENOCARPIC CUCUMBER IN NATURALLY VENTILATED POLY HOUSE"** is a record of research work done independently by **Ms. Gayathri Rajasekharan** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

25/8/2015

Vellanikkara

Date: 25.08.2015

Dr. K. Nandini

(Major Advisor, Advisory Committee)

Professor and Head (Plant Physiology)

College of Horticulture

Vellanikkara.

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Gayathri Rajasekharan., a candidate for the degree of **Master of Science in Agriculture** with major in Plant Physiology, agree that the thesis entitled **"PHOTOSYNTHETIC EFFICIENCY AND PRODUCTIVITY OF GYNOECIOUS PARTHENOCARPIC CUCUMBER IN NATURALLY VENTILATED POLY HOUSE"** may be submitted by **Ms. Gayathri Rajasekharan.**, in partial fulfilment of the requirement for the degree.

25/8/15
Dr. K. Nandini
(Chairman, Advisory Committee)
Professor and Head
Department of Plant Physiology
College of Horticulture, Vellanikkara.

25/08/2015
Dr. T. Girija
(Member, Advisory Committee)
Professor
Department of Plant Physiology
College of Horticulture, Vellanikkara.

25/8/15
Dr. C. Narayanankutty
(Member, Advisory committee)
Professor (Horticulture)
Agricultural Research Station,
Mannuthy.

25/08/15
Dr. S. Krishnan
(Member, Advisory committee)
Associate Professor and Head
Department of Agricultural Statistics
College of Horticulture, Vellanikkara.

25.8.15
EXTERNAL EXAMINER
(Name and Address)

Dr. P. JEYAKUMAR
Professor
Department of Crop Physiology,
Tamil Nadu Agricultural University,
Coimbatore - 641 003.

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ABBREVIATIONS

AA	:	Ascorbic acid
Ci	:	Intercellular CO_2 concentration
CTD	:	Canopy temperature depression
F_0	:	Minimum fluorescence
FIR	:	Far Infrared Radiation
F_m	:	Maximum fluorescence
FR	:	Far-red
F_v	:	Variable fluorescence
GA	:	Gibberelic acid
IAAO	:	Indole Acetic Acid Oxidase
LAI	:	Leaf Area Index
NIR	:	Near Infrared Radiation
PAR	:	Photosynthetically Active Radiation
PE	:	Polyethylene
Pn	:	Photosynthetic rate
PPFD	:	Photosynthetic Photon Flux Density
PS	:	Photosystem
R	:	Red
RH	:	Relative Humidity
TCP	:	Temperature Compensation Point
UV	:	Ultra-violet

INTRODUCTION

1. INTRODUCTION

Green house is the most practical method of achieving the objectives of protected agriculture, where natural environment is modified. The need to protect the crops against unfavourable environmental conditions led to the development of protected agriculture. The main objective of protected cultivation is the creation of a favourable micro-climate, which favours crop production. This specialized production technology helps to overcome biotic and abiotic stresses and to break the seasonal barrier to production and ensures the availability of vegetables throughout the year. Hence, it provides a new scope for commercial production of high value vegetable crops. It is being practiced in more than fifty countries all over the world (Parvej *et al.*, 2010).

Protected cultivation offers many resources to control the conditions of light (quantity and quality), temperature, humidity, CO_2 concentration, water and nutrient availability. Usually greenhouse is made up of different types of covering materials, such as a glass, polycarbonate or plastic roof and frequently glass or plastic walls. The greenhouse covered with simple plastic sheet is termed as poly house.

The top of poly house is covered with UV stabilised plastic sheet which selectively screen the various spectral components of solar radiation and transform direct sunlight into scattered light in poly houses. This type of spectral manipulation is aimed to specifically promote desired physiological process and to modulate morphological and photosynthetic responses of plants.

Air exchange with the outside is restricted, so water vapour transpired by the plants and evaporated from warm soil tends to accumulate, creating a low vapour pressure deficit (high humidity). Poly house permits easy entrance of short-wave radiation but traps the outgoing long-wave radiation. As a result the air temperature inside the poly house gradually increases due to the greenhouse effect. The CO_2 released by the plants at night is also trapped inside, which increases the rate of photosynthesis during morning hours. Therefore, the environment is generally warm, humid and wind-free inside the poly house. Such an environment promotes the fast growth of most crops.

Protected cultivation has high water and nutrient use efficiencies. Increasing photosynthetic efficiency and reduced transpiratory losses are added advantages of protected cultivation. Both of these factors are of vital importance for healthy growth of crops. It also helps in the production of superior quality produce.

Photosynthetic daily light integral, temperature and relative humidity are the main microclimatic factors inside the photo nets that profoundly influence plant growth and development. Yield of vegetables in protected cultivation are often affected or even cut by 20 to 30 per cent due to insufficient light intensity, particularly non uniform spectral energy distribution under covered environment.

Cucumber, tomato, capsicum and leafy vegetables are major crops grown in naturally ventilated poly houses. Gynoecious parthenocarpic F_1 hybrids of cucumber are widely used in poly houses as they bear only female flowers and produce fruits without pollination. Such parthenocarpic fruit set also occur naturally under low light and cool–night growing conditions.

The greenhouse varieties of cucumber (*Cucumis sativus* L.) belong to an ecological type naturalized and selected for a low light and low temperature environment of spring and winter season. These varieties therefore have a high hereditary adaptation to low light and low temperature than open field varieties. The warm humid climate of Kerala is ideal for cucumber cultivation and so cucumber is a major crop grown in poly houses (Narayanankutty *et al*., 2013).

The optimum Leaf Area Index (LAI) varies with the amount of light reaching the crop. Reports on production under various photo selective nets in Kerala also indicate variability in yield response for same crop or different crops. The mechanism of light quality on flowering and yield formation of vegetables is not fully understood. Distorted fruit formation in cucumber, poor pollination and flower abortion in tomato are reported to be due to poor light and low or high temperature inside the poly houses.

Though poly house cultivation shows promise for vegetable production, the high variability in results among 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 objectives.

1. To understand the morphological, phenological and biochemical variation in growth and development of gynoecious parthenocarpic F_1 cucumber in naturally ventilated poly house compared to open condition.
2. To compare the photosynthetic productivity of gynoecious parthenocarpic F_1 cucumber under open and poly house conditions.
3. To understand the quality of poly house grown gynoecious parthenocarpic F_1 cucumber when compared to open condition.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

This chapter reviews the relevant literature available at national and international level on various aspects pertinent to the present study under the following headings.

2.1 Protected cultivation for production of vegetables

2.2 Growth and yield of cucumber as influenced by climatic factors in the growing environment

2.3 Morphological characters of cucumber as influenced by growing environment

2.4 Biochemical characters of cucumber as influenced by growing environment

2.5 Physiological characters of cucumber as influenced by growing environment

2.6 Phenological characters of cucumber as influenced by growing environment

2.7 Yield parameters of cucumber as influenced by growing environment

2.8 Quality attributes of cucumber as influenced by growing environment

2.9 Incidence of pest and diseases

2.1 PROTECTED CULTIVATION FOR PRODUCTION OF VEGETABLES

The productivity of crop is influenced not only by its genetic makeup but also by the micro-climate around it. Protected cultivation is a cropping system in which the micro environment surrounding the plant is controlled partially or fully during their period of growth to maximize the growth and yield.

Protected cultivation plays an important role in the production of fresh vegetables. Tomato, capsicum and cucumber are the most extensively grown vegetables under green houses and give higher returns (Chandra *et al.*, 2000). Green house is the most practical method of accomplishing the objectives of protected cultivation (Nagarajan *et al.*, 2002).

Green house products have high visual quality, so that their market value is high in comparison with other field grown vegetables. The naturally ventilated green houses with larger ventilation areas, provided at the ridge and sides covered with insect-proof nets (20–40 mesh size) and covering material properties of NIR (near infrared radiation) reflection during the day and FIR (far infrared radiation) reflection during night is suitable for green house production throughout the year in tropical and subtropical regions (Kumar *et al.*, 2009). The area under green house cultivation was about 110 ha in India and world over 275,000 hectare (Mishra *et al.*, 2010).

Introduction of parthenocarpic varieties revolutionized the protected cultivation of cucumber. Parthenocarpic varieties set fruits without fertilization of ovules. So the resulting fruit is seedless. These types generally produce higher yields and do not require bees for pollination.

Kanthaswamy *et al.* (2000) conducted studies on the effect of spacing and various pruning levels on growth and yield of cucumber grown under poly house conditions revealed that the maximum yield (125.82 t/ha) was obtained at 60×60 cm^2 spacing with pruning of all the primary branches after two nodes. Green house cucumber varieties have higher adaptability than open field varieties (Yong-Jian *et al.*, 2001).

Hybrid cucumber varieties have a superior genetic architecture and hence higher overall performance compared to open pollinated varieties grown on open condition (Bisht *et al.*, 2010). Integrated nutrient management with partial shading is needed to produce high-quality cucumbers in green houses (Anjanappa *et al.*, 2012).

Green house covering is the material that covers the green house frame and plays a key role in heat retention. The most widely used materials are polycarbonate and polyethylene film. These covering materials also have an effect on growth and development of crop plants. Hao and Papadopoulos (1999) studied the effects of the cover materials and supplementary lighting on plant growth, photosynthesis, biomass partitioning, early fruit yield and quality. They reported that supplemental lighting promoted plant development and increased leaf chlorophyll, leaf photosynthesis, plant biomass and early marketable yield production. It also increased biomass allocation to fruit, fruit dry matter content and skin chlorophyll content in fruits.

The marketable yield and the number of tomato fruit per square meter in double inflated poly ethylene cladded poly houses were higher by 15 to 16 per cent and 13 to 17 per cent, respectively, than in glasshouses (Erhioui *et al.*, 2002).

Sandri *et al.* (2003) revealed that the total plant growth was reduced to 21.7 per cent by shading in tomato. The use of light selective and movable screen may substantially improve water use efficiency and radiation use efficiency of warm season crops, under water limited conditions (Rouphael and Colla, 2005).

Gent (2007) found that shading increased the fraction of marketable tomato fruit without affecting the fruit size.

Photoselective shade-netting is an emerging approach in protected cultivation. While selecting photoselective net as cover for a sunlight environment it is important to know the spectral distribution of incident sunlight, the spectral transmittance of the film and response spectra of the principal photochemical and phototropic response in plants (Hanson, 1963).

The photoselective net products are based on the introduction of various chromatic additives, light dispersive and reflective elements into the netting materials (Shahak *et al.*, 2008). They observed that those nets are designed to selectively screen various spectral components of solar radiation (UV, PAR and beyond), and transform direct light into scattered light. Hence the spectral manipulation is aimed to specifically promote desired physiological responses, while the scattering improves the penetration of the modified light into the inner plant canopy. They found that the photoselective, light-dispersive shade nets provide a unique tool that can be further implemented in protected cultivation practices.

White net green house cover optimized the growth and yield of cucumber plant (Hashem *et al.*, 2011). Abdel-Ghang *et al.* (2012) observed the effect of cover type on the transmittance of Photosynthetically Active Radiation (PAR), the reflectance or absorptance of near infra-red (NIR) and the green house air temperature. They found that NIR-reflecting plastic films are most suitable and simplest technique for covering green houses under arid conditions. NIR reflecting materials are more efficient than NIR-absorbing materials.

2.2 GROWTH AND YIELD OF CUCUMBER AS INFLUENCED BY CLIMATIC FACTORS IN THE GROWING ENVIRONMENT

2.2.1 Relative Humidity

Relative humidity fluctuation affects crop growth and development. Relative humidity inside the poly house was higher than that of the outside and the maximum difference was 9.1 per cent at 10.30 hours (Chaugule *et al.*, 1990). Higher humidities combined with higher sunlight resulted in higher rate of photosynthesis (Dalakka *et al.*, 2000).

A field experiment was conducted by Dhandare *et al.* (2008) to study the various climatological parameters taken under the environmental controlled and naturally ventilated poly house using capsicum as test crop. They found that relative humidity was high in naturally ventilated poly house than in open field condition.

An increase in RH can have a detrimental effect on growth and development of crops. Ramesh and Arumugam (2010) conducted an experiment using five types of vegetables (Tomato, Brinjal, Chilly, Bhindi and Cluster bean) under naturally ventilaled poly house. They reported that poly house had highest relative humidity over open field. Experiment conducted by Rajasekhar *et al.* (2013) to assess the efficacy of shaded net cultivation compared to open field on growth and yield of vegetables during summer and winter also revealed that RH was always higher under shade net house than in open field.

2.2.2 Temperature

Temperature is one of the major environmental factor which affects growth, development and productivity of a crop. Temperature influenced sex expression in cucumber (Cantliffe, 1981). Yield data from green house trials revealed that the influence of temperature was stronger during the early stages of growth of cucumber than during the harvesting period (Liebig and Krug, 1991).

The temperatures in the poly house was considerably higher compared to ambient temperatures in which summer season vegetables like cucumber could be grown profitably inside poly house and as off season crop during winter months (Saikia *et al.*, 2001).

The effects of air temperature and relative humidity in green house grown autumn-cropped cucumbers were investigated by Hirama *et al.* (2003). They found that the total number of fruits increased at air temperature of 25°C and 40 per cent relative humidity. They also concluded that the percentage of marketable fruits decreased during low temperature seasons.

According to Zhen-Xian *et al.* (2003) the Temperature Compensation Point (TCP) of cucumber leaves was 3.3°C at low temperature (3-15°C) and 8.9-50.7°C at high temperature (40-48°C). They reported that the effect of low temperature on TCP in different cucumber cultivars was small and the TCP of old leaves was higher than that of young leaves under low temperature. They also found that TCP of 'Xintai mici', a solar green house cultivar, was relatively lower than that of 'Jinyan 4', an open-field cultivar, at high temperature.

Experiments were carried out to investigate the effect of high temperature stress on the yield and quality of cucumber cultivars by Ling-Bo *et al.* (2004). They found that under high temperature, the neck of fruits became longer, abnormal fruits increased, skin of fruits became harder and the ascorbic acid concentration decreased.

Wein *et al.* (2004) found that the high temperature resulted in fruitlessness, delayed formation and anthesis of female flowers in pumpkin grown in green house condition. Capsicum varieties were compared in poly house and open conditions at North West Himalayas in Uttaranchal by Pandey *et al.* (2005). They found that the temperature in the open field was lower than those in the green house structures throughout the cropping period. The higher temperature was due to trapping of short wave radiations. Maximum yield of 2.41 kg per plant was recorded in poly house. In open field condition, it was only 1.51 kg per plant.

Kumar and Kumar (2006) reported that optimum temperature is essential for the normal functioning of all metabolic activities. Temperature inside the naturally ventilated poly house was more when compared to open field, which favours crop productivity (Dhandare *et al.*, 2008). They also reported that the high temperature inside poly house was related to outside temperature, depends on physical properties of poly house covering material, outside wind velocity, incident solar radiation and transpiration rates of crops grown inside the poly house.

Better growth, development and yield of tomatoes were reported under poly house due to optimum temperature and lower RH during warmer months which in turn influences the morphophenological and physiological events of tomato plants (Parvej *et al.*, 2010). Rajasekhar *et al.* (2013) reported that mean weekly temperature during summer and winter were higher under open field condition than in the shaded net house.

2.2.3 Light intensity

Light is an important natural resource for plant growth and development, in which irradiance affects plant biochemical composition and morphology. The growth rate of poly house crop gradually follows the light intensity changes which occur according to the changes in season. The growth rate of vegetable crop was proportional to light, except at very low light levels (Challa *et al.*, 1984). According to Nederhoff (1994) the light use efficiency was increased by about 10 to 15 per cent per 100 µmol mol^{-1} increase in carbon content inside poly house. Light (Photosynthetic Photon Flux Density, PPFD) was the most important factor affecting productivity in green house tomato (Papadopoulos and Pararajasingham, 1997). For healthy growth of crop in poly house minimum light requirement is 50,000 to 60,000 lux.

A study was carried out to investigate the effect of weak light on the photosynthetic properties of cucumber leaves at low temperature (Qi-Lin *et al.*, 2001). The results indicated that exposure to 100 µmol m^{-2} s^{-1} at 5°C caused severe damage to cucumber leaf photosynthetic function. The exposure of cucumber leaves to 100 µmol m^{-2} s^{-1} resulted in photosystem II photo inhibition and reduced trans-thylakoidal proton gradient.

Zhen-Xian *et al.* (2003) found that a PPDF of 400 µmol m^{-2} s^{-1} for cucumber grown at low temperature (3-15 ^{0}C) and PPFD of 1300 µmol m^{-2} s^{-1} at high temperature (40-48 ^{0}C) were required.

Cucumber hypocotyls respond to light with a high developmental plasticity in green houses (Shinkle *et al.*, 2005). Xiao-Bo *et al.* (2005) conducted a study on the effects of sustained low intensity light (40, 60, 80 and 110 µmol m^{-2} s^{-1}) on cucumber growth and photosynthesis. They concluded that sustained low intensity light treatment led to severe abortion of young cucumber fruits.

The relative effect of light on growth is greater at lower light levels (Marcelis *et al.*, 2006). Light quality (the R/FR ratio) is the most important component of shade for controlling hypocotyl growth and elevated growth hormone content (Kurepin *et al.*, 2007). Haque *et al.* (2009) observed that cucumber crop was suitable for reduced light conditions based on the total dry matter produced and fruit yield obtained from poly house. Light intensity inside the poly house was lower than in the open field (Kumar and Arumugam, 2010).

Experiment conducted by Yang *et al.* (2012) revealed that an optimum light intensity was needed for maximum rate of photosynthesis and too low light intensity did not satisfy the requirement of photosynthetic capacity and this resulted in insufficient synthesis of photoassimilates, which severely influences vegetable growth, development, and yield. They found that too high light intensity may cause significant decline in the photochemical activity of PS II or PS I, which is known as photoinhibition.

According to Hemming *et al.* (2013) diffused light is advantageous for green house crops. They noticed that modern green house covering materials were able to convert direct sunlight into diffuse light. They found that after entering the green house sunlight was scattered and penetrates into the crop and thus used for photosynthesis. They also reported that experimental research with different crops showed an increased production up to 10 per cent under diffused light conditions at different places.

2.2.4 UV-radiation

Solar radiation is the main climatic parameter needed to evaluate the climatic suitability of a region for poly house cultivation of crops. According to Deckmyn *et al.* (1994) a 15 per cent increase in UV-B radiation resulted in equal reductions in total dry weight and effective photosynthesis. Inhibition in hypocotyl elongation in response to UV-B exposure was observed in tomato and cucumber (Barnes *et al.*, 1996). Strida *et al.* (1996) found that UV-B radiation caused a lowering in chlorophyll fluorescence. UV-B radiation under well watered condition significantly reduced plant height, leaf enlargement and biomass accumulation of cucumber (Yang *et al.*, 2000).

Under UV-B stabilized sheet, the depletion of UV-B radiation affected the quality of fruits (Giuntini *et al.*, 2005). Kittas *et al.* (2006) observed that egg plants grown at low UV-level grew taller compared to those at high UV-level. The increased amount of ultraviolet (UV) radiation due to depletion of stratospheric ozone layer will exert its deleterious effect on growth and productivity by destruction of chlorophyll and reducing photosynthetic rate (Bhat *et al.*, 2009).

The effect of blocking the UV solar radiation using a UV-absorbing low density polyethylene (PE) film on tomato crop yield and fruit quality was evaluated by Papaioannou *et al.* (2012). They concluded that under the UV-absorbing film the number of insect injured fruit was reduced and the marketable yield was similar or higher than that under the common PE film. Singh and Singh (2015) also reported that prolonged UV-B exposure decreased total chlorophyll levels several plants.

2.2.5 Photosynthetically Active Radiation (PAR)

Photosynthetically active radiation is in the spectral range of solar radiation from 400 to 700 nm that photosynthetic organisms are able to use in the process of photosynthesis. An experiment was conducted by Haque *et al.* (2005) from April to September in Bangladesh under varying light intensity 100, 75, 50 and 25 per cent PAR. They found that cucumber crop duration increased with reduced PAR levels due to delayed flowering and longer fruit development period. PAR below 50 per cent caused a reduction of yield also.

Akhter *et al.* (2009) studied the light levels on dry matter partitioning in garden pea and observed that increased total dry matter was achieved at 75 per cent PAR compared to 100 per cent PAR. The PAR inside the poly house was reduced by about 40 per cent compared to the outside condition (Parvej *et al.*, 2010). Cucumbers require at least 250 $\mu mol\ m^{-2}\ s^{-1}$ of photosynthetically active radiation (PAR), below which the productivity will decline.

2.2.6 Carbon dioxide concentration

Carbon dioxide is necessary for photosynthesis which utilizes CO_2 to produce carbohydrates. Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), is an enzyme involved in the first major step of photosynthesis. Besford (1990) examined tomato leaves grown at higher CO_2 concentration, Rubisco activity was reduced at 60 per cent leaf expansion compared with the controls. Response of photosynthesis towards elevated CO_2 concentration in tomato was measured by Stanghellini and Bunce (1993). Results of the study indicate that increasing atmospheric CO_2 concentration might not increase photosynthesis.

Carbon dioxide enrichment inside the poly house increased the chlorophyll content in *Cucumis melo* (Mavrogianopoulos *et al.*, 1999). Higher levels of carbon dioxide can cause necrosis of old tomato and cucumber leaves under green house cultivation (Blom *et al.*, 2001). Sanchez-Guerrero *et al.* (2001) reported that the cucumber yield was significantly increased by CO_2 enrichment and the effect was enhanced by controlling the minimum temperatures.

Most green house crops show a positive response to increased CO_2 levels up to 1000-1500 ppm (Nelson, 2002). Initial stimulation of photosynthesis associated with CO_2 enrichment can be reduced during long-term elevated CO_2 exposure, often referred as "photosynthetic acclimation" or "down-regulation" (Ainsworth and Rogers, 2007).

Carbon dioxide enrichment treatments were conducted in open-top plastic green houses to investigate their effects on photosynthesis and growth in *Gerbera jamesonii* by Xu *et al.* (2014). Results revealed compared to the atmospheric CO_2 concentration, the leaf net photosynthetic rate and contents of photoas-similates (soluble sugar, starch, and chlorophyll) were increased, but the contents of soluble proteins decreased.

2.3 MORPHOLOGICAL CHARACTERS OF CUCUMBER AS INFLUENCED BY GROWING ENVIRONMENT

Micro-climate modifications inside the poly house influence morphological development of crop plants. Chaugule *et al.* (1990) studied the feasibility of growing capsicum in plastic tunnels during the winter season. They observed that vegetative growth inside the poly house was vigorous while outside plants were stunted.

Myster and Moe (1995) studied the difference between day temperature and night temperature influence on internode length, plant height, leaf orientation, shoot orientation, lateral branching and petiole and flower stalk elongation in plants. They concluded that internode length increases as difference between day temperature and night temperature increases and the effects of difference between day temperature and night temperature on stem elongation and leaf expansion are a result of increased cellular elongation rather than division.

Green house cucumbers are generally tall, with large leaves (Gruda, 2007). A poly house experiment was conducted during winter season in Noida to study the effect of poly house condition on the growth pattern and biomass yield in *Stevia rebaundiana* (Bert.) (Jena *et al.*, 2011). The study revealed that poly house environment triggered the production of plant material especially leaf numbers, leaf fresh weight, plant height and total biomass considerably over open climatic condition.

Malu (2011) conducted an experiment to study the feasibility of cabbage cultivation in protected and open field condition during on and off seasons. Results of study revealed that performance of cabbage under protected condition was high and seeds of NS 43 were ideal for protected cultivation. The study also reported that off season cultivation under rain shelter was found better.

A study was conducted in Kerala Agricultural University to analyse the comparative performance of cucumber crops in rain shelter and open field by Sadanendan (2013). Study concluded that overall performance was better inside rain shelter. The growth of cucumber at various stages had some relationship to temperature and humidity in poly house (Xiao-Tao *et al.*, 2013). They observed that in the whole cucumber growing period, leaves grew quickly at the early stages and slowly at the later stages.

The optimum LAI varies with the amount of sunlight reaching the crop. Under full sun the optimum LAI is seven whereas at 60 per cent sunlight it is five

(Salisburry and Ross, 1978). Generally crop productivity increases with LAI up to certain level because of more efficient light interception. When LAI enhances beyond this level further enhancement in photosynthetic efficiency is not possible.

Qing-Jun *et al.* (1996) found that when light intensity was lower inside the poly house and under low light, leaf area of cucumber per plant was affected, the number of leaves was reduced and the internodes were longer. They also observed that LAI was 1 to 2.4 during fruiting.

Patel *et al.* (2003) evaluated twenty cucumber hybrids for growth, yield and fruit quality traits in Allahabad agroclimatic conditions. The study revealed that the hybrid 'Garima Super' recorded highest vine length (249.17 cm) and number of branches per vine (11.42). Parvej *et al.* (2010) conducted an experiment in a covered poly house along with an open field tomato as test crop. They concluded that the microclimatic variables inside poly house favoured the growth and development of tomato plant through increased plant height, number of branches per plant, rate of leaf area expansion and leaf area index over the plants grown in open field. The leaf area index of the tomato crop was higher under the Near Infrared-Poly Ethylene (NIR-PE) green house during the summer period (Kittas *et al.*, 2012).

According to Pradhan *et al.* (2008) cauliflower recorded maximum plant height, number of leaves, length and breadth of leaf inside poly house compared to open condition. The vine length and number of leaves of cucumber were significantly higher under naturally ventilated poly house and insect proof net house compared to open field in both seasons (Kaddi *et al.*, 2014).

2.4 BIOCHEMICAL CHARACTERS OF CUCUMBER AS INFLUENCED BY GROWING ENVIRONMENT

2.4.1 Chlorophyll content

Chlorophyll is the green pigment found in plants which absorbs light energy needed for photosynthesis. It can absorb sunlight directly. SPAD is an instrument used for chlorophyll measurements. Haque *et al.* (2009) reported that SPAD value increased with the reduction of PAR level in cucumber leaves. These results indicated that reduced light stimulated higher amount of chlorophyll content in cucumber leaves.

Thapa *et al.* (2013) conducted an experiment to determine the growth, yield and quality of sprouting broccoli under poly house and open field condition. The study revealed that quality attributes like chlorophyll a, chlorophyll b and total chlorophyll content significantly increased in poly house grown crops.

2.4.2 Indole Acetic Acid Oxidase (IAAO) activity

Indole acetic acid (IAA) is an important endogeneous hormone found in plants. It has various physiological functions. IAA oxidase is the enzyme which control level of IAA in plants and IAA concentration in plant tissue is inversely correlated with IAAO activity.

The activity of IAA oxidase was higher in gynoecious than in monoecious plants (Retig and Rudich, 1972). The increased activity of IAA oxidase may cause the retardation of growth generally observed under low temperature (Orman, 1980).

Ludnikova (1984) analysed the IAA content in gynoecium of parthenocarpic and non-parthenocarpic varieties of cucumber. The study revealed that the pericarp of developing fruit and all the somatic tissues of the gynoecium had a higher content in parthenocarpic varieties.

Talanova *et al.* (1990) observed changes in IAA content in cucumber leaves during heat adaptation. The heat resistance was determined by assessing the 50 per cent death rate of parenchymatous cells after five minutes heating of leaf discs in water. They found that heat resistance decreased the IAA level in leaves. Kim *et al.* (1992) reported that genetic factor for parthenocarpy was associated with high content of IAA in the ovary with low IAAO activity.

Changes in the levels of indole-3-acetic acid in tomato fruit pericarp tissue during fruit development and ripening were measured by Buta and Spaulding, (1994). They concluded that the highest IAA levels were found at the earliest stage of fruit development followed by a rapid decline in levels of the hormone.

In a green house experiment on cucumber cultivars, NAA application produced the largest fruits with the more flesh (Das and Rabha, 1999). Ikeda *et al.* (1999) found that the growth of the ovaries of facultatively parthenocarpic eggplant is supported by the availability of endogenous IAA. Endogenous IAA is the key hormone for sex differentiation of cucumber (Xue-Hao *et al.*, 2002).

Gibberelic acid (GA) and auxin were found to accumulate during dark period and their rapid adjustment to lower levels in light has been reported by Folta and Childers (2008). An imbalance in the endogeneous auxin level may occur as a consequence of either excess synthesis of IAA or change in the activity of IAA oxidase, which degrades auxin (Shirashyad and Kanade, 2013).

2.4.3 Gibberelic acid (GA) content

Gibberelic acid is an endogeneous hormone which helps in plant growth and development. This hormone is also responsible for the parthenocarpic frui development. It is well established that endogeneous gibberellin delayed female flower formation (Wittawer *et al.*, 1957) or increased maleness in cucumbers (Peterson and Andher, 1960). Hayashi *et al.* (1971) reported that higher level of GA in monoecious than gynoecious varieties of cucumber.

The gibberelin content of the ovaries was nearly three times higher in parthenocarpic variety than non-parthenocarpic hybrid of tomato which confirms the importance of high ovary GA content for parthenocarpic fruit set (Hassan *et al.*, 1987). They also reported that GA_3 application induces parthenocarpy in tomato. Light regulation of gibbrelin and auxin metabolism and the importance of these regulation on stem growth during early development of crop is well documented (Peng and Harberd, 1997; Stavang *et al.*, 2007).

Grindal *et al.* (2000) studied the importance of gibberelin and phytochrome in the development of taller stems and internodes under a combination of high day and low night temperature than under a low day temperature and high night temperature in peas, cucumbers and ornamentals. The results indicate that GA plays a key role in thermoperiodic stem elongation.

2.5 PHYSIOLOGICAL CHARACTERS OF CUCUMBER AS INFLUENCED BY GROWING ENVIRONMENT

2.5.1 Photosynthetic rate

Photosynthesis is the important physiological function which produces carbohydrate. Bykov (1970) examined variation in photosynthesis between cucumber and cabbage cultivars in plastic houses. According to Xu *et al.* (1993) the net photosynthetic rate of cucumber leaves in protective field was in the range of 9 to 22 μmol CO_2 m^{-2} s^{-1}. They reported that response characteristic of photosynthesis was affected by temperature conditions during the growth.

Nederhoff and Vegter (1994) observed large variability in photosynthesis. They concluded that low light conditions reduced sensitivity of the canopy to CO_2 and decreases photosynthetic rate. According to Zhen-Xian *et al.* (2003) starting time of photosynthesis (from zero to maximum) was 42-45 minutes in functional or young leaves, and 54-60 minutes in old leaves of cucumber grown inside the glasshouse.

Chen *et al.* (2005) observed that elevated CO_2 concentration inside the poly house enhances photosynthesis. They also found that in the long term, plants grown at an elevated CO_2 concentration may have a lower photosynthetic rate at a given CO_2 concentration than plants grown at a lower CO_2 concentration.

Wang *et al.* (2005) reported that growth and development of cucumber in spring green house were affected by low light. They found that in the low light the stomata factors resulted in decreasing the Photosynthetic rate of cucumber seedling.

Tao *et al.* (2010) studied the effects of shading on growth and the diurnal changes of photosynthesis in vegetables. The results indicated that dry matter accumulations of the vegetables were greatly decreased by shading and intercellular CO_2 concentration was greater for green house having more amount of shade.

The change in photosynthetic rate, photochemical efficiency and capacity of energy distribution in light induction process of cucumber in low light acclimated leaves remains unclear (Sui *et al.*, 2011).

Qian *et al.* (2012) observed that CO_2 concentration was higher in the semi-closed than conventional modern green houses due to the reduction of window ventilation. They concluded that photosynthetic acclimation to elevated CO_2 concentration only occurred in plants with low sink strength.

2.5.2 Transpiration

Aubinet *et al.* (1989) observed that green house limits water-vapour exchange with the outside air which results in a feedback effect. They also concluded that a change in crop transpiration alters the water-vapour content in the green house air that affects the transpiration rate. Another research conducted in poly house also shows that transpiration rate inside the poly house was higher than outside (Chaugule *et al.*, 1990).

Yang *et al.* (1990) measured transpiration rate of green house cucumber and found that the transpiration rate varied with solar radiation and was not uniformly distributed within the canopy. Bakker (1991) took porometer measurements of crops like eggplant, cucumber, sweet pepper and tomato inside a glasshouse during day and night conditions at different levels of air vapour pressure deficit. They reported that highest stomatal conductance was observed for tomato and cucumber.

Medrano and Lorenzo (2005) found a reduction in the foliar transpiration rate of green house cucumber crop over its ontogeny under high and low radiation levels. Under poly house conditions, there was more transpiration than in open condition (Brar *et al.*, 2006).

2.5.3 Stomatal resistance

Stomatal apertures control the movement of CO_2 from the atmosphere into the mesophyll of leaves and water vapour towards outside. Stomatal resistance is the resistance offered by stomata for gaseous exchange. Reduction in transpiration and photosynthesis can be mainly attributed to a stomatal closure, which increases the resistance in the gaseous pathway for water vapour and CO_2 (Vaadia *et al*,. 1961).

An experiment was conducted on stomatal resistance, transpiration and relative water content of cucumber, beans and tomato under controlled conditions by Al-Ani and Bierhuizen (1971). They observed that resistance value of cucumber was greater than that of tomato and beans.

Stomatal aperture appears to be controlled by complex mechanisms which operate to maintain a variable balance between allowing CO_2 uptake to proceed, while restricting the loss of water vapour, and preventing leaf desiccation (Schulze and Hall, 1982).

The reduced CO_2 intake due to stomatal resistance results in reduced photosynthesis (Chaves *et al.*, 2002). The stomatal transpiration and resistance levels may vary daily or seasonally according to the species or plant variety (Sena *et al.*, 2007).

2.5.4 Carboxylation efficiency

Carboxylation efficiency indicates the increase in photosynthetic rate achieved per unit increase in CO_2 fixation. Xiaolei *et al.* (2005) studied the effect of photosynthesis-light response curve and CO_2 response curve of the seedlings of four pepper cultivars treated under different low light intensities. They found that carboxylation efficiency decreased under shade. The response of photosynthesis to increase in carbon dioxide concentration is often considered as a fairly good estimate of carboxylation efficiency (Bindhumadhava *et al.*, 2005). High temperature stress reduces carboxylation efficiency (Cui *et al.*, 2006).

The ratio of photosynthesis to intercellular CO_2 concentration (Pn/Ci) can be considered as the efficiency of Rubisco activity, which decides the stomatal limitation under stress condition (Niinemets *et al.*, 2009). Carboxylation efficiency calculated can be correlated with stomatal limitation. In sugarcane a high Ci value indicated a decrease in the Pn/Ci ratio (Machado *et al.*, 2009; Endres *et al.*, 2010).

Shade-induced reductions in the carboxylation efficiency were reported in sesame (Alam *et al.*, 2011). Sui *et al.* (2012) studied two genotypes of sweet pepper varieties 'ShY' and '20078' under low light condition. They reported that carboxylation efficiency of sweet pepper leaves increased gradually and decreased after reaching the maximum levels.

2.5.5 Canopy Temperature Depression (CTD)

Canopy temperature is measured by the infrared thermometer. Canopies emit long-wave infrared radiation and the Infra-Red (IR) thermometer senses this radiation and converts it to an electrical signal, which is displayed as temperature of canopy. Canopy temperature depression (CTD) is the difference between leaf temperature and ambient air temperature. It is an indication of plant stress from heat, light and water stress. With high light leaf temperature will be higher and that is important for photosynthesis, stomatal opening and respiration. Leaf temperature was lower than air temperature on clear summer days in green house cucumber (Yang *et al.*, 1990).

2.5.6 Chlorophyll fluorescence

Chlorophyll fluorescence is light re-emitted by chlorophyll molecules from excited to non-excited states and used as indicator of photosynthetic energy conversion in higher plants. Chlorophyll fluorescence was found to be a useful indicator of freshness and marketable quality of Broccoli (Krans and Weis, 1984). Usually fluorescence yield is highest when photoreaction and heat dissipation was lowest. Thereafter changes in fluorescence yield reflect changes in photochemical efficiency (Cao and Govindjee, 1990).

The development of photochemical activity and carbon assimilation in light-grown cucumber leaves was studied to determine the pattern of acquisition and its relationship to leaf growth and expansion (Croxdale and Omasa, 1990). They found that measurements of chlorophyll a fluorescence showed that leaves acquire photochemical function over a period of six or more days, and gas exchange studies showed increase in carbon assimilation over a parallel time period. They concluded that as leaves expand and mature, they undergo a sequential series of changes in fluorescence response.

Chlorophyll fluorescence is measured using a fluorometer. This instrument gives the information on the functioning of PS II. It measures minimum fluorescence (F_0), maximum fluorescence (F_m) and variable fluorescence (F_v=F_m-F_0). The ratio F_v/F_m indicates quantum efficiency of PS II.

Among all the physiological parameters photosynthesis was highly co-related with F_v/F_m value. The changes in photosynthetic rate, F_v/F_m ratio (based on maximum and variable fluorescence) and quantum yield indicate physiological rearrangements that take place with seasonal change in temperature and these changes vary with light environment (Cornie and Ghashghaie, 1991). Sasaki *et al.* (1994) found that the cucumber plants grown at 25°C had higher F_v/F_m values than plants grown at 35 or 15°C.

A comparative study was carried out by Fu-Mam and Guo-Cheng (1995) with 3 cucumber cultivars differing in their sensitivity to light and temperature. This study on the kinetics of chlorophyll fluorescence induction in functional leaves of each cultivar indicated that the slow fluorescence transient (M peak), reflecting the activity of the assimilation enzyme or associated with photosynthetic induction, was less clear in winter than in spring. They found that it varied among different cucumber cultivars and the M peak of Changchunmici variety was the clearest.

The effect of temperature on chlorophyll fluorescence was studied in sweet pepper and cucumber. The results indicate that temperature had a significant effect on initial, maximum and variable fluorescence (Kosson, 1999). The chlorophyll fluorescence measurement indicated low values causing decrease in photosynthetic efficiency of tomato plants during summer in response to increasing photosynthetic photon flux under green house conditions (Ayari *et al.*, 2000).

Rapid assessment of the fluorescence response of green house crops to temperature will provide better information for the design of poly house or green house cooling systems (Willits and Peet, 2001). Leaves grown under high irradiance often have higher rate of photosynthesis due to higher Rubisco carboxylation activity. Thus high light response occurs to maximum light-saturation ratio of photosynthesis (Murchie *et al.*, 2005).

Under high temperature stress, chlorophyll fluorescence of cucumber decreases (Hong-Mei *et al.*, 2012). Chlorophyll fluorescence is one of the most popular techniques in plant physiology due to the ease with which the user can gain detailed information on the state of PS II (Murchie and Lawson, 2013).

2.5.7 Light absorption coefficient

The proportion of intercepted light depends on leaf area and is characterised by the LAI which is the number of leaves per unit land area. Since leaf mass per unit leaf area is closely related to long term light interception by leaves, the canopy light interception and absorption can be estimated from the above parameter instead of LAI (Rosati *et al.*, 2001).

The efficiency of transformation of intercepted light in to biomass eventually depends on photosynthetic rate of leaves (Brissan *et al.*, 2003) and this efficiency differs between species (Hammer *et al.*, 2010).

2.6 PHENOLOGICAL CHARACTERS OF CUCUMBER AS INFLUENCED BY GROWING ENVIRONMENT

Any modification in the micro-climate surrounding the plants affects the flowering and fruiting of crops. Under poly house the crops open flower and mature fruits earlier than in open field. (Nagalakshmi *et al.*, 2001). The total crop duration was found extended in poly house grown capsicum from 117 days to 218 days which facilitates maximum number of branches and higher yield in poly house (Patel and Rajputh, 2003).

In capsicum, the total fruit bearing period was also prolonged inside poly house condition than open field (Pandey *et al.*, 2005).

Flowering, fruit setting and fruit maturity in poly house tomato plants were advanced by about 3, 4 and 5 days respectively compared to the crop raised in open field condition. Poly house plants had a higher number of flower clusters per plant and flowers per cluster (Parvej *et al.*, 2010). Hybrid cucumber variety 'Garima Super' recorded highest number of male flowers (206.33) and female flowers (29.17) per vine among different hybrid varieties (Patel *et al.*, 2013).

2.7 YIELD PARAMETERS OF CUCUMBER AS INFLUENCED BY GROWING ENVIRONMENT

The ultimate aim of crop production is to enhance the final yield. Drews (1980) observed that the marketable fruit production was higher under poly house as compared to open field. He found that fruit development is closely related to the temperature and very high temperatures reduced fruit set to 30 per cent. He also noted that low night temperatures increased cucumber fruit set and total yield, while a rise in light intensity and air temperature improved fruit development and shortened the time from pollination to harvest.

According to Marcelis and Hofman-Eijer (1993) when the growth of a fruit was not constrained by assimilate supply, a decrease in growing period with increasing temperature was noticed resulting in an increase in final fruit weight. Nimje and Shyam (1993) reported poor yield in tomato under green house as compared to open field crop because of higher temperature during growth, flowering and fruiting period in the green house. Fresh weight of fruit per unit CO_2 was highest in cucumber (Nederhoff, 1994).

Nagalakshmi *et al.* (2001) reported that capsicum crops grown in the naturally ventilated poly house had four times more yield compared to those grown in the open field. Sood and Sharma (2006) conducted experiment on protected environment using cucumber cultivars and observed that protected environment had distinct superiority and significantly higher number of fruits, fruit weight, fruit length and diameter.

According to Kanwar (2011) cultivation of tomato under the poly house produced 136.12 per cent more yield per hectre and 188.93 per cent more fruits per plant compared to open field cultivation. The maximum growth of the capsicum fruit occurred between 6-14 days after flower opening and the fruit become uniformily cylindrical at 14^{th} day after flower opening (Singh, *et al.*, 2011).

Singh *et al.* (2012) reported that number of fruit clusters per plant, fruits per cluster, fruits per plant, fruit length, fruit diameter, individual fruit weight, fruit weight per plant and fruit yield were higher in poly house over open field condition. They also reported that the reduction in yield and economic loss were high under open field crops in comparison of poly house cultivation.

'Garima Super', a hybrid cucumber has the highest number of fruits per vine (13.83), fruit weight (168.33 g), fruit length (168.33 cm), fruit diameter (4.03 cm) and fruit yield (2.24 kg per vine) compared to open field grown crop (Patel *et al.*, 2013). Yield attributes like number of fruits per wine, fruit length and fruit diameter are the crucial factors which decides the yield and market appeal of the fruit (Arun and Jaykumar, 2014). Fruit weight, fruit length and fruit width were significantly higher under naturally ventilated poly house compared to open field in summer and kharif seasons (Kaddi *et al.*, 2014).

2.8 QUALITY ATTRIBUTES OF CUCUMBER AS INFLUENCED BY GROWING ENVIRONMENT

Quality of harvested products is the major attribute which determines acceptance among people. Ascorbic acid (AA) is considered as one of the quality parameter of cucumber fruits. In general, lower the light intensity during growth, lower the AA content of the plant tissues (Harris, 1975).

The influence of CO_2 enrichment on fruit growth, firmness and colour, together with its effect on the concentrations of ascorbic acid, organic acids and sugars, were determined at various stages of maturity in fruits of tomato by Islam *et al.* (1996). They found that CO_2 enriched tomatoes had lower amounts of citric, malic and oxalic acids, and higher amounts of ascorbic acid, fructose, and glucose than the control.

Jolliffe and Lin (1997) reported that the measures of fluorescence were negatively correlated with shelf life. And the F_v/F_m ratio, which more directly measures photosynthetic competence, was positively correlated with shelf life. They found that longer shelf life was associated with fruit in which photosynthetic systems were more functional at harvest. Though longer shelf life is achieved in cucumber when fruits are well exposed to sunlight, the physiological roles of light in extending shelf life are not yet clear.

The concentration of ascorbic acid ranged between 14.6 and 21.7 mg/100 g fresh weight of ripe tomato fruit (Abushita *et al.*, 2000). Ascorbic acid is present in plant tissues undergoing active growth and development, and the amount of AA varies among species and cultivars (Lee and Kader, 2000). Many pre and post-harvest factors influence the AA content of horticultural crops.

Dorais *et al.* (2004) reported that commonly seen physiological disorders of tomato crop inside green house are blossom-end rot, bronzing of the tissue immediately under the skin of the fruit, blotchy ripening, blossom drop, 'hollow fruit', and 'oedema' or 'dropsy'. They also noted that concentric cuticle cracking in green house tomatoes production, where the percentage of fruit affected can vary from 10 to 95 per cent of total fruit harvested.

Singh *et al.* (2004) found that capsicum fruits under poly house cultivation are more uniform shape, larger size and mature one month earlier than field grown crop. Increased levels of relative humidity and CO_2 concentrations at a high ambient temperature, accompanied by an increase in mean temperature promoted secondary metabolism, resulting in a maximum increase in contents of lycopene (by 49%), carotene (by 35%), and phenolic compounds (by 16%) as well as antioxidant activity compared to open field grown crop (Dannehl, 2012). Evidence of ascorbic acid content among different hybrid cultivars of cucumber revealed that the variety 'Garima Super' recorded highest content of 7.28 mg/100 g (Patel *et al.*, 2013).

Sensory analysis of six salad cucumber varieties was carried out by varied Pevicharova and Velkov (2007). They observed that flesh colour was the most stable character while appearance, skin colour, aroma, texture and taste varied. They also reported that the high temperature and low air moisture probably contributed to deterioration of the sensory qualities. Sensory evaluation provides information related to the multiple attributes of food perceived simultaneously by the human senses (Taniwaki and Sakurai, 2010).

2.9 INCIDENCE OF PEST AND DISEASES

Incidence of pest and diseases reduces marketable yield remarkably. Both these can be controlled to some extend inside protected structures. The warm, humid conditions under protected conditions provide a favourable environment for pest development Plants grown in controlled environments, such as green houses and growth chambers, are affected earlier, more frequently and to a greater extent by tipburn than field grown plants (Saure, 1998).

Singh *et al.* (2011) observed the performance of sweet pepper (*Capsicum annum*) varieties under protected and open field conditions in Uttarakhand region. They reported that minimum bacterial wilt (3.40%) and blossom end-rot of fruit (4.32%) was observed under poly house condition, while it was maximum in open field condition (68.7 and 17.10%) respectively.

Mites are sap-sucking pests which attack a wide range of green house plants like tomato, cucumber, chilly etc. Sallam *et al.* (2009) observed spider mites in cucumber under protected cultivation. Maklad *et al.* (2012) found a positive relationship between environmental (temperature and relative humidity) factors and population of aphids, spider mites, thrips and whitefly under protected cultivation. Mites are capable of causing extensive damage to a range of green house crops (Murphy, 2014). He observed that hot, dry climate inside the green house was favourable for mite growth.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The study was conducted in a farmer's poly house (Shri. Rajan Valath, Thannyam, Thrissur District) during March 2014 to June 2014. The details of materials used and methods adopted are presented in this chapter.

3.1 GENERAL DETAILS

3.1.1 Location

The geographical co-ordinates of the location of Thannyam are 10° 24' 15.8004"N and 76° 8' 7.8144"E with an altitude of 6 m above MSL.

3.1.2 Season

The crop was raised in the poly house from March 2014 to June 2014.

3.2 EXPERIMENTAL DETAILS

The crop raised was gynoecious parthenocarpic F_1 cucumber. The size of poly house was 180 m^2 and covered with a five layer ultra violet stabilized low density polyethylene sheet of 200 micron thickness with 85 per cent light transmissibility. Insect proof net of 40 mesh was used for covering the sides. Vertical trailing system up to a height of 4m was followed inside the poly house. The crop was raised simultaneously in open condition also for comparing the growth and development in two conditions (Plate 1).

T_1: Open condition

T_2: Poly house condition

The variety used was 'ZECO F_1'

Plate 1. View of experimental plot: Naturally ventilated poly house

Plate 1a. Open field

Plate 1b. Poly house

3.2.1 Varietal Details

ZECO F_1

The variety ZECO F_1, a gynoecious parthenocarpic hybrid cucumber, is an early maturing with very high yield potential (4-5 kg $plant^{-1}$). It is released by ENZA ZADEN plant breeding company, Netherlands. Fruits are uniform in size and shape with rounded ends, strong and straight with an approximate length of 15 to 17 cm. Skin colour attractive with a colour range from green to dark green. The variety is suitable for green house and low tunnel planting. The seeds are coated with Thiram and have 97% germination and 99% purity.

3.2.2 Raising of crop and management

The crop was raised in rows of 20 m length. Seeds were sown with a spacing of 100 cm x 50 cm in each row. Farm yard manure was given at the time of land preparation at the rate of 40 t/ha. The N, P, and K were given at the rate of 175:125:300 Kg/ha. Fertilizers were applied through fertigation once in three days (Plate 2). Pruning of basal leaves up to a height of two feet from the base was done at 45 DAS in both conditions. Other agronomic and cultural operations were made as per adhoc Package of Practice (POP) of Kerala Agricultural University for protected cultivation. The crop was raised simultaneously in open condition also. In open condition length of row was 20 m with spacing of 100 cm × 50 cm. The same facilities and other management practises given in poly house were given in open condition also.

3.3 OBSERVATIONS RECORDED

3.3.1 Climatic variables

All the climatic parameters temperature, Relative humidity (RH), Ultra-violet radiation (UV), light intensity, Photosynthetically Active Radiation (PAR) and carbon dioxide concentration were observed under both conditions from 9.00

Plate 2. Fertigation tank

Plate 2a. Drip irrigation

am to 12.00 pm at one hour interval (4 hours daily) which is considered as the biologically active photoperiod for inducing the physiological process.

3.3.1.1 Relative humidity

Relative humidity outside and inside the poly house was observed at weekly interval throughout the crop period using a sensor in a temperature and humidity meter. It was expressed in percentage.

3.3.1.2 Temperature

Maximum temperature both outside and inside the poly house was recorded at weekly interval using a sensor in a temperature and humidity meter. It was expressed as ^{0}C.

3.3.1.3 UV radiation

The UV radiation inside and outside of poly house was measured using UV-B meter (Model-3414F, Field scout, Spectrum technology, Inc. USA) throughout the growing period at weekly intervals during morning hours and expressed as Wm^{-2}.

3.3.1.4 Light intensity (lux)

Light intensity of crop both outside and inside the poly house was measured using lux meter (Digital Lux Meter, TES 1332) and expressed in lux.

3.3.1.5 Photosynthetically Active Radiation

Photosynthetically Active Radiation (PAR) was observed weekly using the instrument Model-3415F, Field scout, Quantum Light Meter, Spectrum technology, Inc. USA. The intensity of PAR is referred as PPFD (Photosynthetic Photon Flux Density) which is measured in unit $\mu mol\ m^{-2}\ s^{-1}$.

3.3.1.6 Carbon dioxide concentration

Reference CO_2 concentration, which indicates the ambient CO_2 was measured using portable photosynthesis system (PPS) (Model - LI-6400 of LICOR Inc. Lincoln, Nebraska, USA). The CO_2 concentration was recorded at 15 days interval throughout the growing period of the crop for both open and poly house conditions along with the photosynthetic measurements.

3.3.2 Morphological observations

Six plants each were selected randomly from open and poly house condition and tagged to measure morphological observations. All morphological observations were recorded at 15 days interval from date of sowing throughout the crop period.

3.3.2.1 Leaf area

Individual leaf area was taken using Portable Leaf Area Meter (LI 3000 A, LI-COR, Lincoln, Nebraska, USA). Total leaf area was measured in all the selected plants and expressed as cm^2 $plant^{-1}$.

3.3.2.2 Leaf area index

Leaf area index is a unit less parameter. It was calculated using the formula given by Williams (1946).

$$LAI = \frac{\text{Total leaf area of plant}}{\text{Land area occupied by plant}}$$

3.3.2.3 Internodal length and number of nodes

Number of nodes from base to top was counted and length between nodes was measured in all the selected plants as internodal length and expressed in cm.

3.3.2.4 Number of leaves

Total number of leaves from the selected plants was counted from both open and poly house conditions and expresses in number.

3.3.3 Biochemical characters

Biochemical parameters were estimated at 15 days interval up to 75 DAS.

3.3.3.1 Total chlorophyll content

Chlorophyll a, chlorophyll b and total chlorophyll were estimated by the method suggested by Hiscox and Israelstam (1979). For chlorophyll estimation, 100 mg leaf sample was added to 10 ml DMSO (Dimethyl Sulphoxide) and kept in darkness overnight. The final volume was made up to 25 ml after filtering. Then the chlorophyll content was estimated in spectrophotometer (Model-4001/4 Thermo Spectronic, Thermo Electron Corporation, USA) at two wavelengths 645 nm and 663 nm and expressed as milligram g^{-1} fresh weight of plant tissue. The calculation was done by the following formulae.

Chlorophyll 'a' = [(12.7 x A663) – (2.69 x A645)] x V/1000 x W
Chlorophyll 'b'= [(22.9 x A645) – (4.68 x A663)] x V/1000 x W
Total chlorophyll = [(20.2 x A645) + (8.02 x A663)] x V/1000 x W

Where,
A = Absorption at given wavelength
V = Total volume of sample in extraction medium
W = Weight of sample

3.3.3.2 IAA Oxidase activity

IAA Oxidase activity was estimated by the method suggested by Parthasarathy *et al.* (1970) with little modification, using Garden Weber reagent. Two hundred and fifty milligram plant sample was homogenised in a mortar and pestle using phosphate buffer and centrifuged. Extract was collected and volume made up to 25 ml. Ice-cold phosphate buffer and auxin were added to 1 ml sample extract taken from 25 ml. The absorbance was read at 520 nm and the enzyme activity was expressed as μg of unoxidised auxin g^{-1} h^{-1}.

3.3.3.3 Gibberelic acid

The method for the extraction, purification and estimation of endogenous plant hormone Gibberelic acid (GA) was modified from those described by Sunderbarg (1990) and Kojima (1995). Two hundred and fifty milligram plant sample was homogenised in a mortar and pestle with methanol (ice cold) and kept at 4^0C in dark for four hours. The homogenate was centrifuged, filtered and the solid residue was further extracted twice with the same solvent.

All the methanolic extracts was combined and concentrated to a water residue in vaccum at 50^0C for one hour. The volume was adjusted to 10 ml with phosphate buffer and partitioned in a separating funnel with 10 ml diethyl ether by stirring for three minutes. The ether phase was discarded and the aqueous phase was adjusted to pH 2.7 with 0.4 M HCl. The aqueous phase again was partitioned as above and the aqueous phase thus collected was further partitioned two times with 0.4 M $NaHCO_3$.

The finally partitioned aqueous phase was collected and again partitioned with 10 ml ethyl acetate. The aqueous phase was decanted and stored at 4 ^{0}C after adding 2 ml of methanol. This was used for Gibberelin estimation by adding Zinc acetate, Potassium ferrocyanide and centrifugation of extract. The supernatant collected was kept at 20 ^{0}C for 75 minutes after adding 30 per cent HCl. The absorance was read at 254 nm using a UV-VIS spectrophotometer. GA content was calculated and expressed in μg g^{-1}.

3.3.4 Physiological observations

Physiological observations were also recorded at 15 days interval up to 75 DAS during the crop growth period.

3.3.4.1 Leaf gas exchange parameters

Leaf gas exchange measurements were performed using portable photosynthesis system (PPS) (Model - LI-6400 of LICOR Inc. Lincoln, Nebraska, USA). A total of three measurements were taken in the same leaf for each selected plant (Plate 3 and 3a). Leaf was inserted in leaf chamber. Reading was taken between 9.00 am and 12.00 pm using this instrument. The following gas exchange parameters were recorded and the unit expressed is given in parenthesis.

(a) Photosynthesis rate (μ mol CO^2 m^{-2} s^{-1})

(b) Transpiration rate (mmol H_2O m^{-2} s^{-1})

(c) Stomatal conductance (mol H_2O m^{-2} s^{-1})

(d) Intercellular carbon dioxide concentration (Ci in ppm)

(e) Reference carbon dioxide concentration (ambient CO_2 concentration in ppm)

Stomatal resistance was calculated from stomatal conductance using the formula,

Stomatal resistance (s cm^{-1}) = 1/ Stomatal conductance

3.3.4.2 Number of stomata

Number of stomata from lower side of leaf was counted from open field and poly house grown crops using research microscope. It was expressed as number per mm^{-2}.

3.3.4.3 Carboxylation efficiency (μmol CO_2 m^{-2} s^{-1} ppm^{-1})

Instantaneous carboxylation efficiency was calculated from leaf intercellular CO_2 concentration (Ci) and photosynthetic rate (Pi) obtained from gas exchange measurements using portable photosynthesis system (PPS) (Model - LI-6400 of LICOR Inc. Lincoln, Nebraska, USA).

Carboxylation efficiency = Photosynthetic rate (Pi) / Intercellular CO_2 content (Ci)

Plate 3. IRGA measurements from open field

Plate 3a. IRGA measurements from poly house environment

Plate 3c. Chlorophyll fluorescence measurements

3.3.4.4 Canopy Temperature Depression (CTD: ^0C)

Canopy temperature depression was measured using Infrared thermometer (Model-6110L AGRITHERM IIITM Infrared thermometer by Everest Interscience Inc. Tuscon, USA) during 9.00 am and 12.00 pm and expressed in ^0C. Canopy Temperature Depression (CTD) was also measured using Infrared thermometer.

3.3.4.5 Light absorption coefficient

Light absorption above canopy (I) and below canopy (I_0) was measured by using Digital Light Meter (TES 1332) during 9.00 am and 12.00 pm from the selected plants. Light absorption coefficient was calculated using the formula suggested by Monsi and Saeki (2005).

Light absorption coefficient = $\log (I/I_0) \times 1/L$

Where,

I_0 = light absorption below canopy
I = light absorption above canopy
L = Leaf Area Index

3.3.4.6 Chlorophyll fluorescence

The chlorophyll fluorescence of the crop was measured by portable Modulated Chlorophyll Fluorometer, OS1p (OPTI-SCIENCES: Hudson, USA). Readings were taken at morning hours from 9.00 am to 12.00 pm during the growth period of crop from an additional crop raised at ARS, Mannuthy (Plate 3c). The key fluorescence parameters, F_0 (initial fluorescence) and F_m (maximum fluorescence) were measured. From this, F_v (variable fluorescence) was derived as $F_v = F_m - F_0$.

The F_v/F_m ratio was worked out as

$$F_v/F_m = \frac{\text{Variable fluorescence}}{\text{Maximum fluorescence}}$$

This F_v/F_m is a useful ratio that indicates the proportion of quantum yield or quantum efficiency of PS II in relation to a high degree of photosynthesis.

3.3.5 Phenological observations

Six plants were randomly selected in both conditions to record the phenological observations.

3.3.5.1 Days to flowering

Number of days was counted from the date of sowing to the date when first flower opened in both poly house and open condition and the values expressed as days to flowering.

3.3.5.2 Days to first harvest

The number of days taken from sowing to first harvest at tender fruit stage was recorded for both poly house and open condition and the values expressed as days to first harvest.

3.3.5.3 Days to last harvest

The number of days taken to last harvest from the date of first harvest was counted for both conditions and expressed as days to last harvest.

3.3.5.4 Number of harvest

Total number of harvests made from both the conditions was recorded.

3.3.6 Yield components

3.3.6.1 Number of fruits per plant

The number of fruits produced in each plant under each condition in each harvest was counted, added and the average for six plants were calculated and expressed as number of fruits per plant.

3.3.6.2 Fruit weight

The weight of single fruit from the selected plants from both conditions was recorded and the mean was calculated. It was expressed in gram.

3.3.6.3 Fruit length

The length of each fruit from the selected plants was measured for both conditions and mean was calculated. It was expressed in cm.

3.3.6.4 Fruit yield

The yield of 46 plants from open as well as poly house conditions was recorded and mean was calculated. It was expressed in kilogram.

3.3.6.5 Marketable yield

Marketable yield was calculated from total yield obtained from 46 plants for both conditions and expressed in kilogram.

3.3.7 Quality parameters

3.3.7.1 Ascorbic acid content

Ascorbic acid content of fruit was estimated by the method suggested by Sadasivam and Balasubraminan (1987). Five gram of fruit sample was taken and extracted with 4 per cent oxalic acid. Ascorbic acid content was estimated using standard indicator dye 2,6-dichlorophenol indophenol and expressed as mg g^{-1}.

3.3.7.2 Fruit colour

Fruit quality was assessed through visual appearance by observing colour of the fruit.

3.3.7.3 Organoleptic evaluation

The organoleptic characters of cucumber fruits were evaluated using a nine point hedonic scale (Amerine *et al.*, 1965) to assess the colour and appearance, flavour, taste, texture, after taste and overall acceptability of the products by a panel of 15 judges from different age groups (Watts *et. al.*, 1989). For organoleptic test, Kendall's Co-efficient of Concordance was performed and the mean rank scores were taken to differentiate the best fruit based on quality parameters.

Hedonic scale for sensory quality evaluation

Rating	Numerical value
Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

3.3.8 Incidence of pest and diseases

Incidence of pest and diseases throughout the growing period of crop was monitored for both outside and inside conditions.

3.4 Statistical analysis

The data was analysed using statistical software SPSS. The t-test and paired t-test were used for comparing two growing environments with regard to quantitative parameters.

RESULTS

4. RESULTS

Results obtained from the observations made on morphological, biochemical, physiological, phenological, yield, quality and climatic parameters of gynoecious parthenocarpic F_1 cucumber hybrid ZECO F_1 grown in poly house and open conditions are presented in this chapter.

4.1 VARIATION IN CLIMATIC PARAMETERS IN OPEN AND POLY HOUSE ENVIRONMENT

Climatic parameters like Temperature, Relative humidity (RH), Ultra-violet radiation (UV), Light intensity and Photosynthetically Active Radiation (PAR) were recorded at weekly interval throughout the growing period of the crop from open and poly house conditions. Carbondioxide concentration was recorded at 15 days interval from open poly house conditions throughout the crop growing period.

4.1.1 Relative humidity (%)

Table 1 shows the mean values obtained for Relative humidity. There was no significant difference in RH under open and poly house conditions.

4.1.2 Temperature (^{0}C)

The mean values for temperature measured are given in Table 1. The mean temperature observed from 9.00 am to 12.00 pm was significantly higher under poly house condition (39.62 ^{0}C) compared to open condition (37.86 ^{0}C).

4.1.3 UV radiation (Wm^{-2})

The mean values obtained for UV radiation are given in Table 1. UV radiation was found to be significantly high under open condition compared to poly house condition. It was 67.29 Wm^{-2} under open condition where as it was 32.26 Wm^{-2} under poly house condition.

4.1.4 Light intensity (lux)

Table 1 shows the mean values derived for light intensity from open and poly house condition. Light intensity was significantly more under open condition. The mean values were 120083 lux and 89970 lux under open and poly house condition respectively.

4.1.5 Photosynthetically Active Radiation (PAR: µmol m^{-2} s^{-1})

The mean values derived for PAR are shown in Table 1. PAR was significantly high under open condition. The mean value of PAR was 1063 µmol m^{-2} s^{-1} under open condition where as it was 551 µmol m^{-2} s^{-1} under poly house condition throughout the crop growing period.

4.1.6 Carbon dioxide concentration (ppm)

The mean values derived for carbon dioxide concentration are given in Table 2. The CO_2 concentration inside the poly house condition was significantly higher at all the growth stages of the crop. The initial value of 449.39 ppm at 15 DAS enhanced and reached to a maximum value of 472.00 ppm at 30 DAS. Later it decreased and reached the lowest value of 444.68 ppm at 75 DAS. Similarly in open condition, from an initial value of 418.88 ppm, it increased and reached maximum value of 458.40 ppm at 30 DAS. Afterwards, it decreased and reached the lowest value of 439.40 ppm at 75 DAS.

Table 1. Variation in climatic parameters in open and poly house environment

Parameters	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
Temperature (°C)	37.86	2.13	39.62	2.33	2.84**
Relative humidity (%)	66.50	9.89	66.70	9.57	NS
UV radiation (Wm^{-2})	67.29	34.68	32.26	18.18	3.45**
Light intensity (Lux)	120083	36017	89970	32976	3.15*
PAR ($\mu mol\ m^{-2}\ s^{-1}$)	1063	404	551	246	5.05**

SD: Standard deviation ** Significant at 1% level NS: Non-significant

Table 2. Variation in ambient CO_2 concentration (ppm) in open and poly house environment

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	418.88	0.17	449.39	2.05	51.49**
30	458.40	4.99	472.00	1.84	8.87**
45	406.51	0.28	409.38	0.25	26.36**
60	446.82	0.03	454.81	0.02	786.69**
75	439.40	1.05	444.68	0.04	17.45**

SD: Standard deviation ** Significant at 1% level

4.2 MORPHOLOGICAL CHARACTERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

4.2.1 Variation in total leaf area per plant (cm^2) in open and poly house grown cucumber

The leaf area was taken at an interval of 15 days from date of sowing in both the conditions up to 75 DAS. The mean values are shown in Table 3. Leaf area measured was found to be significantly higher inside the poly house condition at 15, 30, 45, 60 and 75 days from date of sowing. The mean values for leaf area was maximum at 45 days after sowing both in open (5057.93 cm^2) and poly house (10369.20 cm^2) condition. The leaf area decreased from 45 DAS in both condition and lowest value of 1597.65 cm^2 was recorded in open condition at 75 DAS where as it was 3351.75 cm^2 in poly house condition.

Table 3. Variation in total leaf area per plant (cm^2) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	186.23	13.40	369.97	25.36	6.41**
30	1405.99	350.95	2901.74	224.31	3.59**
45	5057.93	680.19	10369.20	545.72	6.09**
60	4770.72	561.03	10001.42	523.45	6.82**
75	1597.65	175.25	3351.75	373.35	4.25**

SD: Standard deviation ** Significant at 1% level

4.2.2 Variation in Leaf Area Index (LAI) per plant in open and poly house grown cucumber

Leaf Area Index was calculated from leaf area taken from randomly selected plants. The mean values obtained for LAI for open and poly house conditions are given in Table 4. The canopies of poly house grown cucumber had a significantly higher LAI when compared to open condition at all growth stages. Lowest value of LAI was recorded at 15 DAS, under both conditions and thereafter it increased. Highest LAI of 1.01 was recorded under open condition at 45 DAS where as it was 2.00 in poly house condition at the same time. Thereafter the LAI decreased to 0.32 and 0.67 under open and poly house condition respectively at 75 DAS.

Table 4. Variation in Leaf Area Index (LAI) per plant in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	0.04	0.01	0.07	0.01	6.41**
30	0.28	0.17	0.58	0.11	3.59**
45	1.01	0.33	2.07	0.27	6.09**
60	0.95	0.26	2.00	0.26	6.82**
75	0.32	0.89	0.67	0.18	4.25**

SD: Standard deviation ** Significant at 1% level

4.2.3 Variation in number of nodes per plant in open and poly house grown cucumber

Number of nodes on main stem was counted from base to top of the crops in open and poly house conditions and the mean values derived are shown in Table 5. Initially at 15 DAS there was no significant difference in number of nodes between crop grown under open and poly house conditions. Poly house grown cucumber recorded significantly more number of nodes at 30 and 45 days after sowing. Maximum nodes were produced at 45 DAS in both open (19.75) and poly house (28.25) condition. Afterwards the same number was maintained in both conditions till harvest.

Table 5. Variation in number of nodes per plant in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	2.75	0.25	3.00	0.00	NS
30	8.25	0.48	12.25	0.25	7.41**
45	19.75	2.17	28.25	0.95	3.58*

Note: No change in number of internodes beyond 45 DAS

SD: Standard deviation * Significant at 5% level ** Significant at 1% level
NS: Non-significant

4.2.4 Variation in internodal length per plant (cm) in open and poly house grown cucumber

The mean values obtained for internodal length are given in Table 6. Initially at 15 DAS there was no difference in internodal length of crop between open and poly house condition. Later, this parameter was significantly high inside poly house environment at 30, 45, 60 and 75 DAS when compared to open condition. In open condition the internodal length enhanced and reached highest (4.20 cm) at 60 DAS and there was no further enhancement in internodal length at 75 DAS. But in poly house the maximum intermodal length of 7.53 cm was attained at 45 DAS and the same length was retained without further elongation at 60 and 75 DAS.

Table 6. Variation in internodal length per plant (cm) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	3.10	0.82	4.46	1.13	NS
30	4.34	0.41	7.22	0.29	11.45**
45	4.16	0.45	7.53	0.39	11.39**
60	4.20	0.36	7.53	0.39	12.64**
75	4.20	0.36	7.53	0.39	12.64**

SD: Standard deviation ** Significant at 1% level NS: Non-significant

4.2.5 Variation in number of leaves per plant in open and poly house grown cucumber

The mean values obtained for number of leaves are shown in Table 7. Poly house grown cucumber produced significantly more number of leaves at all the growth stages compared to field grown cucumber. Number of leaves increased up to 60 DAS under both conditions. The mean number of leaves produced ranged from 6.00 to 75.67 under poly house condition whereas under open condition it ranged from 3.67 to 42.67. In poly house initial number of 6.00 at 15 DAS increased and recorded maximum number (75.67) at 60 DAS. Under open condition same trend was observed and the maximum number of 42.67 was produced at 60 DAS. Thereafter the leaf number was reduced to 65.17 under poly house condition whereas it was 36.33 under open condition.

Table 7. Variation in number of leaves per plant in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	3.67	0.52	6.00	0.89	5.53**
30	11.17	1.17	16.67	0.82	9.45**
45	37.67	6.77	71.33	6.92	8.52**
60	42.67	6.98	75.67	4.59	9.68**
75	36.33	6.47	65.17	6.97	7.43**

SD: Standard deviation ** Significant at 1% level

4.3 BIOCHEMICAL CHARACTERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

4.3.3 Chlorophyll content

Chlorophyll a, Chlorophyll b and Total chlorophyll content was estimated at 15 days interval up to 75 DAS for both open and poly house grown cucumber and was expressed in mg g^{-1} plant tissue.

4.3.3.1 Variation in chlorophyll 'a' content (mg g^{-1}) in open and poly house grown cucumber

The mean values for Chlorophyll 'a' are shown in Table 8. Chlorophyll content was significantly higher inside poly house at 15, 30, 45, 60 and 75 DAS. The chlorophyll 'a' content increased from 15 DAS to 45 DAS and thereafter it decreased. The maximum content of 2.57 mg g^{-1} inside poly house grown crop and 1.70 mg g^{-1} under open condition was observed at 45 DAS. The lowest values were recorded at 75 DAS as 0.90 and 1.19 mg g^{-1} under open and poly house grown crop respectively.

Table 8. Variation in chlorophyll 'a' content (mg g^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	1.18	0.02	1.79	0.05	11.19**
30	1.63	0.08	2.05	0.07	3.89**
45	1.70	0.25	2.57	0.26	5.98**
60	1.05	0.10	2.08	0.38	6.51**
75	0.90	0.06	1.19	0.11	2.37*

DAS: Days after sowing   SD: Standard deviation   * Significant at 5% level
** Significant at 1% level

4.3.3.2 Variation in chlorophyll 'b' content (mg g^{-1}) in open and poly house grown cucumber

The mean values for Chlorophyll 'b' are shown in Table 9. The chlorophyll 'b' content did not show a uniform pattern in both conditions. Under open condition the chlorophyll 'b' content was initially 0.35 mg g^{-1} which increased and reached highest value of 0.55 mg g^{-1} at 45 DAS. Then from 45 DAS it gradually decreased and reached lowest value of 0.26 mg g^{-1} at 75 DAS. But under poly house condition initially (15 DAS) it was 0.57 mg g^{-1}which decreased in later stages and reached the lowest value of 0.25 mg g^{-1} at 60 DAS. Again the chlorophyll 'b' content increased to 0.34 mg g^{-1} at 75 DAS.

Table 9. Variation in chlorophyll b content (mg g^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	0.35	0.01	0.57	0.02	10.53**
30	0.44	0.03	0.54	0.02	2.44*
45	0.55	0.04	0.53	0.02	NS
60	0.35	0.01	0.25	0.04	2.5*
75	0.26	0.03	0.34	0.03	NS

SD: Standard deviation   * Significant at 5% level   ** Significant at 1% level
NS: Non-significant

4.3.3.3 Variation in total chlorophyll content (mg g^{-1}) in open and poly house grown cucumber

The mean values for total chlorophyll content for open and poly house condition are given in Table 10. Total chlorophyll content was significantly higher for poly house grown crop at 15, 30, 45 and 75 DAS. Comparing different intervals, maximum amount of total chlorophyll content was observed at 45 DAS under both conditions. At this stage, the poly house grown crop expressed more total chlorophyll content (3.11 mg g^{-1}) when compared to open condition (2.23 mg g^{-1}). Total chlorophyll content enhanced up to 45 DAS inside poly house and thereafter it declined. Similar pattern was observed in open condition also. The lowest total chlorophyll content in leaves was produced at 75 DAS (1.16 mg g^{-1} under open and 1.53 mg g^{-1} under poly house) in both conditions.

Table 10. Variation in total chlorophyll content (mg g^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	1.53	0.08	2.37	0.16	11.70**
30	2.09	0.27	2.59	0.09	4.38**
45	2.23	0.32	3.11	0.41	3.84**
60	1.36	0.11	2.31	0.79	NS
75	1.16	0.18	1.53	0.33	2.42*

SD: Standard deviation * Significant at 5% level ** Significant at 1% level
NS: Non-significant

4.3.4 Variation in IAA Oxidase activity (IAAO: µg of unoxidised auxin g^{-1} fresh weight) in open and poly house grown cucumber

IAA Oxidase activity was expressed as µg of unoxidised auxin g^{-1} hr^{-1}. More of unoxidised auxin indicates low activity of IAAO or otherwise it is inversely related to free auxin content in plants. The mean values obtained for IAAO activity estimated at different intervals and expressed in terms of unoxidised auxin are given in Table 11. It varied significantly inside the poly house condition at 15 and 60 DAS. Initially the IAAO activity was low as evident from high unoxidised auxin content in open (5.32 μg of unoxidised auxin g^{-1} hr^{-1}) and poly house environment (6.15 μg of unoxidised auxin g^{-1} hr^{-1}).

Later the enzyme activity enhanced by decreasing the auxin content to 2.21 μg of unoxidised auxin g^{-1} hr^{-1} in open condition and 2.20 μg of unoxidised auxin g^{-1} hr^{-1} in poly house at 30 DAS. Again the activity decreased as indicated by maximum amount of unoxidised auxin in poly house (6.90 μg of unoxidised auxin g^{-1} $hr^{-1)}$ and open condition (6.79 μg of unoxidised auxin g^{-1} hr^{-1}) at 60 DAS. The enzyme activity enhanced at 75 DAS under both condition, it was non-significant. Same trend was observed under both conditions for enzyme activity at different growth intervals of the crop. The maximum content of unoxidised auxin or low activity of IAAO was observed at 60 DAS under open and inside poly house.

Table 11. Variation in IAAO activity (IAAO: μg of unoxidised auxin g^{-1} fresh weight) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	5.32	0.17	6.15	0.09	4.21**
30	2.21	0.04	2.20	0.03	NS
45	5.46	0.06	5.42	0.07	NS
60	6.79	0.04	6.90	0.02	2.44*
75	1.86	0.04	1.87	0.02	NS

SD: Standard deviation * Significant at 5% level ** Significant at 1% level
NS: Non-significant

4.3.5 Variation in Gibberelic acid content (GA: μg g^{-1}) in open and poly house grown cucumber

The mean values obtained for endogenous GA content are given in Table 12. Gibberelic acid content of the crop was estimated and was expressed as μg g^{-1}. Significant difference in GA content was observed only at 75 DAS in poly house crop. Endogenous GA content increased from 15 DAS (0.16 μg g^{-1}) to 60 DAS

(0.24 μg g^{-1}) and decreased to 0.22 μg g^{-1} at 75 DAS in poly house crop. The maximum GA content was observed at 60 DAS in poly house condition. But in open condition the GA content increased from 15 DAS (0.18 μg g^{-1}) to 45 DAS and then decreased at 75 DAS. The maximum GA content of 0.23 μg g^{-1} was observed at 45 DAS in open condition which further decreased to 0.13 μg g^{-1} at 75 DAS.

Table 12. Variation in Gibberelic acid content (GA: μg g^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	0.18	0.01	0.16	0.002	NS
30	0.19	0.03	0.18	0.01	NS
45	0.23	0.06	0.22	0.04	NS
60	0.20	0.06	0.24	0.06	NS
75	0.13	0.05	0.22	0.03	2.98*

SD: Standard deviation NS: Non-significant * Significant at 5% level

4.4 PHYSIOLOGICAL PARAMETERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

Physiological parameters like photosynthetic rate, transpiration rate, stomatal resistance, intercellular CO_2 concentration, carboxylation efficiency and canopy temperature depression was recorded at 15 days interval throughout the growing period of the crop in open and poly house condition. Chlorophyll fluorescence and stomatal number were measured once in growing period of a crop grown at the same season at Agricultural Research Station (ARS), Mannuthy. Light absorption coefficient was also worked out from light and photosynthetic measurements at different intervals.

4.4.1 Variation in photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) in open and poly house grown cucumber

The mean values obtained for photosynthetic rate recorded are shown in Table 13. Photosynthetic rate was significantly high under open condition at 15, 30 and 45 DAS. But it was significantly high inside poly house condition at 60 and 75 DAS compared to open field crop. The initial photosynthetic rate of 9.43 µmol CO_2 m^{-2} s^{-1} at 15 DAS enhanced to 28.13 µmol CO_2 m^{-2} s^{-1} at 30 DAS in open condition where as it enhanced from 7.61 µmol CO_2 m^{-2} s^{-1} to 23.46 µmol CO_2 m^{-2} s^{-1} under poly house condition. Later it decreased to 20.98 µmol CO_2 m^{-2} s^{-1} in open condition and 18.23 µmol CO_2 m^{-2} s^{-1} in poly house condition at 45 DAS. In both conditions, the photosynthetic rate started to decrease from 30 DAS and the lowest value was recorded at 75 DAS.

Table 13. Variation in photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	9.43	0.90	7.61	1.33	3.93**
30	28.13	0.93	23.46	0.78	13.33**
45	20.98	2.74	18.23	3.21	2.26*
60	6.95	0.23	13.07	1.21	17.18**
75	3.48	0.73	8.14	0.75	15.50**

SD: Standard deviation ** Significant at 1% level * Significant at 5% level

4.3.2 Variation in transpiration rate (mmol H_2O m^{-2} s^{-1}) in open and poly house grown cucumber

The mean values of transpiration rate recorded are shown in Table 14. Transpiration rate was significantly higher (3.35 mmol H_2O m^{-2} s^{-1}) under open condition at 30 DAS when compared to poly house condition. But later it showed significantly higher values of 2.89 mmol H_2O m^{-2} s^{-1} and 2.08 mmol H_2O m^{-2} s^{-1} in poly house condition at 45 and 75 DAS respectively. The initial transpiration rate under open condition increased from 2.08 mmol H_2O m^{-2} s^{-1} to 3.35 mmol H_2O m^{-2} s^{-1} at 30 DAS and thereafter it decreased to 1.87 mmol H_2O m^{-2} s^{-1} at 75 DAS. But in poly house condition, the initial transpiration rate of 2.06 mmol H_2O m^{-2} s^{-1} enhanced to 2.89 mmol H_2O m^{-2} s^{-1} at 45 DAS. Later it decreased to 2.08 mmol H_2O m^{-2} s^{-1} at 75 DAS. The lowest values were recorded at 75 DAS under both conditions.

Table 14. Variation in transpiration rate (mmol H_2O m^{-2} s^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	2.08	0.33	2.06	0.16	NS
30	3.35	0.19	2.82	0.11	8.31**
45	2.51	0.39	2.89	0.04	3.43**
60	2.39	0.38	2.57	0.07	NS
75	1.87	0.16	2.08	0.08	3.99**

SD: Standard deviation ** Significant at 1% level NS: Non-significant

4.4.3 Variation in stomatal resistance (s cm^{-1}) in open and poly house grown cucumber

Stomatal resistance indicates the resistance offered by stomata for gaseous exchange. Low value of stomatal resistance indicates more stomatal conductance and thereby more photosynthetic rate. Table 15 shows the mean values obtained for stomatal resistance. Stomatal resistance was significantly higher inside the poly house at 15 and 30 DAS. But under open condition it was significantly higher at 45 and 75 DAS. Under open condition stomatal resistance increased from 0.39 s cm^{-1} at 15 DAS to 0.80 s cm^{-1} at 75 DAS whereas in poly house condition stomatal resistance decreased from 0.68 s cm^{-1} at 15 DAS to 0.66 s cm^{-1} at 75 DAS. Highest stomatal resistance of 0.68 s cm^{-1} was recorded inside poly house at 15 DAS whereas highest value of resistance (0.80 s cm^{-1}) was recorded at 75 DAS under open condition.

Table 15. Variation in stomatal resistance (s cm^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	0.39	0.13	0.68	0.32	2.96**
30	0.32	0.01	0.37	0.01	13.40**
45	0.59	0.17	0.43	0.08	3.13**
60	0.62	0.19	0.60	0.16	NS
75	0.80	0.03	0.66	0.02	15.86**

SD: Standard deviation ** Significant at 1% level NS: Non-significant

4.4.4 Variation in number of stomata per leaf (mm^{-2}) in open and poly house grown cucumber

The values obtained for stomatal number are shown in Table 16. Open field grown cucumber leaves have more number of stomata compared to poly house grown cucumber (Plate 4).

Table 16. Variation in number of stomata per leaf (mm^{-2}) in open and poly house grown cucumber

	Number of stomata (mm^{-2})
Open condition	2.23
Poly house	1.91

4.4.5 Variation in intercellular CO_2 concentration (ppm) in open and poly house grown cucumber

The mean values obtained for intercellular CO_2 concentration are shown in Table 17. Intercellular CO_2 concentration was significantly higher under open condition at 15, 30 and 45 DAS whereas it was significantly higher inside poly house grown crop at 60 and 75 DAS. The initial value (79.02 ppm) of intercellular CO_2 concentration under open field increased and reached highest value of 180.00 ppm at 30 DAS. Thereafter it declined and lowest value of 61.67 ppm was reached at 75 DAS. In poly house condition, the initial value of 68.09 ppm

Plate 4. Microscopic view of stomata from two conditions: stomata from open field grown cucumber leaf

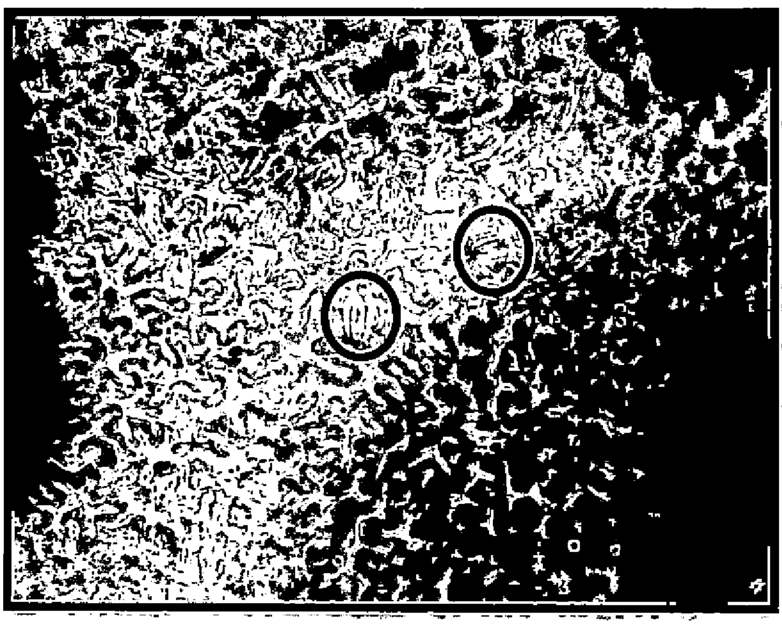

Plate 4a. Stomata from poly house grown cucumber leaf

increased and recorded highest value of 170.17 ppm at 30 DAS. Afterwards it decreased and reached a value of 81.50 ppm at 75 DAS.

Table 17. Variation in intercellular CO_2 concentration (ppm) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	79.02	2.03	68.09	1.42	15.30**
30	180.00	0.00	170.17	0.39	87.51**
45	178.33	5.07	169.83	0.84	5.73**
60	102.50	1.51	147.92	0.67	95.40**
75	61.67	1.56	81.50	1.24	34.48**

SD: Standard deviation ** Significant at 1% level

4.4.6 Variation in carboxylation efficiency (µmol CO_2 m^{-2} s^{-1} ppm^{-1}) in open and poly house grown cucumber

The mean values obtained for carboxylation efficiency are given in Table 18. It was significantly higher under open condition at 30 DAS. But it enhanced significantly inside the poly house at 60 and 75 DAS. Highest carboxylation efficiency was obtained at 30 DAS in both conditions. The mean values obtained for carboxylation efficiency at this stage were 0.16 µmol CO_2 m^{-2} s^{-1} ppm^{-1} and 0.14 µmol CO_2 m^{-2} s^{-1} ppm^{-1} under open and poly house grown crop respectively. Maximum reduction in carboxylation efficiency was observed at 75 DAS in both conditions.

Table 18. Variation in carboxylation efficiency (µmol CO_2 m^{-2} s^{-1} ppm^{-1}) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	0.12	0.01	0.11	0.02	NS
30	0.16	0.01	0.14	0.01	9.13**
45	0.12	0.01	0.11	0.02	NS
60	0.07	0.01	0.09	0.01	8.40**
75	0.06	0.01	0.10	0.01	10.28**

SD: Standard deviation ** Significant at 1% level NS: Non-significant

4.4.7 Variation in Canopy Temperature Depression (CTD: ^{0}C) in open and poly house grown cucumber

Table 19 shows the mean values obtained for CTD. There was no significant difference for CTD between open and poly house conditions. In open condition the canopy temperature depressed in the range of 1.04 ^{0}C to 1.42 ^{0}C below ambient temperature, whereas in poly house condition CTD ranged from 1.07^{0}C to 1.32^{0}C.

Table 19. Variation in Canopy Temperature Depression (CTD: ^{0}C) in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	1.10	0.29	1.08	0.22	NS
30	1.42	0.28	1.32	0.21	NS
45	1.16	0.66	1.28	0.02	NS
60	1.11	0.05	1.10	0.05	NS
75	1.04	0.03	1.07	0.1	NS

SD: Standard deviation NS: Non-significant

4.4.8 Variation in quantum efficiency of PS II based on chlorophyll fluorescence measurement in open and poly house grown cucumber

The mean values derived are given in Table 20. F_v/F_m ratio was found to be significantly higher inside poly house. The mean value of F_v/F_m ratio was 0.73 and 0.48 for poly house and open condition respectively.

Table 20. Variation in quantum efficiency of PS II based on chlorophyll fluorescence measurement in open and poly house grown cucumber

	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
F_v/F_m	0.48	0.07	0.73	0.07	6.21**

SD: Standard deviation ** Significant at 1% level

4.4.9 Variation in light absorption coefficient in open and poly house grown cucumber

The mean values for Light absorption coefficient are shown in Table 21. Light absorption coefficient was found to be significantly higher under open condition at 15, 60 and 75 DAS. It was significantly higher inside poly house at 30 DAS. Initial light absorption coefficient value decreased from 1.83 to 0.27 at 30 DAS and thereafter it increased to 1.81 at 75 DAS under open condition. Whereas in the case of poly house condition, from initial value of 0.62 at 15 DAS it decreased to 0.38 (30 DAS). Later it enhanced to 0.60 at 75 DAS.

Table 21. Variation in light absorption coefficient in open and poly house grown cucumber

Days after sowing	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
15	1.83	0.59	0.62	0.10	4.08**
30	0.27	0.09	0.38	0.08	2.36*
45	0.09	0.03	0.08	0.01	NS
60	0.93	0.33	0.21	0.02	5.43**
75	1.81	1.13	0.60	0.18	4.62**

SD: Standard deviation * Significant at 5% level ** Significant at 1% level

NS: Non-significant

4.5 PHENOLOGICAL CHARACTERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

Phenological observations were taken from selected plants from open and poly house condition.

4.5.1 Days to flowering

The mean values recorded for days to flowering are given in Table 22. There was no significant difference in the number of days taken for flowering in open and poly house. Both condition recorded 25 days to flowering from date of sowing.

4.5.2 Days to first harvest

The mean values obtained for days to first harvest are shown in Table 22. There was no significant difference in days to first harvest between open and poly house condition. The harvest started from 40 to 41 DAS in both the conditions.

4.5.3 Days to last harvest

Table 22 shows the mean values derived for days to last harvest. The days to last harvest was significantly prolonged in poly house grown cucumber (78.80).

4.5.4 Number of harvest

Table 22 shows the mean values obtained for number of harvest. The total number of harvest made from poly house and open condition varied significantly. Under open condition total 15.80 harvests were taken. In poly house it went up to 19.20.

Table 22. Phenological characters of cucumber in open and poly house environment

Observations	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
Days to flowering	25.00	0.71	24.80	1.30	NS
Days to first harvest	40.80	0.45	41.20	0.84	NS
Days to last harvest	70.80	0.84	78.80	0.84	15.12**
Number of harvest	15.80	0.84	19.20	0.84	6.43**

SD: Standard deviation * Significant at 5% level ** Significant at 1% level
NS: Non-significant

4.6 YIELD PARAMETERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

4.6.1 Fruit length (cm)

Fruit length of five fruits each from selected plants were measured from open and poly house condition. The mean values for fruit length (cm) are given in Table 23. There was no significant variation in fruit length between poly house and open condition.

4.6.2 Fruit width (cm)

Upper, middle and lower fruit width was measured from fruits collected from selected plants. The mean values arrived for fruit width are given in Table 23. Upper fruit width was found to be significantly higher (11.70 cm) inside poly house where as it was only 9.88 cm under open condition. There was no significant difference in middle and lower fruit width.

4.6.3 Fruit weight (g)

Weight of five fruits from selected plants was measured from open and poly house condition. The mean values derived for fruit weight are given in Table 23. Fruit weight was significantly higher inside poly house when compared to open condition. Mean values obtained was 165.70 g and 146.18 g for poly house and open condition respectively.

4.6.4 Number of fruits

Number of fruits per plant was estimated from selected plants. The mean values obtained are shown in Table 23. It was significantly higher inside poly house condition.

4.6.5 Yield per plant (kg)

The mean values obtained for yield per plant are given in Table 23. Yield per plant was significantly higher inside poly house. It was 2.30 kg and 0.99 kg inside poly house and open condition respectively.

4.6.6 Marketable yield per plant (kg)

The mean values derived for marketable yield are given in Table 23. Marketable yield was significantly higher under poly house condition (2.26 kg) when compared to open condition 0.90 (kg).

Table 23. Yield parameters of cucumber in open and poly house environment

Parameters	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
Fruit length (cm)	17.48	1.14	18.20	0.98	NS
Fruit width upper (cm)	9.88	0.68	11.70	0.57	4.57**
Fruit width middle (cm)	10.48	1.05	11.36	0.46	NS
Fruit width lower (cm)	10.56	0.90	11.56	0.40	NS
Fruit weight (g)	146.18	14.82	165.70	4.25	2.83*
Number of fruits	7.40	1.82	15.40	1.14	8.34**
Yield per plant per pant (kg)	0.99	0.07	2.30	0.73	4.02*
Marketable yield per plant (kg)	0.90	0.06	2.26	0.71	4.25*

SD: Standard deviation * Significant at 5% level ** Significant at 1% level

NS: Non-significant

4.7 QUALITY ATTRIBUTES OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

4.7.1 Variation in ascorbic acid content (mg 100 g^{-1}) in open and poly house environment

Table 24 shows the mean values obtained for ascorbic acid content. The ascorbic acid content of cucumber fruits was estimated and expressed as mg g^{-1} fresh weight. It was significantly higher under open condition when compared to poly house. The mean values were 7.33 mg g^{-1} and 5.33 mg g^{-1} respectively under open and poly house environment.

Table 24. Variation in ascorbic acid content (mg 100 g^{-1}) in open and poly house environment

Open condition		Poly house		t-value
Mean	SD	Mean	SD	
7.33	0.79	5.33	0.17	5.51**

SD: Standard deviation ** Significant at 1% level

4.7.2 Fruit colour

Fruit colour was assessed through visual appearance by observing colour of the fruit. More amount of greenness was observed under poly house when compared to green in open condition.

4.7.3 Organoleptic evaluation of cucumber fruits in open and poly house environment

Sensory evaluation was carried out on a nine point hedonic scale using score card for eight attributes namely appearance, colour, odour, flavour, texture, taste, after taste and overall acceptability. The mean sensory score of cucumber fruits are given in Table 25. Important parameters like colour, texture and overall acceptability were significantly higher for poly house grown fruits.

Table 25. Organoleptic evaluation of cucumber fruits in open and poly house environment

Parameters	Open condition	Poly house	Kendall's W(a)
Appearance	2.15	2.85	NS
Colour	2.00	3.00	0.29**
Flavour	2.17	2.83	NS
Texture	1.85	3.15	0.43**
Odour	2.40	2.60	NS
Taste	2.43	2.57	NS
After taste	2.27	2.73	NS
Overall acceptability	1.93	3.07	0.38**

NS: Non-significant   ** Significant at 1% level

4.8 Incidence of pest and diseases

Incidence of pest and diseases was monitored throughout the growing period of the crop for both open and poly house conditions. Serpentine leaf miner, bacterial wilting and fruit rot was observed under open condition (Table 26; Plate 5). Mite attack was observed under poly house condition.

Table 26. Incidence of pest and diseases

Sl. No.	Pest and diseases	Open condition	Poly house condition
1	Serpentine leaf miner	✓	-
2	Fruit fly	✓	-
3	Fruit rot	✓	-
4	Bacterial wilting	✓	-
5	Mite	-	✓

Plate 5. Serpentine leaf miner

Plate 5a. Fruit rot

Plate 5b. Bacterial wilting

Plate 5c. Mite attack inside poly house grown crop

DISCUSSION

5. DISCUSSION

The present investigation was carried out to study the photosynthetic productivity of poly house grown gynoecious parthenocarpic F_1 cucumber in comparison with open environment. The study also envisaged to understand the physiological basis of growth and productivity of gynoecious parthenocarpic F_1 cucumber in naturally ventilated poly house and open condition. The experiment was conducted in farmer's field at Thannyam and the variety used was ZECO F_1 which is a gynoecious parthenocarpic F_1 salad cucumber.

To understand the physiological parameters that influence growth and productivity in poly house conditions, the salad cucumber variety ZECO F_1 was raised in naturaly ventilated poly house and also in open condition. 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 VARIATION IN CLIMATIC PARAMETERS IN OPEN AND POLY HOUSE ENVIRONMENT

Under poly house cultivation the crop is protected from unfavourable environmental conditions by modifying the micro-climate which favours the crop productivity. Hence observations on temperature, relative humidity, light intensity and UV radiation inside poly house and open condition were observed at equal intervals throughout the crop growing period. All the physiological observations were recorded at one hour interval between 9.00 am and 12.00 pm. The climatic variables recorded at the same time were statistically analysed and discussed as under.

The micro-climate inside and outside the poly house varied considerably depending on the prevailing weather conditions in the experimental site. The temperature recorded was significantly higher inside the poly house when compared to open condition. There was 4.65 per cent increase in temperature inside the poly house from 9.00 am to 12.00 pm during the entire growth period of the crop (Table 1; Fig. 1). At 15 DAS, there was a difference of 1.1^{0}C in temperature between poly house and open field grown crops. During the flowering stage (at 30 DAS) the difference in temperature was 2.1 ^{0}C. Highest temperature was found inside the poly house at 45 DAS. Later the difference was 1.5^{0}C and 1.9 ^{0}C respectively at 60 and 75 DAS (Table 1; Figure 1). Pandey *et al.* (2005) found a difference of 6 to 7°C in greenhouse structures and open field conditions. Dhandare *et al.* (2008) also reported that temperature inside the naturally ventilated poly house was more when compared to open field, which favours crop productivity. High temperature inside the poly house may be due to physical properties of poly house covering material, which traps the short wave radiations. The temperatures in the poly house was considerably higher compared to ambient temperatures and resulted in better morphological growth and increased number of fruits (Hirama *et al.*, 2003).

The relative humidity recorded at weekly intervals did not give a significant variation between inside and open condition during the entire crop growth period. (Table 1; Fig. 2). The RH was on par in both conditions, though earlier reports indicate that RH inside the poly house was always 5-10 per cent lower than open condition (Parvej *et al.*, 2010) or it was higher inside poly house than open field (Rajasekhar *et al.*, 2013). Such a condition was not obtained in this study.

Ultra-violet light is available in the shorter wavelength range *ie.* less than 400 nm and a large quantity of it is harmful to crop growth. UV radiation was higher under open condition than poly house condition. There was 52.06 per cent reduction in UV radiation inside the poly house when compared to open condition (Table 1; Fig. 3). This decline in UV radiation may be due to UV-B stabilized sheets provided in the growth structure of the poly house. The basic objective of photo-selective cover nets is to reduce solar radiation inside the poly house during summer months. The poly house covering materials are photo-selective nets which are designed to selectively screen various spectral components of solar radiation UV radiation and PAR (Shahak *et al.*, 2008). There was a difference of

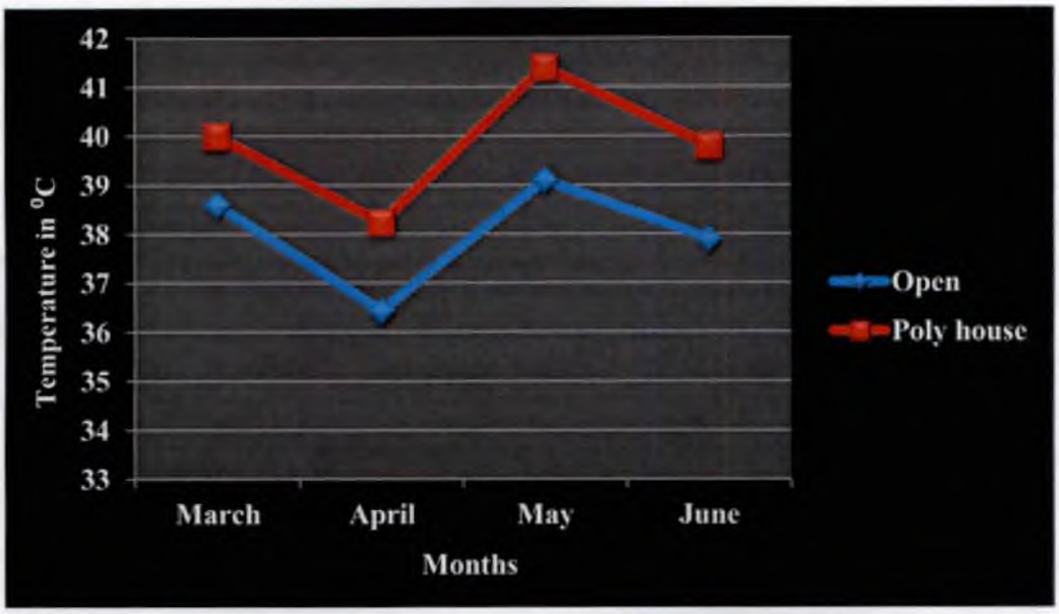

Fig. 1 Variation in temperature in open and poly house environment

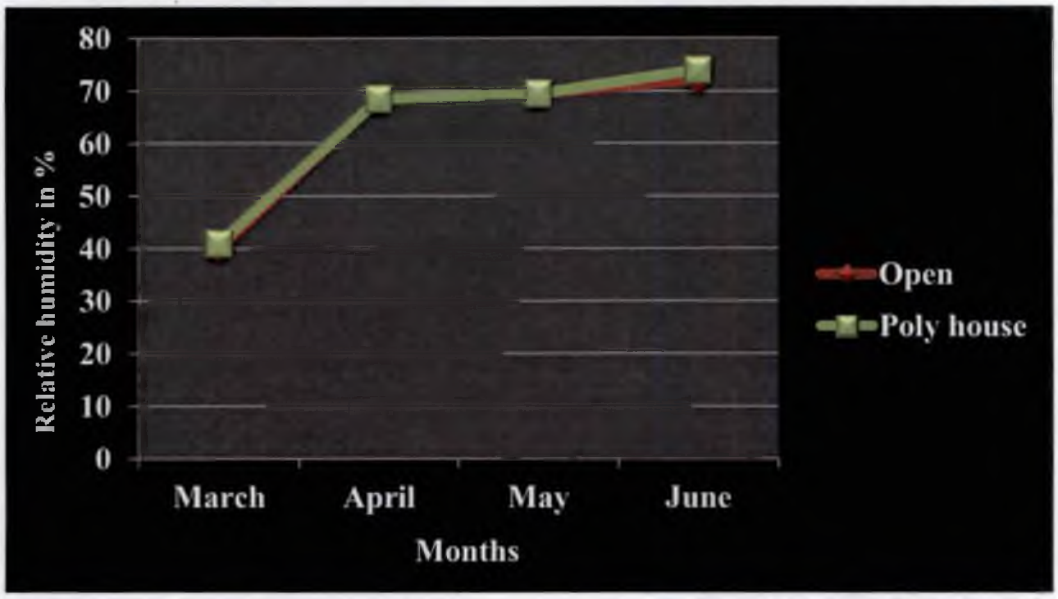

Fig. 2 Variation in relative humidity in open and poly house environment

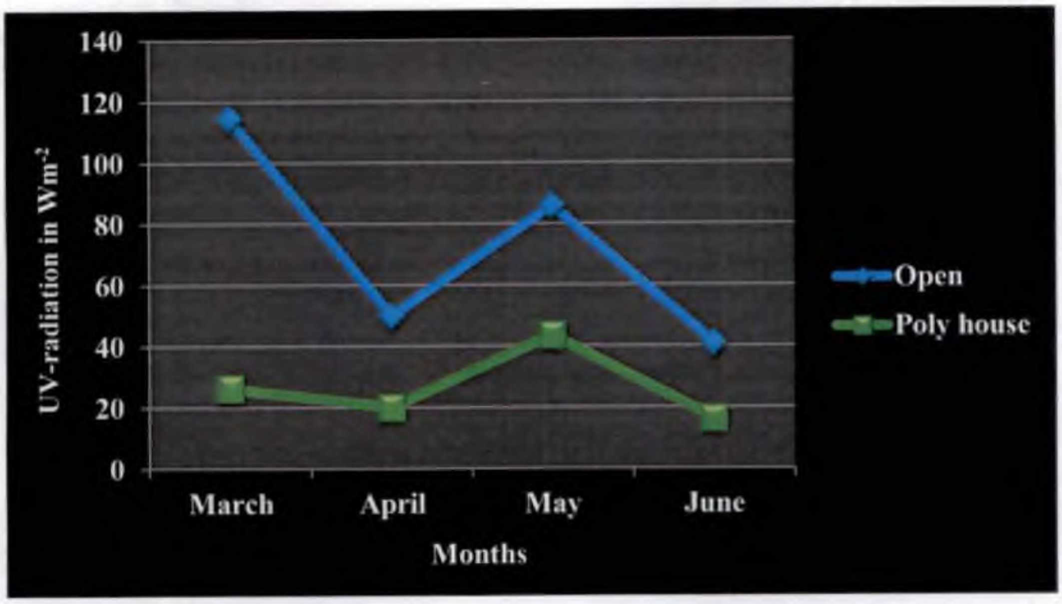

Fig. 3 Variation in UV-radiation in open and poly house environment

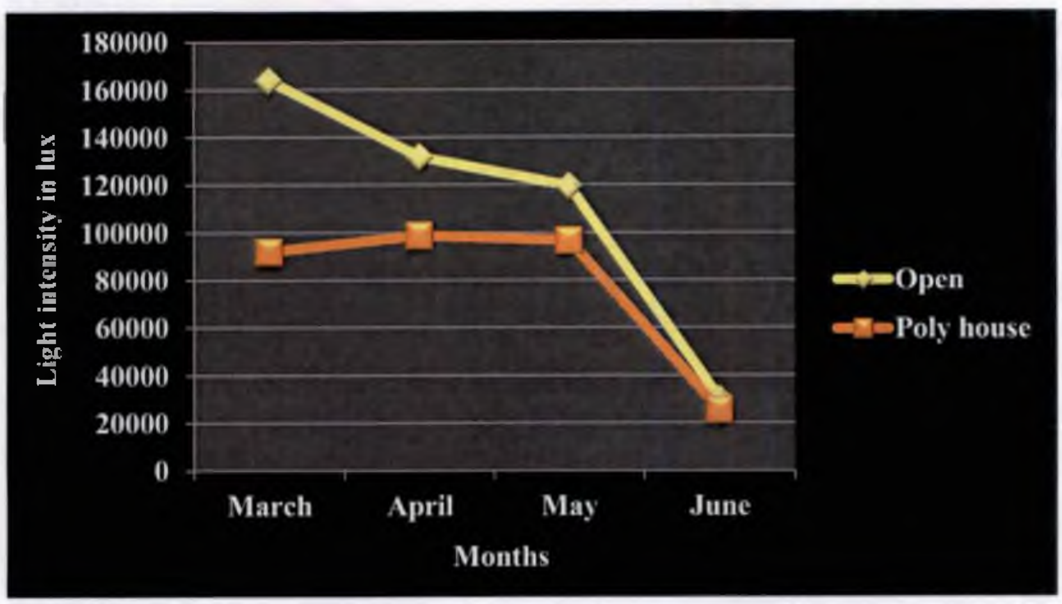

Fig. 4 Variation in light intensity in open and poly house environment

17.8 Wm^{-2} in UV radiation between open and poly house condition at 15 DAS, which enhanced to 25.2 Wm^{2} during flowering period. During peak flowering period and initial harvest time the difference was about 39.63 Wm^{2}. Thereafter it decreased to 10.30 Wm^{-2} at 60 DAS and again enhanced to 24.5 Wm^{2} 75 DAS. Reduced UV radiation is advantageous to crop growth. An experiment in rice grown under UV reduced condition recorded 44.40 per cent increase in shoot length compared to open condition (Yogesh, 2015).

The light intensity measured was 25 per cent higher under open condition (Table 1; Fig. 4) compared to poly house environment. The poly house covering material usually diffuses light which reaches the plant canopy varies with location and prevailing climatic condition. This diffused light transmission in a poly house is reported as advantageous for light penetration. Diffused light penetrated deeper into the canopy and the middle leaves intercepted more light, which caused an increase in photosynthesis, leading to higher fruit production (Hemming and Reinders, 2007; Li *et al.*, 2014).

The PAR, which profusely influences plant growth and development, reduced to 48.16 per cent inside the poly house when compared to full sunlight under open condition (Table 1; Figure 5). Shadenet cover of poly house usually reduces PAR which is an important factor regulating photosynthesis and dry matter production and thereby yields of crops. Earlier reports of Haque *et al.* 2005 also agrees with these findings.

The CO_2 concentration which is the important natural resource involved in photosynthesis was significantly high inside poly house throughout the growing period (Table 2; Fig. 6). Though the CO_2 concentration was high inside the poly house, it did not contribute to the high photosynthetic rate inside poly house. This was in agreement with the findings of Stanghellini and Bunce (1993) and Ainsworth and Rogers (2007) that the increasing atmospheric CO_2 concentration might not increase photosynthesis instead it may cause down regulation of the process.

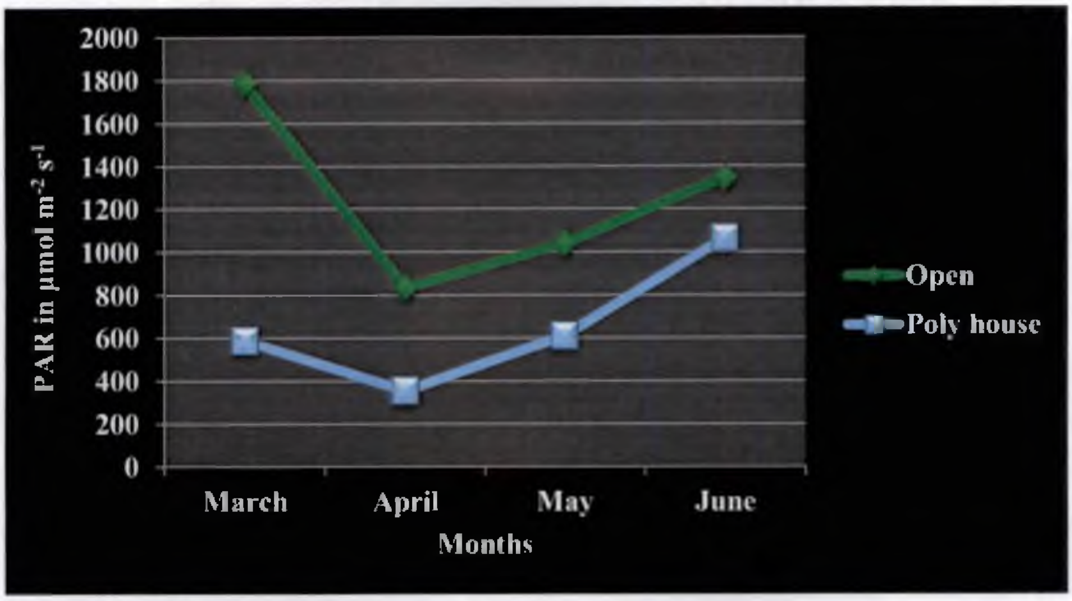

Fig. 5 Variation in PAR in open and poly house environment

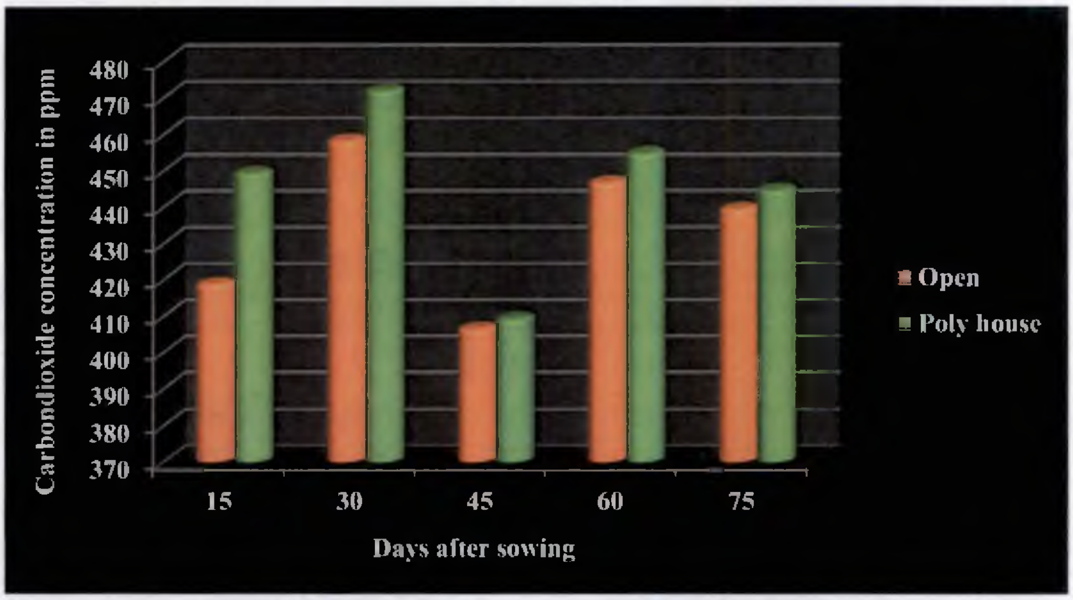

Fig. 6 Variation in ambient CO_2 concentration (ppm) in open and poly house environment

Diurnal pattern of CO_2 indicated that the CO_2 level was lower during the day time at 8.00 am to 10.00 am in both conditions (Fig. 7). During this time, the plants use CO_2 for photosynthesis and draw down the level of CO_2 in both conditions.

5.2 MORPHOLOGICAL CHARACTERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

All the morphological characters like total leaf area, number of internodes, internodal length and number of leaves were observed at 15 days interval under both conditions up to 75 DAS. LAI was worked out from total leaf area observed at different intervals.

The poly house grown crop recorded maximum leaf area throughout the growing period. This may be due to decreased UV radiation, light intensity and PAR inside the poly house. Significant increase in leaf area under poly house environment may be due to more favourable growing conditions when compared to open condition. This is in agreement with the findings of Haque *et al*. 2009. Carbondioxide enrichment inside the poly house also contributes to higher leaf area. Mavrogianopoulos *et al*. (1999) reported that CO_2 enrichment increased leaf growth significantly.

The leaf area, LAI, number of internodes, internodal length and number of leaves were found influenced by growing environment (Table 3 to 7; Fig. 8 and 9). The maximum leaf area and number of internodes were observed at 45 DAS in open and poly house conditions. But the number of leaves was maximum at 60 DAS. This may be due to pruning of basal leaves at 45 DAS, which stimulated the production of new leaves. Though more number of leaves was produced after pruning, it did not contribute to more leaf area. At 60 DAS, the crop was on fruiting stage and at this period a competition between newly formed leaves and fruits may occur for photoassimilates. Hence, LA development was not in a faster rate as observed during the early stages of growth.

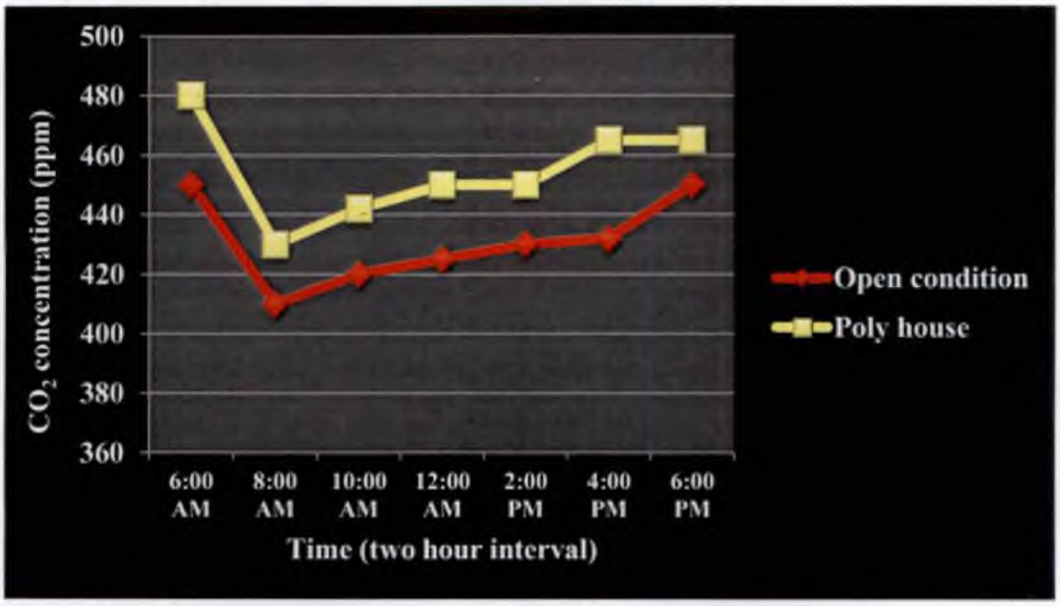

Fig. 7 Diurnal variation in CO_2 concentration in open and poly house environment

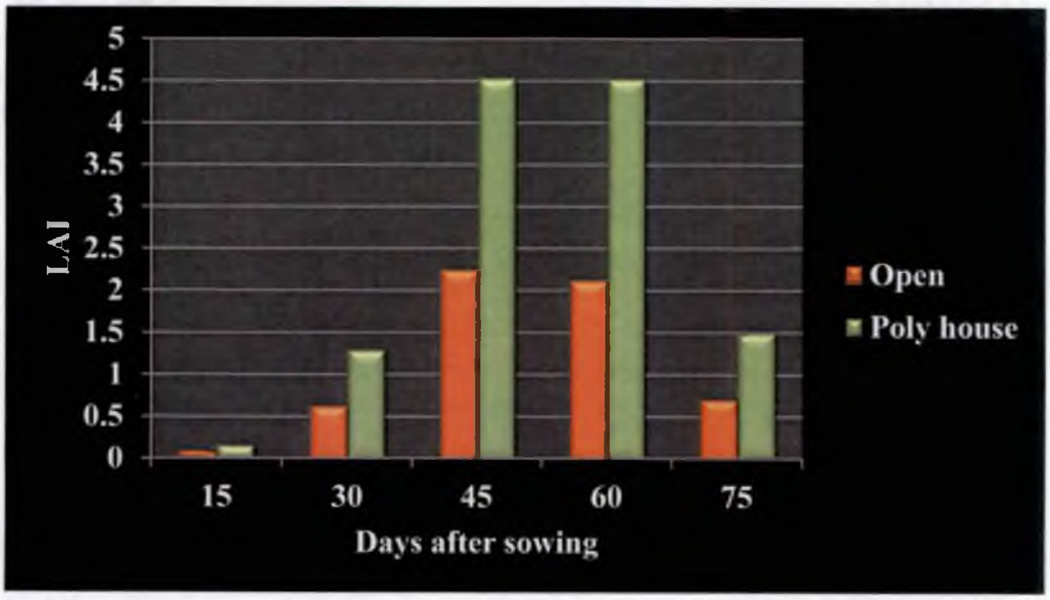

Fig. 8 Variation in LAI per plant in open and poly house grown cucumber

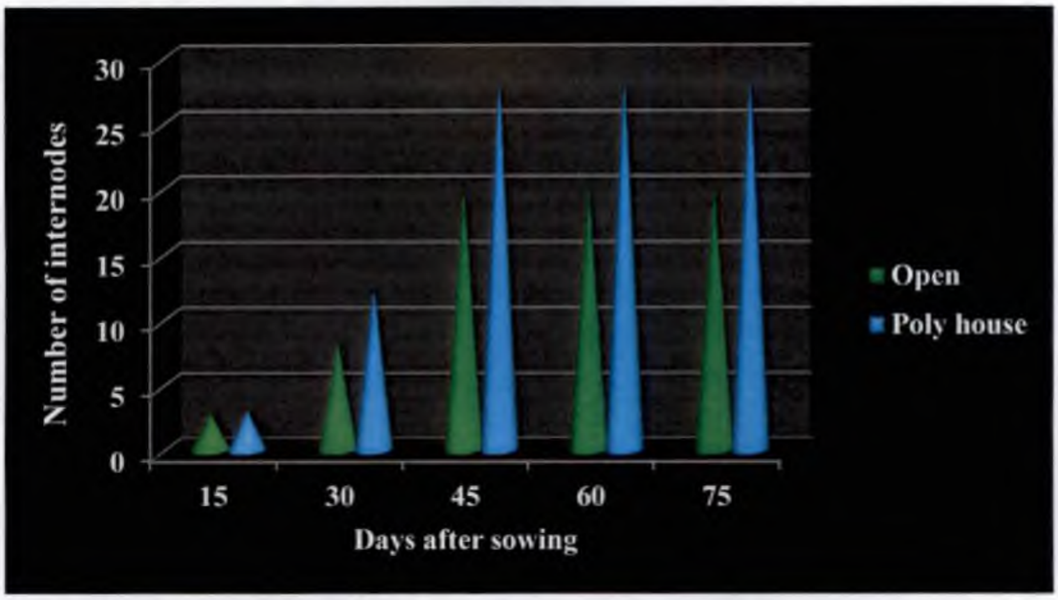

Fig. 9 Variation in number of internodes per plant in open and poly house grown cucumber

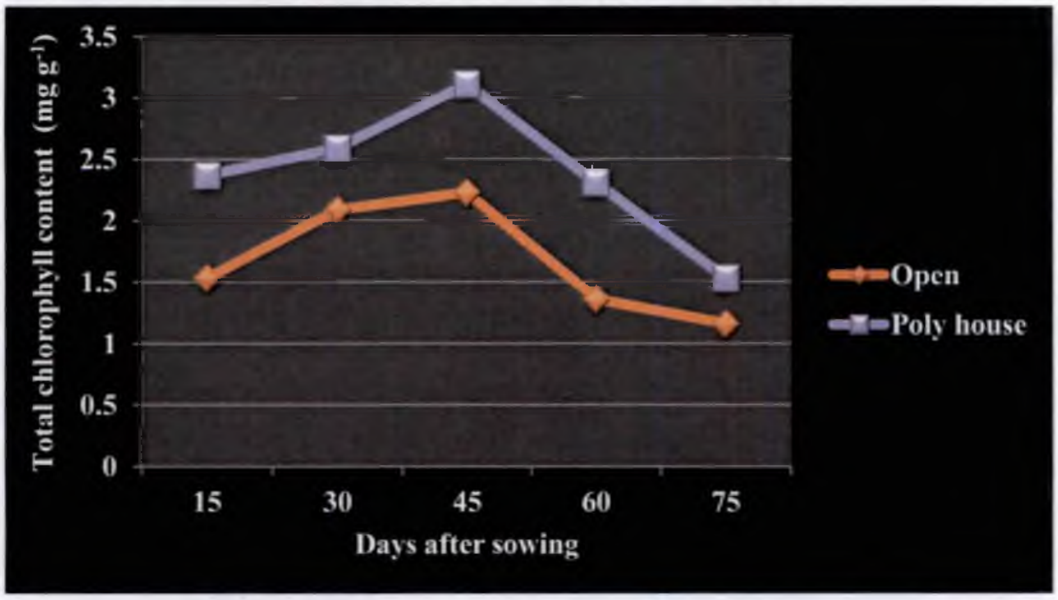

Fig. 10 Variation in total chlorophyll content in open and poly house grown cucumber

Higher values for morphological characters inside the poly house condition may be due to favourable micro-climatic conditions in the poly house. This agrees with the results of Ramesh and Arumugam (2010) and Rajasekhar *et al.* (2013). In this study the low canopy light along with low PAR inside the poly house may be the reason for leaf enlargement and thereby high LAI.

Moreover low PAR indicates a low red to far-red ratio which is stimulatory for stem elongation whereas in open condition, the crop growing under full sunlight is exposed to high PAR thereby high R/FR ratio causing a reverse effect as previously reported by Smith (2000). When crops are grown under far-red levels the internodes were tall resulting in tall plants.

Kurepin *et al.* 2007 and Qing-Jun *et al.* (1996) also reported that under low light, the internodes of cucumber were long. Kittas *et al.* (2006) also are in the opinion that plants grown at reduced UV level grow taller compared to those grown at high UV level as observed in egg plants.

5.3 BIOCHEMICAL CHARACTERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

The biochemical characters like chlorophyll a content, chlorophyll b content, total chlorophyll content, IAA oxidase activity and Gibberelic acid content were estimated at 15 days interval upto 75 DAS from both conditions. Chlorophyll 'a', chlorophyll 'b' and total chlorophyll, the pigment controlling photosynthetic activity, were significantly higher inside the poly house throughout the growth period.

Chlorophyll a which is the major light absorbing pigment in plants, was significantly higher inside the poly house at all the growth stages of cucumber (Table 8). Initially at 15 DAS, chlorophyll a content of crop inside the poly house was 51.69 per cent more than open field grown crops. The content increased up to 45 DAS in both conditions. Afterwards a drastic reduction of 38.00 per cent chlorophyll a content was observed under open condition whereas it was only

19.00 per cent inside the poly house grown crops. This drastic reduction under open condition may be associated with early senescence of the crop. Later at 60 DAS a reduction of 14 per cent and 43 per cent was observed under open and poly house condition respectively.

Chlorophyll b content was 38.6 per cent lower under open condition during 15 DAS. Maximum content was observed at 45 DAS (Table 10). Later 28.57 per cent reduction was recorded under poly house condition compared to open field.

Total chlorophyll content was significantly higher for poly house grown crop at all stages of observation except 60 DAS (Table 10; Fig. 10). Initial total chlorophyll content inside poly house was 54.00 per cent higher than open field grown crops. Afterwards content increased and reached maximum value at 45 DAS under both conditions. Later it lowered by 34 per cent under open condition and 25 per cent inside poly house condition. There was 31.89 per cent more total chlorophyll content inside the poly house at 75 DAS when compared to open condition.

Though light is essential for the synthesis of chlorophyll, high light intensity will slow down the chlorophyll synthesis. In this study also the high light intensity prevailed under open condition reduced chlorophyll a, chlorophyll b and total chlorophyll for the crop raised under open condition. The reduced light inside poly house stimulated higher amount of chlorophyll content in leaves. Earlier reports of Haque *et al.* (2009) also support this observation. Significant increase in chlorophyll content under poly house condition may also be due to high CO_2 concentration inside poly house. These results were corroborated by the results obtained by Mavrogianopoulos *et al.* (1999).

IAA oxidase activity differed significantly inside the poly house condition at 15 and 60 DAS (Table 12; Fig. 11). IAA Oxidase activity was expressed as µg of unoxidised auxin g^{-1} hr^{-1}. IAAO activity decides the auxin level and is related to IAA catabolism in plants. More of unoxidised auxin indicates low activity of enzyme. IAAO activity inside the poly house condition was 15.60 per cent higher at 15 DAS compared to open condition. Afterwards IAAO activity increased to 27.63 per cent under open condition whereas the increase was only 12.20 per cent inside poly house condition at 60 DAS. The gradual decline in IAAO activity as indicated by gradual increase in the amount of unoxidised auxin from 30 DAS and 60 DAS may be due to high demand of IAA at early stages of fruit development in the parthenocarpic cucumber variety. The drop in IAA content at 75 DAS indicates high IAAO activity which can be related to cell ageing at the later stage of crop growth as previously reported by Galston and Dalberg (1954). The results in this study were consistent with the findings of Ludnikova (1984) and Kim *et al.* (1992).

Low activity of IAAO at initial stages retain auxin level significantly for early vegetative growth whereas high activity as shown by drop in auxin level in later stages may be a mechanism for regulation of endogeneous auxin level for promoting growth at different growth stages. The increased activity of IAA oxidase which cause the retardation of growth was generally observed under low temperature (Orman, 1980). Gibberelic acid (GA) and auxin were found to accumulate during dark period and their rapid adjustment to lower levels in light was also reported by Folta and Childers (2008).

Gibberelic acid content observed was significantly higher only at 75 DAS in poly house crop (Table 12; Fig. 12). Initial GA content at 15 DAS increased to 27.78 per cent at 45 DAS under open field condition, but the enhancement was 37.50 per cent under poly house condition at the same time which was non-significant. Later at 75 DAS there was significant increase (69.23 per cent) in GA content in poly house compared to open condition. The low PAR coupled with light quality ie, R/FR ratio can raise the level of endogeneous GA's in plants (Kurepin *et al.*, 2007a). Here also this can be a reason for enhanced GA in poly house at 75 DAS. It was interesting to note that a few male flowers were also appeared in poly house during this stage. Peterson and Anhder (1960) reported the importance of endogeneous gibberellin in inducing maleness in cucumbers.

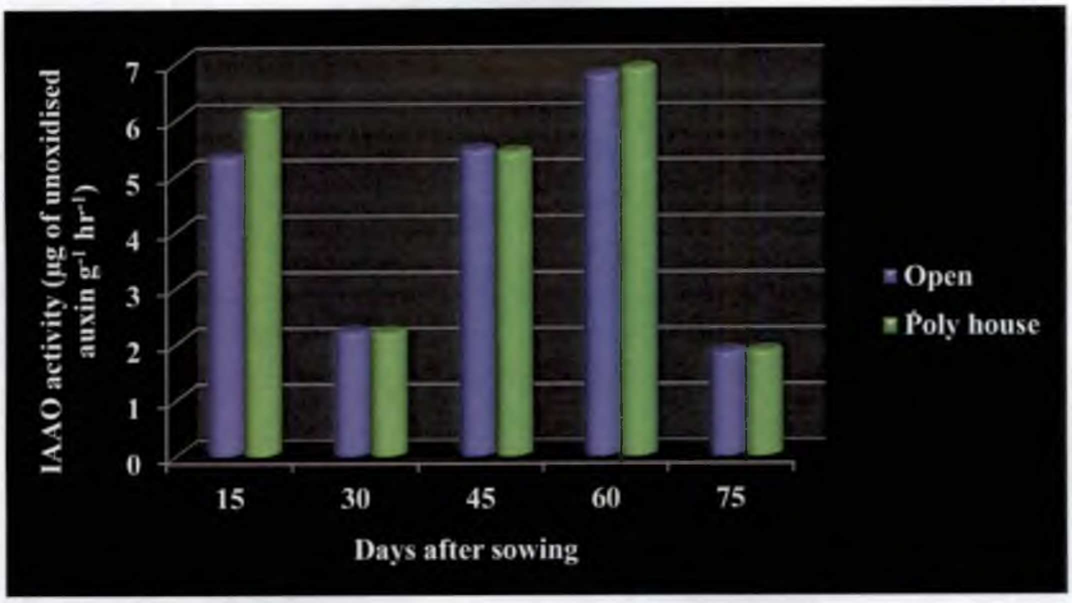

Fig. 11 Variation in IAA Oxidase activity in open and poly house grown cucumber

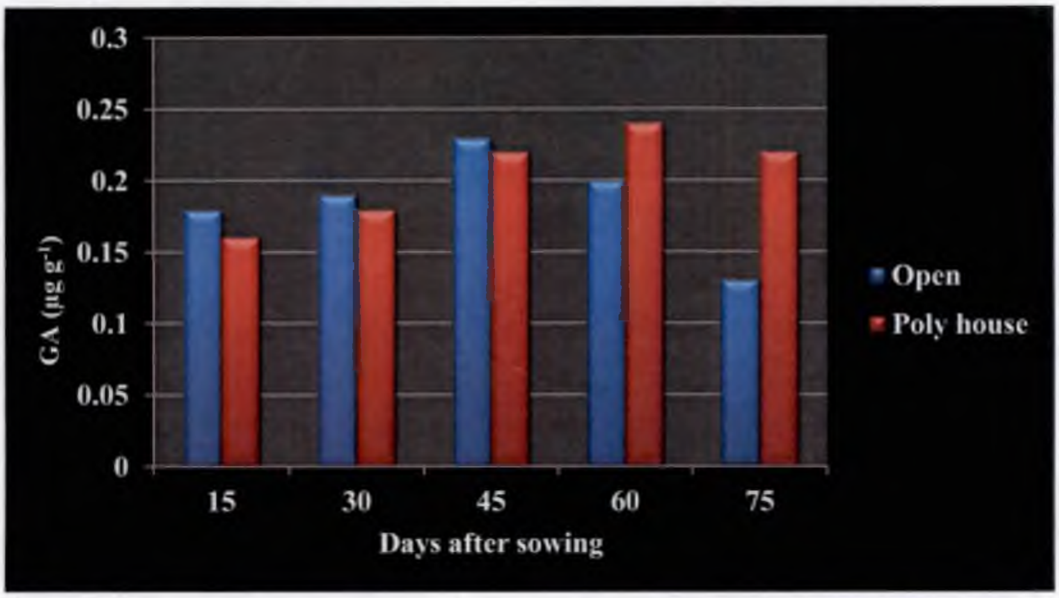

Fig. 12 Variation in Gibberelic acid content in open and poly house grown cucumber

5.4 PHYSIOLOGICAL PARAMETERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

Photosynthetic rate was significantly higher under open condition at 15, 30 and 45 DAS. But it was significantly higher inside poly house condition at 60 and 75 DAS compared to open field crop (Table 13; Fig. 13). During the initial growth stage at 15 DAS the photosynthetic rate inside poly house condition was 19.30 per cent lower than open condition. Later photosynthetic rate increased in both conditions, but it was 16.60 per cent lower inside poly house when compared to open environment. At 60 DAS photosynthetic rate decreased to 75.30 per cent under open condition where as only 44.29 per cent reduction was observed inside poly house. At the final stage of the crop there was a reduction of 57.25 per cent under open condition compared to poly house environment.

This increased photosynthetic rate at 60 and 75 DAS when compared to open condition may be the reason for prolonged yield inside poly house at later stages of growth. Reduced photosynthetic rate under poly house condition at initial stages of the crop may be due to low intercellular CO_2 concentration and high stomatal resistance. It is observed that peak flowering period and later stages of harvest time were associated with higher photosynthetic rate inside the poly house environment compared to open condition.

It was already reported that the reduced CO_2 intake due to stomatal resistance results in reduced photosynthesis (Chaves *et al.*, 2002; Vaadia *et al.*, 1961; Schulze and Hall, 1982). Abdrabbo *et al.* (2009) observed low radiation induced down-regulation of photosynthetic capacity of leaves and consequently a lower light saturated photosynthetic rate in poly house compared to open condition. It is already reported that leaves grown in high light had 10-15 per cent more efficient photosynthesis in direct full sunlight than when exposed to diffused light (Brodersen *et al.*, 2008; Markvart *et al.*, 2010).

Transpiration rate was significantly higher under open condition at 30 DAS when compared to poly house condition. But later it showed significantly higher

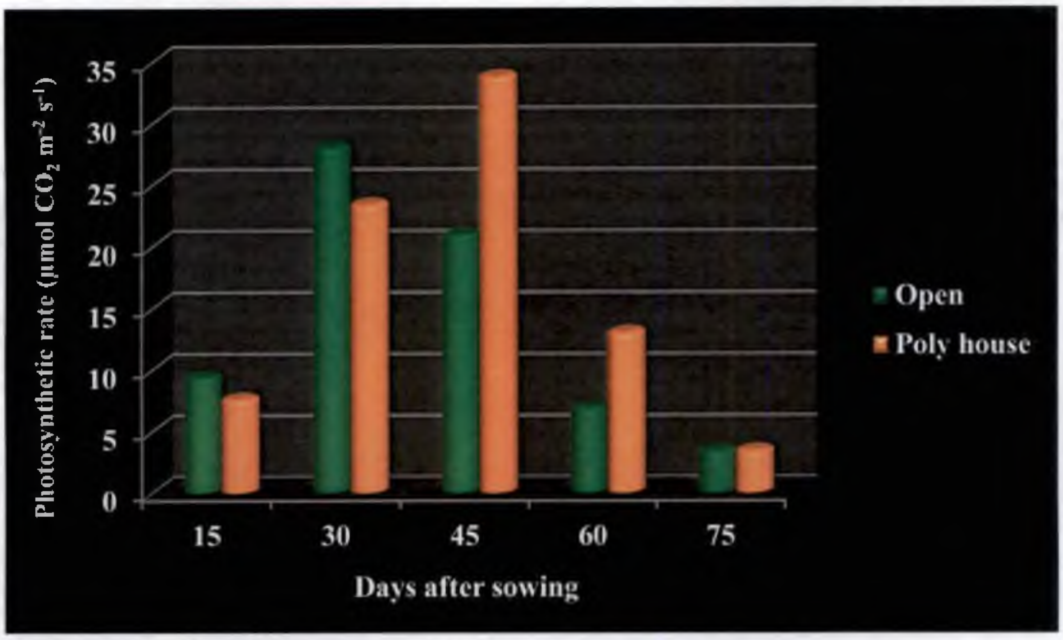

Fig. 13 Variation in photosynthetic rate in open and poly house grown cucumber

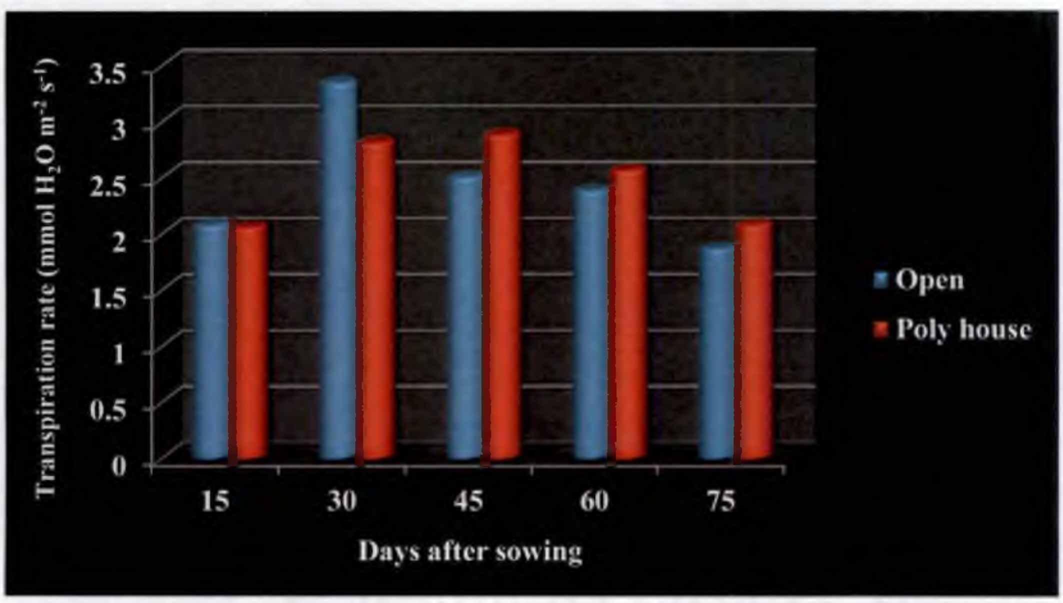

Fig. 14 Variation in transpiration rate in open and poly house environment

values in poly house crop at 45 and 75 DAS (Table 14; Fig. 14). There was an increase of 61.06 per cent under open condition and 36.90 per cent inside poly house environment in transpiration rate during initial stages of the crop from 15 to 30 DAS. The rate was 15.82 per cent lower inside poly house condition when compared to open condition at 30 DAS. Afterwards transpiration rate increased to 15.14 per cent higher inside poly house condition at 45 DAS. During the later stages of growth, transpiration rate was 10.10 per cent more inside the poly house environment compared to open field.

The variation in transpiration rate under both conditions was associated with stomatal limitations which was evidenced by stomatal resistance. Reduction in transpiration was associated with stomatal resistance (Vaadia *et al.*, 1961). Moreover transpiration is a function of three climatic variables temperature, RH and light, which were also significantly different in both conditions. Aubinet *et al.* (1989) observed that greenhouse limits water-vapour exchange with the outside air which produces a feedback effect.

Stomatal resistance was significantly higher inside the poly house at 15 and 30 DAS. But it was significantly higher under open condition at 45 and 75 DAS (Table 15; Fig. 15 and 16). During initial stage at 15 DAS the decrease in stomatal resistance (42.65 per cent) under open condition favours more stomatal conductance and thereby causing high photosynthetic rate at the same time. The reduction of photosynthetic capacity at initial stage may be due to increased stomatal resistance under poly house condition.

At peak flowering and initial harvest stage there was a reduction of 27.12 per cent in stomatal resistance under poly house environment compared to open condition which indicates more influx of CO_2 concentration thereby more photosynthetic rate inside poly house. Stomatal resistance further declined to 17.5 per cent inside poly house at later stages of crop growth maintaining more photosynthetic rate even at this stage when compared to open condition. The

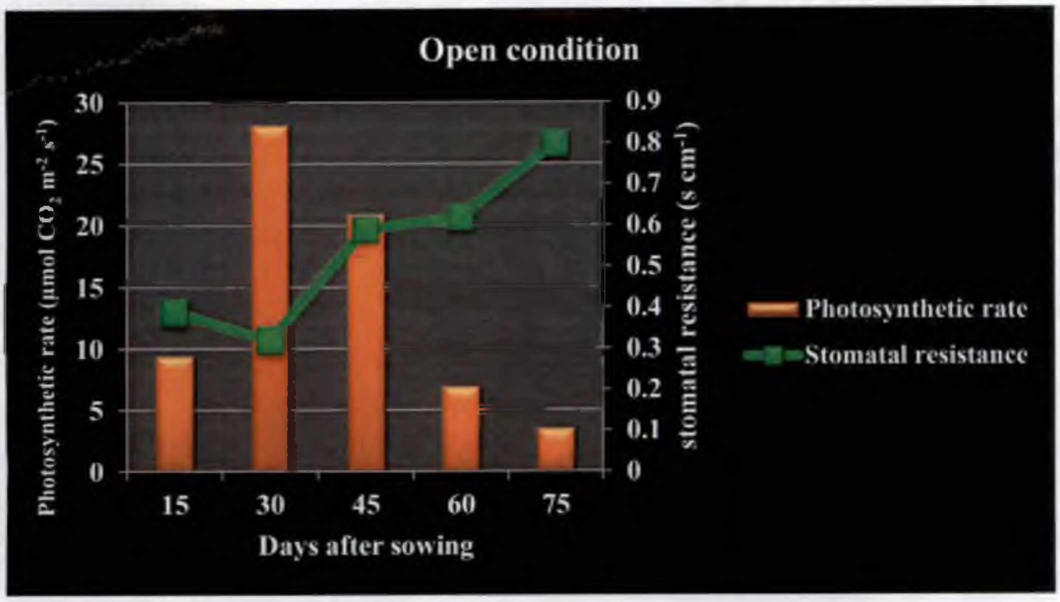

Fig. 15 Variation in photosynthetic rate and stomatal resistance in open environment

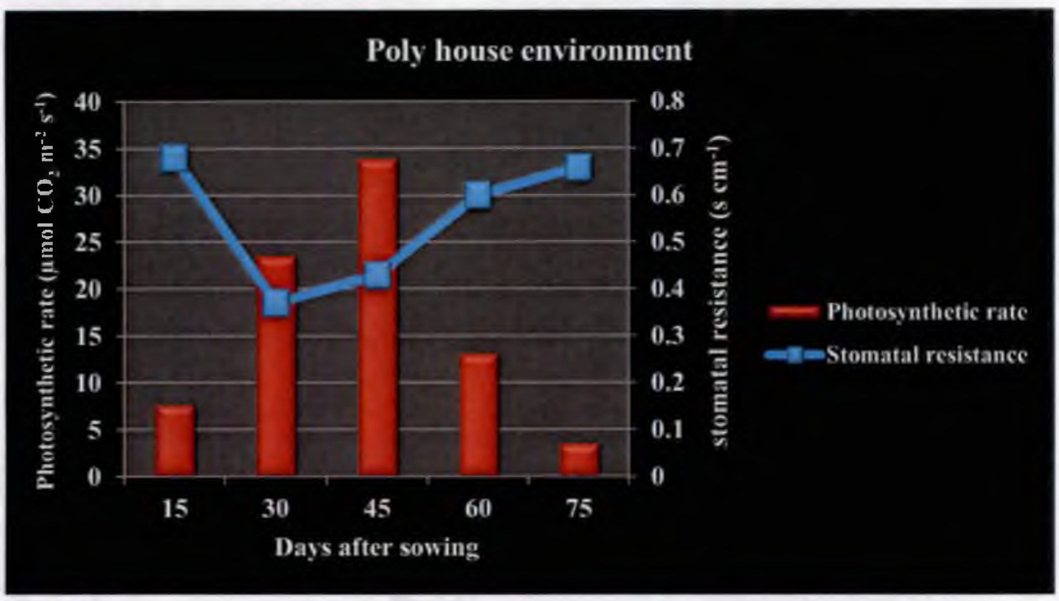

Fig. 16 Variation in photosynthetic rate and stomatal resistance in poly house environment

reduced CO_2 intake due to stomatal resistance results in reduced photosynthesis were reported in earlier studies also (Chaves *et al.*, 2002; Vaadia *et al.*, 1961).

Number of stomata counted from another crop raised at ARS, Mannuthy at the same season, was found less inside poly house grown cucumber leaves compared to open field crop (Table 16). Stomatal density of the low-light leaves or shade-leaves was much lower than that of the leaves under high-light or sun-leaves (Bergmann and Sack, 2007; Sui *et al.*, 2011). In this study also, reduced stomata number in poly house crop may be due to low light intensity inside the poly house.

Intercellular CO_2 concentration was significantly higher under open condition at 15, 30 and 45 DAS whereas it was significantly higher inside poly house grown crop at 60 and 75 DAS (Table 17; Fig. 17 and 18). High intercellular CO_2 concentration and low stomatal resistance during the initial stages of open field grown crop may be the reason for higher photosynthetic rate at that time. Similarly, high intercellular CO_2 concentration and low stomatal resistance may be the reason for higher photosynthetic rate at later stages of poly house grown crop. So this study indicates that high stomatal resistance is recorded with a corresponding change in intercellular CO_2 concentration.

Carboxylation efficiency, which indicates the increase in photosynthetic rate achieved per unit increase in CO_2 at the site of CO_2 fixation, was significantly higher under open condition at 30 DAS. Significantly efficient carboxylation was observed in poly house crop during 60 and 75 DAS only (Table 18). Carboxylation efficiency of poly house grown crops at 30 DAS was 12.50 per cent lower compared to open field grown crops. The photosynthetic rate also reduced at this stage which was coincided with low conductance or more stomatal resistance reflecting poor carboxylation efficiency in mesophyll cell. During the later stages of crop growth at 60 DAS, efficiency increased to 28.57 per cent under poly house condition when compared to open condition. Carboxylation efficiency was 66.67 per cent more inside poly house at 75 DAS compared to

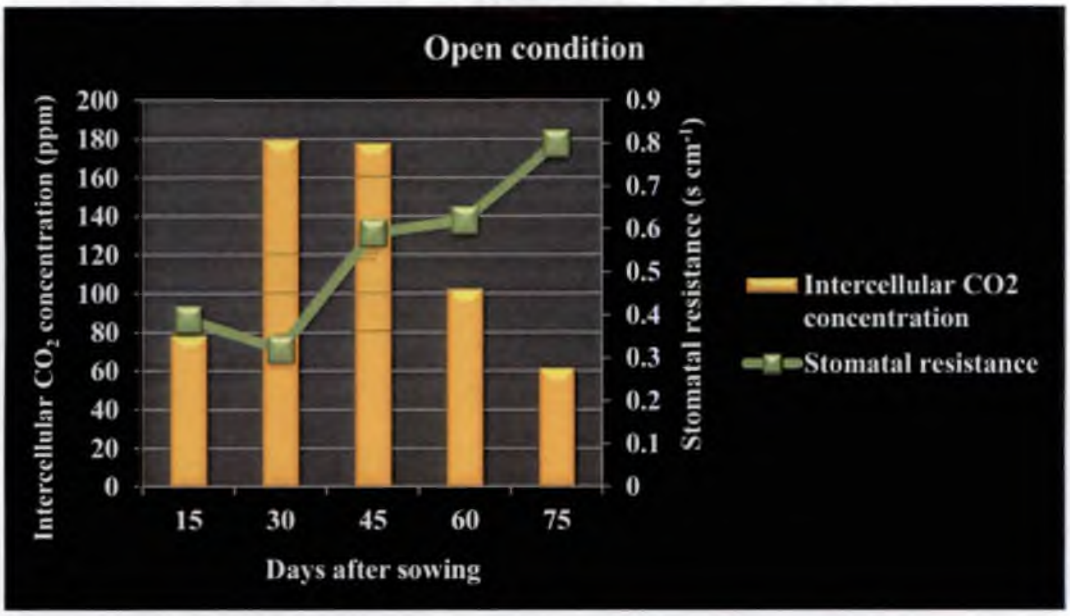

Fig. 17 Intercellular CO_2 concentration and stomatal resistance of crop grown in open condition

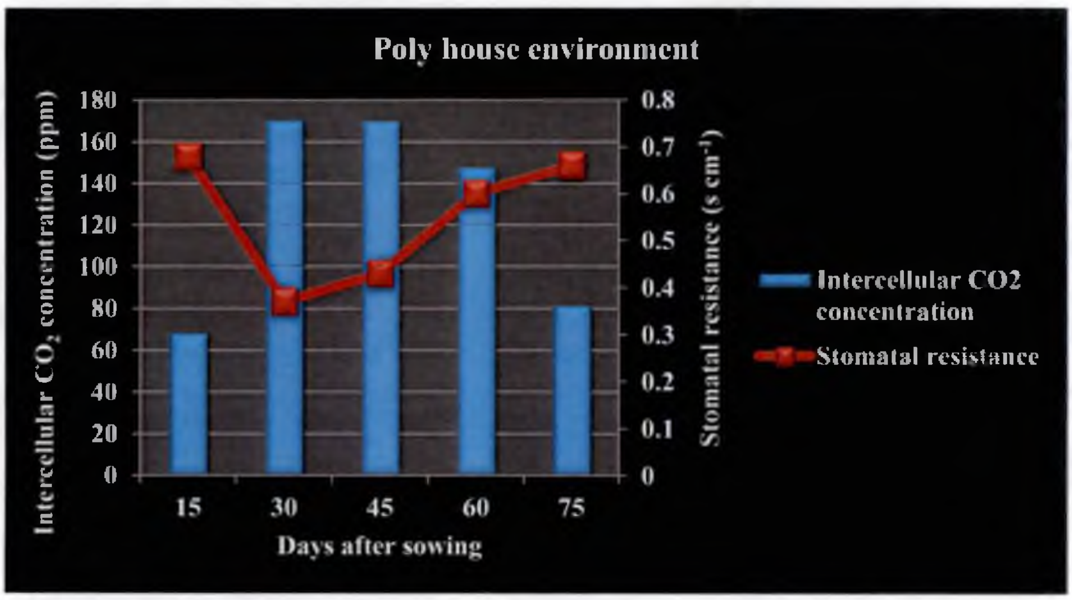

Fig. 18 Intercellular CO_2 concentration and stomatal resistance of crop grown inside poly house

open field crop. Earlier reports of Jacob and Lawler (1992) indicated that A/Ci response has an initial linear phase where Ci is limiting or less and A (photosynthesis) is considered to be limited by the activity of Rubisco. Thus the amount and specific activity of Rubisco and the availability of Ribulose bisphosphate (RuBp) affect carboxylation efficiency and thus the photosynthetic rate. This study reveals that carboxylation efficiency is negatively correlated with stomatal resistance. Lower values of stomatal resistance are associated with high efficiency in carboxylation and higher resistance is related to lower efficiency in carboxylation.

Higher photosynthetic rate and carboxylation efficiency under poly house during 60 and 75 DAS indicate that the carboxylation efficiency is positively related with photosynthetic rate and intercellular CO_2 concentration. Different species cultivated in controlled environment revealed that with high concentration of CO_2, carboxylation efficiency increases and was related to the decrease of the conductance and transpiration (Santos *et al.*, 2010).

Canopy Temperature Depression measured for both conditions did not give any significant variation (Table 19). Though transpiration rate significantly differed between open and poly house environment at 30, 45 and 75 DAS it did not provide a significant difference in CTD.

Chlorophyll fluorescence was measured in open and poly house condition in another crop raised at ARS, Mannuthy at the same season. The F_v/Fm ratio which expresses the maximum photochemical efficiency of PS II, was 34.25 per cent lower under open condition compared to poly house environment (Table 20; Fig. 19). The decrease in F_v/F_m may be related to high light intensity, UV and PAR in open field. An increase in 3.47 per cent light intensity and 92.88 per cent PAR decreased the F_v/F_m to 34.25 per cent under open field grown crop. A lower value indicates damage to PS II due to photoinhibition, which is usually observed in plants exposed to environmental stresses. At high light intensities, fluorescence value decreases (Matysiak, 2004). Upon exposure to excess light, PS II reaction centre gets inactivated by phosphorylation and then degradation (Rintamaki *et al.*, 1996).

Light absorption coefficient was found to be significantly higher under open condition at 15, 60 and 75 DAS. It was significantly higher inside poly house at 30 DAS (Table 21). The light absorption coefficient at initial stage under open condition lowered to 49.18 per cent at later stages where as it was 66.13 per cent lower inside poly house condition at the same time. During the final stages of growth (at 75 DAS) light absorption coefficient was 66.85 per cent lower inside poly house compared to open field grown crops.

The light absorption coefficient indicates absorption of light per unit LAI which is decided by upper and lower canopy light interception. In other words this will give the contribution to canopy light interception by upper and lower leaves per unit land area. Lower values of light absorption coefficient may be related to high LAI inside the poly house. It is clear that from this study that with high LAI, light absorption coefficient was decreased inside the poly house. The light absorption coefficient is related to the LAI, providing an indication of the plants efficiency on intercepting the solar radiation (Bernardes *et al.*, 2011). For LAIs smaller than 3.0-3.5, intercepted radiation was proportional to leaf area, whereas expansion of leaf area at larger LAIs scarcely enhanced radiation interception (Piel *et al.*, 2002).

5.5 PHENOLOGICAL CHARACTERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

There was no significant difference found in days to flowering and days to first harvest between open and poly house grown crops (Table 22). Both conditions took 25 days to flowering from date of sowing and 40-41 days to make the first harvest. But poly house experiments conducted in tomato reported early flowering, fruit setting and harvest under poly house condition when compared to open condition (Parvej *et al.*, 2010).

Days to last harvest of poly house grown cucumber prolonged to 11.3 per cent compared to open field crops (Table 22).

The number of harvests made in open condition was 15.80 whereas it recorded 19.20 number harvests in poly house condition (Table 22). There was an increase of 21.52 per cent for number of harvests made inside the poly house condition than open field crops. In tomato it was reported that poly house plants prolong duration of fruit harvest by about nine days (Parvej *et al.*, 2010). In this study, the days to last harvest and number of harvest made from poly house crop was significantly high when compared to open condition. This may be due to high photosynthetic rate and carboxylation efficiency of the poly house grown crop during later stages of growth. This is also related to low light intensity and PAR in the poly house.

5.6 YIELD PARAMETERS OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

Fruit length did not give any significant variation between open and poly house grown crops (Table 23).

There was 15.56 per cent reduction in upper fruit width measured under open condition when compared to poly house condition (Table 23). The middle and lower fruit width recorded did not give significant difference between open and poly house fruits. Kaddi *et al.* (2014) reported significantly higher fruit length and fruit width under naturally ventilated poly house compared to open field in summer and kharif seasons.

Fruit weight obtained from poly house crop was 13.35 per cent higher than fruits obtained from open condition (Table 23). This higher fruit weight may be associated with more of assimilates produced in source region and their efficient partition to sinks, as partitioning efficiency is decided by sink strength which was evident from earlier reports of Marcelis (1994) also.

There was 51.95 per cent increase in number of fruits under poly house crops compared to open condition (Table 23; Fig. 20). This may be due to more number of internodes and there by more number of flowers per axil of poly house grown cucumber. It may also be associated with high LA and LAI observed in poly house grown crops. The results are in agreement with the observations of Kanthaswamy *et al.* (2000); Gaikwad and Dumbre (2001) and Nagalakshmi *et al.* (2001).

The higher yield inside poly house may be due to more vegetative growth, leaf area, LAI, number of nodes and diffused light at the time of flowering and fruit development. Cucumber crop bears equal distribution of fruits all along the stem *ie.* at each node, hence every leaf in a node supplies photoassimilates to fruits. This demands optimum PAR and light supply at each layer of leaves.

Reduction of total chlorophyll content at later stages was less inside the poly house which contributes to higher photosynthetic rate and thereby higher yield. Higher number of fruits per plant and fruit weight also contributes to more yield per plant. More number of fruits per plant and fruit yield per plant ultimately contributed to more fruit yield per hectare in cucumber (Anjanappa *et al.*, 2012). Similar findings were also reported earlier by Pant *et al.* (2001); Mohomedin *et al.* (1991) in cucumber. Lawlor (1995) reported that crop yield is more related to leaf area and photoasssimilate distribution than photosynthesis.

High yield obtained in poly house grown cucumber is attributed to optimum light intensity and equal distribution of radiation over the crop canopy resulting in production of maximum photoassimilates than at a higher light intensity. Optimum light intensity has also led to optimum stomatal functioning as reported by Umesha *et al.* (2011). Moreover in this study, high carboxylation efficiency at later growth intervals inside the poly house (60 and 75 DAS) was found positively related to high photosynthetic rate and thereby extended the harvesting period and made more number of harvest.

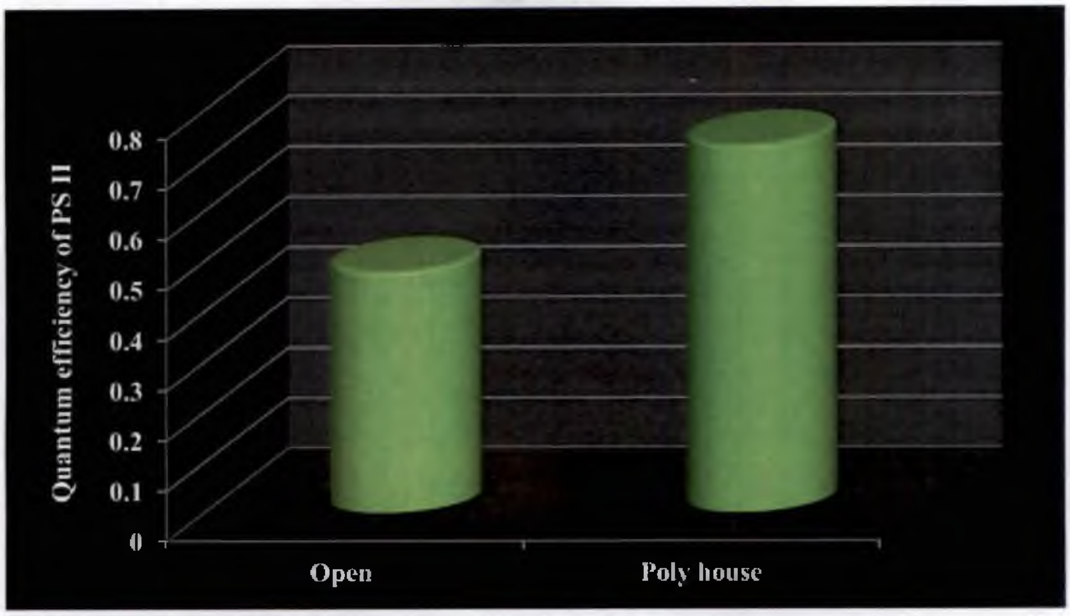

Fig. 19 Variation in quantum efficiency of PS II based on chlorophyll fluorescence measurement in open and poly house environment

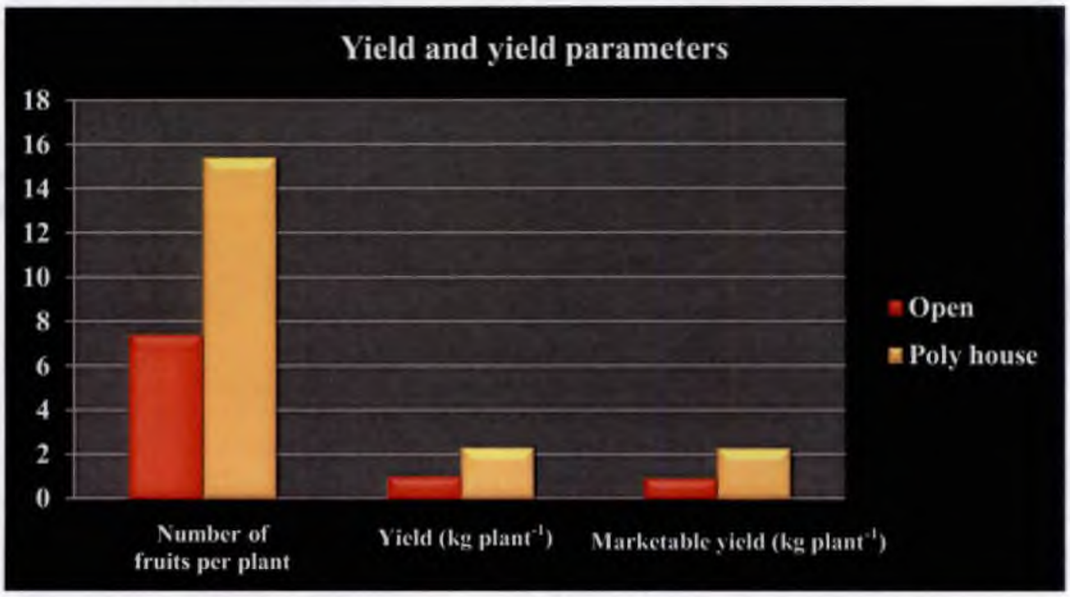

Fig. 20 Yield parameters of cucumber in open and poly house environment

In capsicum, Pandey *et al.* (2005) also observed maximum yield of 2.41 kg per plant for capsicum inside poly house than open field (1.51 kg). They also found that the total fruit bearing period was prolonged inside poly house condition than open field. In tomato, the fruit yield obtained from the polyhouse was 81 t/ha against 57 t/ha from the open field (Parvej *et al.*, 2010). Hemming *et al.* (2013) reported that diffuse light is advantageous for greenhouse crops. They found that different crops showed an increased production up to 10 per cent under diffuse light conditions at different places. Ramesh and Arumugham (2010) also reported similar results.

The marketable yield observed was 60.18 per cent lower under open condition when compared to poly house condition (Table 23; Fig. 20). This reduction may be due to the absence of uniform size and greenness of the fruit under open condition. The absence of uniform size may be associated with poor assimilate partitioning under open field grown crop. This is in agreement with findings of Drews (1980); Sood and Sharma (2006) and Singh *et al.* (2012).

5.7 QUALITY ATTRIBUTES OF CUCUMBER IN OPEN AND POLY HOUSE ENVIRONMENT

The crop grown under open condition recorded higher amount of ascorbic acid (AA) than poly house crop. The ascorbic acid content estimated was 27.29 per cent lower inside poly house grown crop (Table 24; Fig. 21). This reduction may be associated with high temperature and low light intensity prevailed at the time of fruit development inside the poly house. Earlier reports of Klein and Perry (1982) also indicated that climatic conditions including light and temperature have a strong influence on the chemical composition of horticultural crops. This is in consistence with the observation of Lee and Kader (2000) that though light is not essential for the synthesis of AA in crops, the amount and intensity of light during the growing season have a definite influence on the amount of AA formed.

Sensory qualities are important for horticultural crops especially salad vegetables since it is a qualitative measure for market value. Overall acceptability of fruit depends on appearance, colour, texture, flavour, taste and after taste. Characters like colour, texture and overall acceptability of fruits harvested from poly house crop was preferred more by the panel of judges (Table 25; Fig. 22). Micro-climate around a crop contributes to sensory qualities. Preferred colour of fruits from poly house may be due to the presence of more chlorophyll content, which is the colouring pigment and high ambient CO_2 concentration. Similar results were earlier reported on tomato where fruits from the CO_2 enriched plots developed more red colour than control (Islam *et al*., 1996).

Texture is an important character, which decides freshness of the fruit. Barrett *et al*. (2010) reported that the texture of fruits and vegetables is derived from their turgor pressure and the composition of individual plant cell walls. The greatest contributor to the texture of tomato products are the insoluble solids which are derived from cell walls. In this study, preferred texture of poly house fruits may be due to internal composition of fruits and favourable micro-climate or optimum natural resources prevailed inside poly house. Overall acceptability of poly house fruits may be due to uniform size, shape, length and colour of the fruits. This agrees with the findings of Kaddi *et al*. (2014).

5.8 Incidence of pest and diseases

Incidence of pest and diseases were higher under open condition compared to poly house condition (Table 26). In protected cultivation, the crop is protected from unfavourable conditions thereby reducing the chance of pest and disease attack.

Mite attack was observed inside poly house at later stages. This may be due to the presence of hot, humid micro-climate which favours mite growth inside the poly house. Many earlier workers have reported that increased mite incidence in poly houses (Sallam *et al*., 2009; Maklad *et al*., 2012; Murphy, 2014). Leaf miner attack, bacterial wilting, fruit fly and fruit rot were observed under open condition.

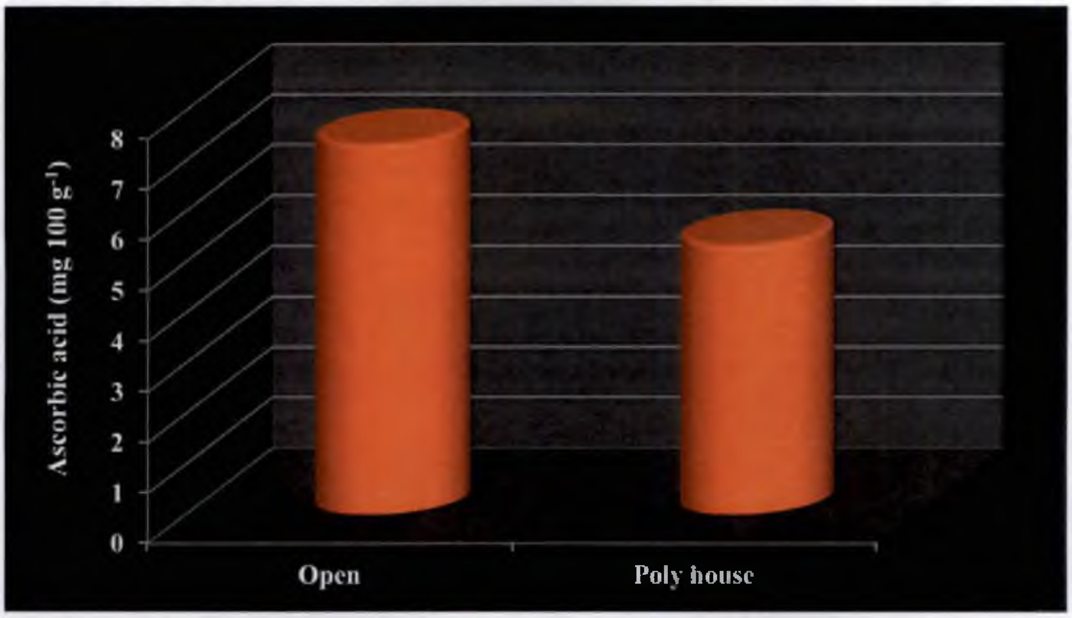

Fig. 21 Variation in ascorbic acid content in open and poly house environment

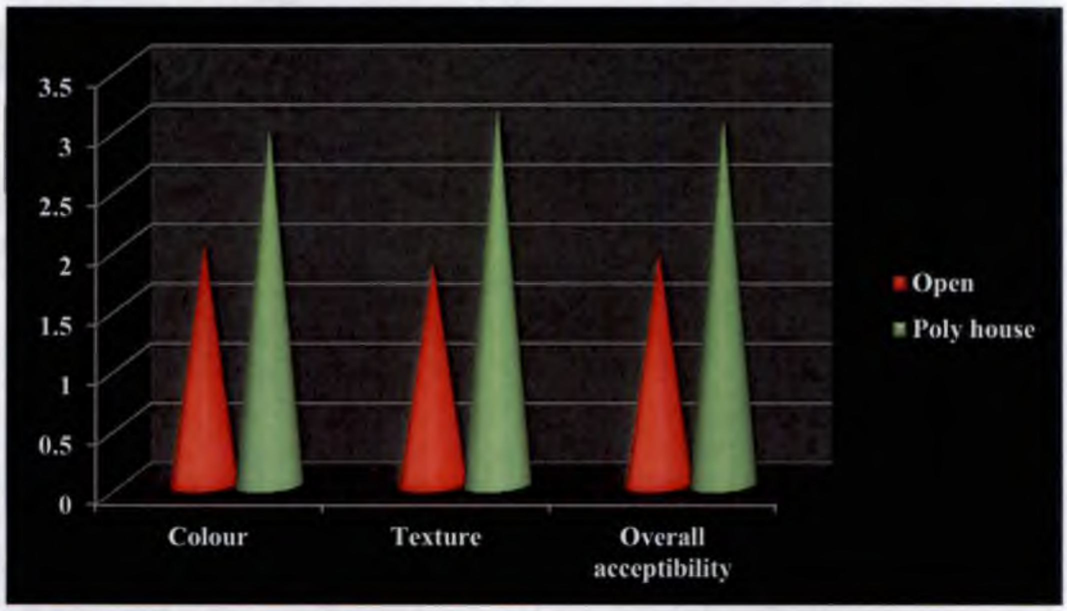

Fig. 22 Organoleptic evaluation of cucumber fruits in open and poly house environment

Fruit malformation was observed in harvests made at later stages under poly house condition. During this stage, there was an increase in GA content in poly house grown crop. Dorais *et al.* (2001) reported misshaped tomato fruits and formation of swollen and hollow fruits due to low light intensity and inappropriate temperature regimes during the growing season in spring inside poly house.

Future line of work

- More emphasis is needed on climatic parameters modified by different types of poly house cladding material, with specific physical properties in cucumber.
- Optimization of light intensity, temperature, RH, UV radiation and PAR for poly house grown cucumber is necessary.
- Seasonal influence on physiological parameters favouring growth and productivity of poly house grown cucumber should be well studied.
- Selection of correct poly house cladding material for spectral management in relation to plant growth and development is a crucial issue to be studied.
- More research is needed on standardization of agro-techniques for crop growth regulation for poly house grown cucumber.

SUMMARY

6. SUMMARY

Protected cultivation is an emerging approach in Kerala. Poly house cultivation is one of the most practical methods of protected cultivation. This technology helps to overcome biotic and abiotic stresses and breaks the seasonal barrier of productivity of crops especially vegetables. Protected cultivation provides favourable micro-climate for better growth and development of crops.

Though poly house cultivation provides a new scope for commercial vegetable production, the high variations in yield and other growth parameters among crops suggest that physiological aspects involved in the photo response on photosynthesis and yield of different crops have to be studied. Hence the present study was proposed to understand the basic physiological mechanism on productivity of poly house crops using cucumber as a test crop. The study was conducted at the Department of Plant Physiology, College of Horticulture, Vellanikkara to understand photosynthetic efficiency and productivity of gynoecious parthenocarpic cucumber in naturally ventilated poly house. The crop was raised in farmer's poly house at Thannyam in Thrissur district.

The main objective of the study was

- To understand the morphological, phenological, biochemical and physiological variation in growth and development of gynoecious parthenocarpic F_1 cucumber in naturally ventilated poly house compared to open condition.

The salient findings of the study are

- High light intensity, UV-radiation and PAR caused a stressful environment which reduced most of the morphological and biochemical characters of cucumber under open condition.
- Light intensity, UV-radiation and PAR were reduced by poly house covering material and its physical properties, which favoured morphological characters of the crop.

- The CO_2 concentration observed was significantly high inside the poly house throughout the growing season.
- The morphological characters like leaf area, LAI, number of leaves, number of nodes and internodal length were significantly high inside poly house grown crops. This may be due to optimum light intensity and PAR maintained in the poly house.
- The maximum leaf area produced by the poly house grown crops may be associated with decreased PAR and high CO_2 concentration.
- More number of nodes produced at 45 DAS coincides with peak flowering and fruiting stage of the crop and thereby contributed more number of fruits per plant, which is one of the important yield component in cucumber.
- High leaf area and LAI observed inside poly house when compared to open field condition indicates better utilisation of light and PAR.
- Chlorophyll content was significantly high inside the poly house grown cucumber leaves. Though light is essential for the synthesis of cholorophyll, high light intensity will slow down the chlorophyll synthesis. The low chlorophyll content recorded under open condition may be due to the high light intensity outside the poly house.
- Poly house grown crop maintained relatively high amount of chlorophyll even at later stages of the crop contributing to delayed senescence.
- The low activity of IAAO observed at 15 and 60 DAS was significantly higher inside the poly house. This indicates more amount of auxin available during early vegetative growth (15 DAS) and later at early stages of fruit development in the parthenocarpic cucumber variety.
- Significant difference in Gibberelic acid content was observed only at 75 DAS in poly house crop.
- Though ambient CO_2 concentration was higher, low intercellular CO_2 concentration (Ci) and high stomatal resistance reduced photosynthetic rate at initial growth intervals inside poly house compared to open condition.

- The photosynthetic rate was significantly high inside poly house condition at 60 and 75 DAS. This enhanced photosynthetic rate when compared to open condition may be the reason for contribution of more photoassimilates and thereby prolonged yield inside poly house.
- More stomatal number per unit leaf area was observed under open condition when compared to poly house condition.
- High carboxylation efficiency at later growth intervals inside the poly house (60 and 75 DAS) was found positively related to high photosynthetic rate and thereby extended the harvesting period and made more number of harvest.
- Photochemical efficiency of PS II as indicated by Fv/Fm ratio (0.73) was higher inside poly house indicating less stress to PS II when compared to open condition.
- Light absorption coefficient was higher in open condition due to low LAI whereas in poly house more LAI reduced light absorption coefficient values.
- Number of days to last harvest and number of harvests made from poly house grown crop were significantly higher when compared to open condition. This may be due to high photosynthetic rate and carboxylation efficiency of the poly house grown crop during the later stages of growth.
- The yield contributing components such as number of fruits per plant, fruit weight, yield per plant and marketable yield were significantly high for poly house grown crop. More number of fruits may be due to more number of internodes which contributed more number of flowers per axil. This is also associated with high leaf area and LAI observed in poly house grown crops. The reduction in per plant yield under open condition is seen associated with less vegetative growth and lesser canopy area.
- Prolonged harvest from poly house may be due to high photosynthetic rate and carboxylation efficiency maintained even at later stages of the poly house grown crop.

- Early senescence of the crop was observed under open condition compared to poly house.
- High yield in poly house grown crops can be related to optimum light intensity and equal distribution of radiation over the crop canopy.
- The quality attributes like ascorbic acid content was low inside poly house compared to open field grown crop. This may be associated with high temperature and low light intensity prevailed at the time of fruit development inside the poly house.
- Organoleptic evaluation of fruits revealed that the poly house grown crops maintained significantly high colour, texture and overall acceptability. These sensory qualities may be related to the favourable micro-climate prevailed during fruit development in poly house.

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APPENDICES

Appendix I

Weather data during crop period: Open field condition

March-2014	Temperature (^0C)	RH (%)	UV-radiation (Wm^{-2})	Light intensity(lux)	PAR (µmol $m^{-2} s^{-1}$)
4th week	38.6	40	114.35	164000	1787
April-2014					
1st week	34.2	67	22.2	127200	227
2nd week	33.9	71	55.4	136900	928.5
3rd week	39.3	69	62.3	134400	927.5
4th week	38.3	68	34.2	129300	1253.67
May-2014					
1st week	40	62	78	138200	1179.33
2nd week	38.5	70	133.6	124433	1042
3rd week	38.1	74	58.63	122333	1145
4th week	39.8	72	73.23	93900	792.33
June-2014					
1st week	37.9	72	41	30167	1345

Poly house environment

March-2014	Temperature (^0C)	RH (%)	UV-radiation (Wm^{-2})	Light intensity (lux)	PAR (µmol $m^{-2} s^{-1}$)
Last week	40	41	26.25	92000	587
April-2014					
1st week	35.3	68	4.4	97200	86
2nd week	38.4	69	18.9	104044	423.5
3rd week	38.8	70	22.8	97050	474.5
4th week	40.4	67	59.4	96975	434
May-2014					
1st week	42.2	66	38.63	99560	672
2nd week	43.8	67	56.9	148100	554.67
3rd week	39.6	69	48.33	47467	543
4th week	40	76	30.5	91767	670
June-2014					
1st week	39.8	74	16.5	25533	1065

Appendix II

Diurnal variation in CO_2 concentration (ppm) in open and poly house environment

Time	Open condition	Poly house environment
6.00 am	450	480
8.00 am	410	430
10.00 am	420	442
12.00 am	425	450
2.00 pm	430	450
4.00 pm	432	465
6.00 pm	450	465

PHOTOSYNTHETIC EFFICIENCY AND PRODUCTIVITY OF GYNOECIOUS PARTHENOCARPIC CUCUMBER IN NATURALLY VENTILATED POLY HOUSE

By

GAYATHRI RAJASEKHARAN

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ABSTRACT OF THE THESIS

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VELLANIKKARA, THRISSUR – 680656

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ABSTRACT

Poly house cultivation of vegetables is an emerging approach for production of vegetables in Kerala. The main principle of poly house cultivation is the facilitation of favourable micro-climates, which favour maximum production. The top of poly house is cladded with UV-stabilised plastic sheet which selectively screen the various spectral components of solar radiation and transform direct sunlight into scattered light inside. This type of spectral manipulation is aimed to specifically promote desired physiological processes and to modulate morphological and photosynthetic responses of plants. Hence, basic information on the physiological aspects involved in the photoresponse of crop in poly house is needed to realize maximum yield potential. In this context, a study was undertaken in a farmer's field at Thannyam to compare the photosynthetic productivity of gynoecious parthenocarpic cucumber in poly house and open condition.

High light intensity, Ultra violet (UV) radiation and Photosynthetically Active Radiation (PAR) caused a stressful environment which in turn reduced most of its morphological and biochemical characters in cucumber grown under open condition. However ambient CO_2 concentration, which decides the photosynthetic rate was more under polyhouse condition. Poly house cladded with UV stabilized sheet, reduced light intensity, UV-radiation and PAR favoured most of the morphological characters of the crop. The morphological characters like leaf area, Leaf Area Index (LAI), number of leaves, number of nodes and internodal length were significantly high for poly house grown cucumber.

The chlorophyll content- Chl a, b and total chlorophyll in leaves was significantly high when grown under poly house. However, the activity of IAA Oxidase (IAAO) observed at 15 and 60 DAS was significantly lower inside the poly house indicating auxin availability for morpho-physiological fuctions. The Gibberelic acid content also increased but significant difference was observed only at 75 DAS in poly house grown crop.

Photosynthetic rate of the crop under both conditions when recorded gradually increased from 15 DAS to 45 DAS and thereafter declined. This was significantly high under open condition at 15, 30 and 45 DAS, whereas it was significantly high in poly house only at 60 and 75 DAS. The poly house crop could maintain higher photosynthetic rate even at later growth stages of crop thereby prolonging the crop duration. Transpiration rate was significantly high under open condition at 30 DAS, but significantly higher values were

observed in poly house condition at 45 and 75 DAS. The lower photosynthetic rate was due to low influx of CO_2 in to mesophyll cells which is evident from low intercellular CO_2 concentration in the poly house crop. This is also related to high stomatal resistance inside the poly house at 15 and 30 DAS.

The carboxylation efficiency, which relates to photosynthetic rate, was significantly high at 60 and 75 DAS in the poly house crop. The photochemical efficiency of PS II as indicated by Fv/Fm ratio was higher under poly house environment. Canopy temperature depression did not give any significant difference between two conditions.

Light absorption coefficient was significantly high in open condition where the LAI was less. The lower values of light absorption coefficient observed inside the poly house may be related to high LAI.

There was no significant difference in number of days to flowering and days to first harvest between open and poly house grown crops. But the number of days to last harvest and number of harvests made from poly house grown crop were significantly high when compared to open condition.

The yield contributing components such as number of fruits per plant, fruit weight, yield per plant and marketable yield were significantly high for poly house grown crop. Early senescence of the crop was observed under open condition compared to poly house. Retention of more chlorophyll content even at later stages of crop delayed senescence in poly house grown crop.

The ascorbic acid content, one of the quality parameter was significantly high in crop grown under open condition. Organoleptic evaluation of fruits revealed that the poly house grown crops maintained significantly high colour, texture and overall acceptability of the fruits.

This study suggests that the diffused light and equal distribution of radiation over the crop canopy favoured morphological characters of poly house grown crop. This in turn helped the crop to maintain high photosynthetic rate and carboxylation efficiency even at later stages of the crop which resulted in increased number of harvest in poly house.