Short communication

Photosynthetic characters in relation to yield of cucumber grown in naturally ventilated poly house

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Abstract:
The main principle of poly house cultivation is the facilitation of favourable micro-climate, which favours maximum production. The UV-stabilized plastic sheet which covers the top of the poly house selectively screens the various spectral components of solar radiation and transforms direct sunlight into scattered light. Optimal photosynthesis of leaves involves the harmonious relationship between spectral management and the resultant PAR in poly house. 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 to compare the photosynthetic productivity of gynoecious parthenocarpic cucumber which is widely grown in naturally ventilated poly house with that in open conditions. The study revealed that the low intercellular CO_2 concentration and high stomatal resistance caused low carboxylation efficiency and photosynthetic rate at early stages of growth in poly house compared to open condition. But at later stages of growth, the carboxylation efficiency and photosynthetic rate was maintained even 60 DAS due to lower rate of stomatal limitations. This facilitates prolonged harvest and more number of harvests from poly house crop. The Fv/Fm ratio, which expresses the maximum photochemical efficiency of PS II, was lower under open condition compared to poly house.

Keywords: Chlorophyll fluorescence, Carboxylation efficiency, Photosynthetically active radiation, Spectral management

The need to protect crops against unfavourable environmental conditions led to the development of protected agriculture. Cucumber, tomato, capsicum and leafy vegetables are major crops grown in naturally ventilated poly houses. It is being practiced in more than fifty countries all over the world (Parvej et al., 2010). The main objective of protected cultivation is the creation of a favourable micro-climate, which favours crop production. The top of the poly house is covered using a UV stabilised plastic sheet, which screens the spectral components of solar radiation including Ultra-Violet (UV) and Photosynthetically Active Radiation (PAR). It also transforms the direct sunlight in to scattered light. This spectral manipulation promotes the morphological and photosynthetic responses of plants.

Greenhouse cucumber has a higher 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). Cucumbers require at least 250 µmol m^{-2} s^{-1} of PAR, below which the productivity will decline.

Though poly house cultivation shows promise for vegetable production, the high variability in results among crops suggest that photosynthetic behaviour

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involved in the photo response of crops under photo selective nets should be well studied. Hence, the study was aimed to understand the different photosynthetic character in relation to yield of poly house grown cucumber in comparison with an open field grown crop.

The study was conducted in a farmer's poly house at Thannyam in Thrissur district of Kerala during March to June, 2014. The size of poly house was 180 m^2 and it was covered with a five layer ultra violet stabilized low density polyethylene sheet of 200 micron thickness and 85% 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 variety used was ZECO F_1, which is a gynoecious parthenocarpic cucumber with early maturation and very high yield. The crop was raised in rows of 20 m length 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. N, P and K were given at the rate of 175:125:300 kg/ha. Fertilizers were applied through fertigation once in three days. Pruning of basal leaves was done at 45 days after sowing. Other agronomic and cultural operations were made as per *ad hoc* Package of Practice (POP) of Kerala Agricultural University for protected cultivation. The crop was raised simultaneously in open condition for comparing the growth and development in two conditions.

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 from the upper third leaf from randomly selected six plants in both conditions at 15 days interval throughout the growing period. Photosynthetic rate (μmol CO_2 m^{-2} s^{-1}), transpiration rate (mmol H_2O m^{-2} s^{-1}), stomatal conductance (mol H_2O m^{-2} s^{-1}), reference carbon dioxide concentration (ambient carbon dioxide concentration, Ca in ppm) and intercellular carbon dioxide concentration (Ci in ppm) were recorded using this instrument. Stomatal resistance was calculated from stomatal conductance using the formula,

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

Instantaneous carboxylation efficiency was calculated from leaf intercellular CO_2 concentration (Ci) and photosynthetic rate (Pi).

Carboxylation efficiency = Photosynthetic rate (Pi) / Intercellular CO_2 content (Ci) (μmol CO_2 m^{-2} s^{-1} ppm^{-1})

The chlorophyll fluorescence of the crop was measured by portable Modulated Chlorophyll Fluorometer, OS1p (OPTI-SCIENCES: Hundson, USA) at 45 DAS (at peak flowering stage) in both conditions. After dark adaptation of leaves the minimal fluorescence (F_0), and at light saturation maximum fluorescence (F_m), were recorded. From this, F_v (variable fluorescence) was derived as $F_v = F_m - F_0$. The Fv/Fm ratio was worked out which indicates the proportion of quantum yield or quantum efficiency of PS II in relation to a high degree of photosynthesis. 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 μmol m^{-2} s^{-1}. The same six plants were sampled for yield and yield contributing traits. The data was analysed using statistical software SPSS. The t-test was used for comparing two growing environments with regard to quantitative parameters.

The results presented in Table 1 showed that photosynthetic rate was significantly higher under open conditions at 15, 30 and 45 DAS. But it was significantly higher inside the poly house at 60 and 75 DAS compared to open field crop. Even though the ambient CO_2 concentration inside poly house was high, it did not contribute to high photosynthetic rate during the initial intervals of growth inside poly house. The initial photosynthetic rate of 9.43 μmol CO_2 m^{-2} s^{-1} at 15

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

Days after	Open condition		Poly house		t-value
sowing	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

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

Days after	Open condition		Poly house		t-value
sowing	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

Table 3. Variation in stomatal resistance (s cm^{-1}) in open and poly house environment

Days after	Open condition		Poly house		t-value
sowing	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

DAS rose to 28.13 µmol CO_2 m^{-2} s^{-1} at 30 DAS in open condition whereas it increased 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. The enhanced photosynthetic rate at later stages of growth when compared to open condition may be the reason for contribution of more photoassimilates and thereby prolonged yield inside poly house. 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.

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 (Table 2). Later it decreased to 1.87 mmol H_2O m^{-2} s^{-1} at 75 DAS. The variation in transpiration rate under both conditions was associated with stomatal limitations which were evident from stomatal resistance offered at this stage. This is in agreement with findings of Vaadia et al. (1961). Aubinet et al. (1989) also observed that greenhouse limits water-vapour exchange with the outside air which produces a feedback effect.

Stomatal resistance indicates the resistance offered by stomata for gaseous exchange. Decrease in stomatal resistance facilitates higher CO_2 uptake and thereby more photosynthetic rate. 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 (Table 3). 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. During the initial stage (at 15 DAS), decreased stomatal resistance (42.65 per cent) under open condition favoured more stomatal conductance and thereby caused high photosynthetic rate at the same time. The reduced photosynthetic rate at initial stages of growth inside poly house was seen associated with high stomatal resistance and lower concentration of intercellular CO_2 in mesophyll cells. At peak flowering and initial stages of harvest, 27.12 per cent decline in stomatal resistance was observed under poly house environment compared to open condition. This indicates more influx of CO_2 into mesophyll cells surrounding chloroplast and 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. Similar results were observed by Vaadia et al. (1961), Al-Ani and Bierhuizen (1971) and Schulze and Hall (1982).

The CO_2 concentration inside the poly house condition was significantly higher at all the growth stages of the crop (Table 4). The initial value of 449.39 ppm at 15 DAS increased and reached to a maximum value of 472.00 ppm at 30 DAS. Later it decreased and reached the lowest value. 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. 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 5). 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 increased up to 30 DAS and reached highest value (170.17 ppm). Afterwards it decreased and reached a value of 81.50 ppm at 75 DAS. 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. Earlier findings of Schulze and Hall (1982) and Chaves et al. (2002) also suggested reduction in photosynthetic rate due to stomatal resistance and reduced intercellular CO_2 concentration. At low to intermediate CO_2 concentration, photosynthesis is limited by carboxylation capacity of rubisco also (Jacob and Lawler, 1992).

Table 4. 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

Table 5. Variation in intercellular CO_2 concentration (ppm) in open and poly house environment

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

Table 6. Variation in carboxylation efficiency (μmol CO_2 m^{-2} s^{-1} ppm^{-1}) in open and poly house environment

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

The carboxylation efficiency was significantly higher under open condition at 30 DAS. But it increased significantly inside the poly house at 60 and 75 DAS (Table 6). 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. Higher reduction in carboxylation efficiency was observed at 75 DAS in both conditions. This study reveals that carboxylation efficiency is positively related with photosynthetic rate and intercellular CO_2 concentration and negatively related 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 (Santos et al., 2010).

The data on chlorophyll fluorescence measured at 60 DAS revealed that Fv/Fm ratio, which expresses the maximum photochemical efficiency of PS II, was 34.25 per cent lower under open condition compared to poly house (Table 7). Lower values indicate damage to PS II due to photoinhibition which is usually observed in crops exposed to environmental stresses. This value is positively related to high photosynthetic rate observed in poly house at 60 DAS. At high light intensities and PAR Fv/Fm ratio decreases (Matysiak, 2004) and PS II reaction centres gets inactivated by photophosphorylation (Rintamaki et al., 1996).

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 7). Shade net cover

Table 7. Variation in quantum efficiency of PS II based on chlorophyll fluorescence measurement and PARat 60 DAS in open and poly house grown cucumber

Observation	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
F_v/F_m	0.48	0.07	0.73	0.07	6.21**
PAR (µmol m^{-2} s^{-1})	1062.73	404.06	550.97	246.40	5.05**

SD: Standard deviation** Significant at 1% level

Table 8. Yield parameters open and poly house grown cucumber

Observations	Open condition		Poly house		t-value
	Mean	SD	Mean	SD	
Number of harvests	15.80	0.84	19.20	0.84	6.43**
Fruit weight (g)	146.18	14.82	165.70	4.25	2.83*
Yield per plant (kg)	0.99	0.07	2.30	0.73	4.02*

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

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 agree with these findings.

The yield per plant lowered to 57 per cent under open condition (Table 8). Fruit weight obtained from poly house crop was 13.35 per cent higher than fruits obtained from open condition. 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 an increase of 21.52 per cent for number of harvests made inside the poly house condition than open field crops. In this study, the days to last harvest and number of harvests made from poly house 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 later stages of growth. Cucumber crop bears equal distribution of fruits all along the stem *i.e.,* 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. In tomato it was reported that poly house plants prolong duration of fruit harvest by about nine days (Parvej et al., 2010).

It is clear from this study that intercellular CO_2 concentration surrounding the chloroplast in mesophyll cell is more important than ambient CO_2 concentration for effecting the optimum photosynthetic rate and thereby prolonging the number of harvests and yield in poly house. This is further favoured by optimum PAR prevailing in poly house throughout the growing period. The reduction in photosynthesis at early stages of crop can be attributed to a decline in intercellular CO_2 concentration (Ci), due to the high stomatal resistance, which leads to over excitation and subsequent photoinhibitory damage of PSII reaction centres. The photosynthetic rate and carboxylation efficiency were significantly high inside poly house condition due to activation of PS II reaction centres at 60 and 75 DAS compared to open field crop. This enhanced photosynthetic rate and carboxylation efficiency maintained even at 60 DAS when compared to open condition may be the reason for contribution of more photoassimilates and thereby prolonged yield inside the poly house.

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