



Research Article

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Cucumber (*Cucumis sativus*) Transplants as Affected by Shade Level: Microenvironment, Growth, Photosynthetic Efficiency, Osmoprotectants, Plant Water Status, and Leaf Mineral Nutrients



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Abstract

Growing vegetables transplants under black shade nets is currently becoming popular to provide protection from high intensities of light and high temperatures. This study evaluated the effects of shade level on microenvironment, vegetative growth, photosynthetic pigments, chlorophyll a fluorescence, osmoprotectants, plant water status, and leaf mineral nutrients of greenhouse-grown summer cucumber transplants at 25%, 50%, 63%, and 75% shade levels. Overall this study, solar radiation decreased with increased shading levels. Average daily temperatures were approximately decreased by 1.5 °C under 75% shade nets compared to the 25% shade nets. Vegetative growth characteristics, photosynthetic pigments, chlorophyll a fluorescence, leaf mineral nutrient, and dehydration tolerance increased when shade level increased. While, clear decreases in free proline, soluble sugars, and total free amino acids with increased shade level have been observed. This study suggests that, nets with higher shading levels (63 and/or 75%) are a potential alternative to alleviate photo-inhibition and heat stress in cucumber transplants production.

Keywords: Cucumber transplants; Shading nets; Microenvironment; Dehydration tolerance

Introduction

In traditional vegetable-producing regions, transplanting is a well-known technique used especially for higher valued vegetables to improve growth performance and productivity. However, young vegetable seedlings transplants in arid and/or semiarid regions are often exposed to environmental stresses of various levels depending on the season, such as drought and heat stresses [1]. In greenhouse system there are many effective growth factors such as temperature, relative humidity, light and solar radiation. Of all the climatic factors affecting vegetable production, temperature is considered as one of the most important factors. Global temperature has increased by 0.3-0.6 °C since the late 19th century and by 0.2-0.3 °C over the last 40 years.

In the last 140 years, the 1990s was the warmest period [2]. Temperature affects growth and development of vegetables in terms of seed germination, development of economic parts, flowering, pollination, fruit set, quality of produce, seed production, seed storage, seed dormancy and occurrence of

disease and pests. Growth and development of most vegetable crops are adversely affected at temperatures less than 5 °C. Growth normally increases with increasing temperatures up to 40 °C, and thereafter it decreases drastically [3]. Moreover, light is the most important environmental parameters that represent the climate of green house, short wave lengths ultraviolet rays, to low energy, long wave length radio waves. Plant life ultimately depends on energy derived from the sun light, and photosynthesis is the only biological important process that can harvest this energy in the form of carbohydrates.

In addition to photosynthesis, there are many other aspects of plant growth most affected by light: chlorophyll synthesis, photoperiod, photomorphogenesis, phototropism and photoinhibition [3]. Low-cost protected cultivation, such as plastic tunnels and net houses, has the potential to reduce different biotic and abiotic stresses, which affect productivity and quality [4]. Netting is frequently used to protect transplants and other commercial crops from excessive solar radiation, to

improve the thermal climate sheltering from wind and hail, and for exclusion of birds and insect-transmitted viral diseases [5-7]. Significant amount of work has been done on the effect of shading material including shade clothes with varying degree of shading, colored shade nets, and partially shade screens [1,4,5,8-11] to reduce the photo-inhibition or/and high temperature caused by light.

Moderate shading could improve the photosynthesis and thereby increase yields and quality through improved carbohydrate supply and efficient water use [12]. Shading effect of black shade nets can lower the inner temperature under the nets with a higher shade factor leading to decreased radiation exposure. The incident of radiation from the sun is partially reflected or absorbed by the shade nets. The part of the radiation that was not reflected or absorbed by the shade nets is transmitted via the nets [13]. However, a negative correlation exists between weight or density of the shade nets and the light transmittance. Lower density of shading gives greater total light transmittance through the nets [14]. Therefore, the objective of the current study was to determine how black shade nets with different degrees of shading (25%, 50%, 63%, and 75% shading with a black net) could influence growth and quality parameters of cucumber transplants.

Materials and Methods

Lay out and experimentation

Experiments were conducted at Demo farm, faculty of agriculture, Fayoum, Egypt located at latitude of 29.18 °N and longitude angle of 30.3°. The experiments aimed to evaluate the response of summer cucumber transplants, hybrid Bahi®, to different degrees of shading nets. Four black shading nets; Shade 75%, Shade 63%, Shade 50%, and Shade 25%, according to the manufacturer, were used [15]. Two experiments were conducted during May and August 2014. The experiments were set out as two blocks in which four shading covers were randomly allocated on eight mini tunnels measuring (2m width X 2m height X 3m length). Seeds of cucumber were sown in foam trays (84 cells) on May 17th and August 15th 2014, where three trays were allocated within each tunnel. Seed germination media contained peat moss: vermiculite (1:1 by volume). Transplants were destructively harvested for morphological, physiological, and biochemical measurements 30 d after sowing [16].

Observation

Average daily temperatures in each tunnel were measured using Tenmars data loggers (TM305-Temperature/RH Data Logger Neihu, Taiwan). The temperature was measured every 10 min and then daily average temperature was computed. Total radiation in each tunnel was measured using Data Acquisition system (Tenmars-Solar power meter- TM206, Neihu, Taiwan). Radiation in each tunnel was measured three days a week from (09.00am to 04.00pm) every 1h and a daily average was computed. 120 destructive transplants after 30 days of sowing

were randomly chosen from each treatment (sixty plants per mini tunnel, twenty plants from each tray). Growth measurements included leaf number, leaf area, leaf thickness, stem diameter, shoot length, as well as fresh and dry leaf weights (g) were conducted at destructive harvest.

Dry weight measurements were carried out after drying to constant weight in a ventilated oven at 70 °C. Stem diameter was measured using (Electronic Digital Calipers, Precision Gold, China). Leaf thickness was measured using (Digital Thickness Gauge, Maplin Electronics, UK). Leaf areas were measured using leaf area-leaf weight relationship as illustrated by 15 with some modifications as described by 16. Leaf surface was thoroughly washed in running tap water followed by washing with double distilled water, thereafter 10-20 leaf discs (10-20 cm²) were dried in an oven at 85 °C for 24h to get discs dry weight (DDW). Total leaf area plant⁻¹ was calculated using the following formula:

$$\text{Total leaf area plant}^{-1} = \left[\frac{\text{LDW}}{\text{DDW}} \right] \times \text{DA}$$

Where, LDW is the total leaf dry weight (g), DDW is the discs dry weight and DA is the discs area. Leaf chlorophyll A, B, and carotenoid concentrations (mgg⁻¹ fresh weight) were measured and calculated according to [17]. Membrane stability index (MSI), relative water content (RWC), and electrolyte leakage (EL %) were determined as described by [18-20] respectively. Leaf N, P, and K contents were determined according to [21-23] respectively. Free proline and Total soluble sugars (TSS) was extracted and measured (in mg per g of leaf DW) in dried leaf tissue as described [24,25] respectively. Total free amino acids were determined as illustrated [26] with some modifications. 0.2g dried leaf tissue was extracted in 10ml of 80% (v/v) ethanol and filtered. 5ml of ninhydrin reagent was added to a 0.1ml aliquot of the extract, shaken vigorously, and heated in a boiling water bath for 10 min. After cooling, the absorbance was recorded at 570nm.

Chlorophyll a fluorescence was measured using a portable fluorometer (Handy PEA, Hansatech Instruments Ltd, Kings Lynn, UK). One leaf (the same age) at solar noon was chosen per plant. Maximum quantum yield of PS II Fv/Fm was calculated using the formula; Fv/Fm = (Fm-F0)/Fm [27,28]. Fv/F0 reflects the efficiency of electron donation to the PSII RCs and the rate of photosynthetic quantum conversion at PSII RCs. Fv/F0 was calculated using the formula; Fv/F0 = (Fm - F0) / F028. Performance index (PI) of photosynthesis based on the equal absorption (PIABS) was calculated as reported [29].

Statistical analysis

All data were subjected to analysis of variance (ANOVA) procedures in Genstat statistical package (version 11) (VSN International Ltd, Oxford, UK). Difference between means was compared using least significant difference test (LSD) at 5% level.

Results

Microenvironment

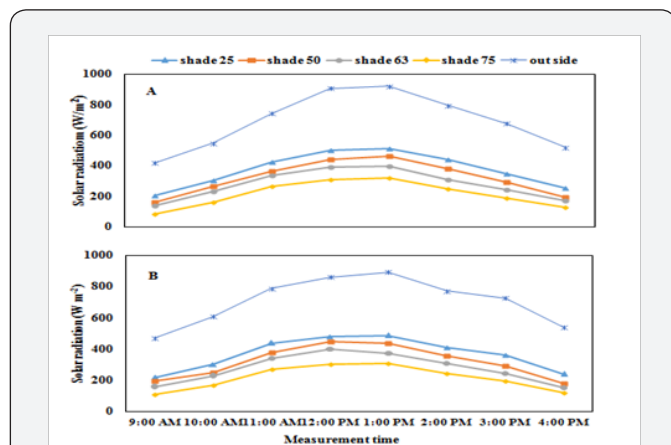


Figure 1: Solar radiation transmission for exp. 1 (A) and exp. 2 (B) under different shade levels in summer cucumber transplants between 9:00 AM and 4:00.

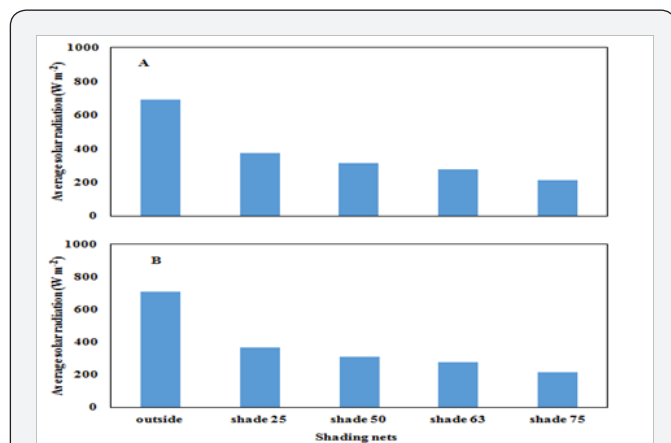


Figure 2: Average solar radiation transmission for exp. 1 (A) and exp. 2 (B) under different shade levels in summer cucumber transplants.

Solar radiation transmission, and mean solar radiation during two growing seasons in 2014 are shown in Figure 1 & 2. Mean daily air temperature and average mean temperature are shown in Figure 3 & 4. Results showed that solar radiation and temperature have been strongly affected by shading level. Solar radiation and temperature decreased with increased shading levels. Of the tested shading nets, 25% shade exhibited the highest light transmission compared to other covers with higher shading levels (50, 63, and 75% respectively). Temperature has been strongly affected by shading level. The 25% shade cover appears to give constantly highest average daily temperature, while the 75% shade nets gave the lowest temperature, and other shading net treatments showed intermediate temperature characteristics. The average daily temperatures under 75% shade nets were approximately decreased by 1.5 °C, compared to the 25% shade nets (Figure 3 & 4).

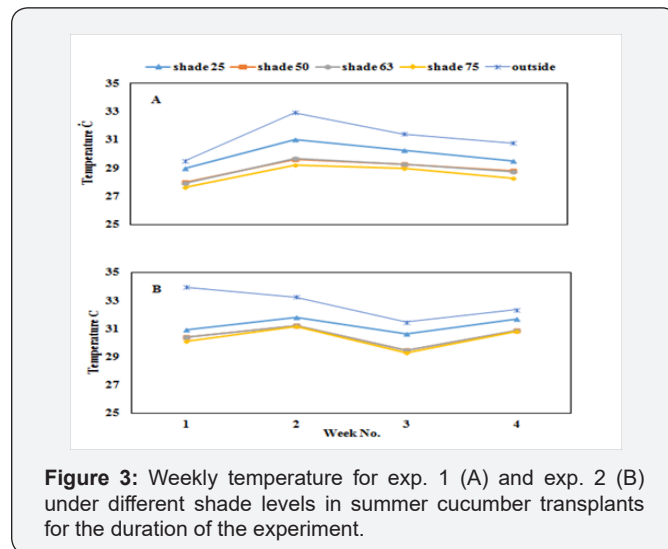


Figure 3: Weekly temperature for exp. 1 (A) and exp. 2 (B) under different shade levels in summer cucumber transplants for the duration of the experiment.

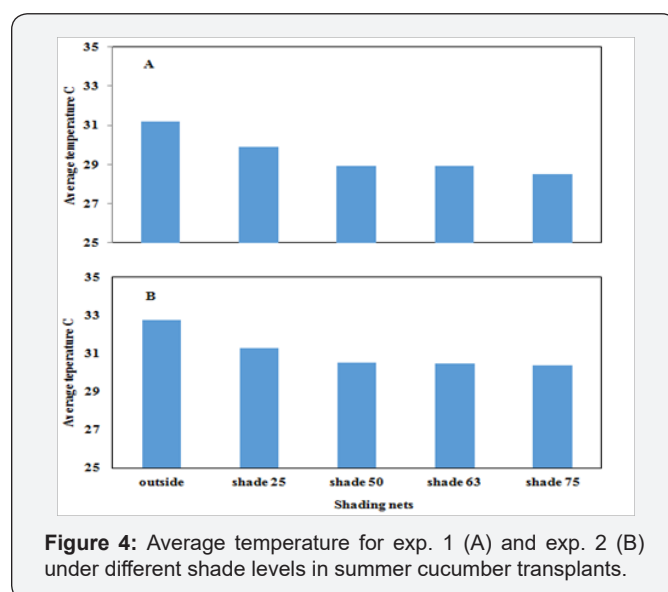


Figure 4: Average temperature for exp. 1 (A) and exp. 2 (B) under different shade levels in summer cucumber transplants.

Vegetative growth and physiological characteristics

Numbers of leaves per transplant, leaf area, shoot length, stem diameter, shoot FW, and Shoot DW increased with increased shade level, whereas leaf thickness was not significantly different among shade levels. Number of leaves per transplant grown under 75%, 63% and 50% of shading were significantly ($p=0.026$ and 0.002 for exp. 1 and 2 respectively) higher as compared to the 25% shades in both experiments. The average of leaves area was significantly ($p<0.001$) higher under 75% and 63% shade followed by other shading levels (50 and/or 25 %) in both experiments (Table 1). Similar trends were observed, in both experiments, for shoot length, stem diameter, shoot FW, and Shoot DW (Table 2). Shoot length and shoot fresh and dry weights were highest ($p<0.001$) for shade 75% followed by shade 63%, shade 50%, and shade 25%. Stem diameter was highest ($p=0.02$ and $p<0.001$ for exp. 1 and 2 respectively) for shade 75% followed by shade 63%, shade 50%, and shade 25%.

Table 1: Effect of shading on number of leaves, leaves area, and leaf thickness of cucumber transplants during the summer season.

Treatment	Number of Leaves	Leaves Area (Dm2)	Leaf Thickness
Summer Cucumber Exp. (1)			
Shade 75%	4.85±0.06a	6.87±0.43a	0.52±0.02a
Shade 63%	4.73±0.07ab	5.5±0.23b	0.48±0.01a
Shade 50%	4.73±0.07ab	3.6±0.13c	0.50±0.02a
Shade 25%	4.55±0.08b	3.8±0.16c	0.51±0.04a
Summer Cucumber Exp. (2)			
Shade 75%	4.90±0.05a	6.94±0.43a	0.52±0.03a
Shade 63%	4.88±0.05a	5.43±0.23b	0.48±0.02a
Shade 50%	4.85±0.06a	3.62±0.13c	0.51±0.02a
Shade 25%	4.62±0.14b	3.98±0.17c	0.41±0.02a

Table 2: Effect of shading on shoot length, shoot fresh and dry weights, and stem diameter of cucumber transplants during the summer season

Treatment	Shoot Length (Cm)	Shoot Fresh Weight (G)	Shoot Dry Weight (G)	Stem Diameter (Mm)
Summer Cucumber Exp. (1)				
Shade 75%	4.91±0.07a	2.10±0.04a	0.32±0.06a	4.30±0.01a
Shade 63%	3.79±0.06b	1.86±0.04b	0.23±0.06c	4.26±0.00a
Shade 50%	3.55±0.07c	1.77±0.04bc	0.25±0.07b	4.15±0.01a
Shade 25%	3.55±0.06c	1.69±0.05c	0.20±0.07d	4.05±0.00a
Summer Cucumber Exp. (2)				
Shade 75%	5.58±0.12a	3.45±0.07 a	0.20±0.00a	3.89±0.13a
Shade 63%	4.31±0.10b	3.20±0.08 b	0.18±0.01b	3.97±0.07a
Shade 50%	4.42±0.14b	2.26±0.09 c	0.18±0.01b	3.86±0.11a
Shade 25%	3.69±0.10c	2.13±0.06 c	0.16±0.00c	2.78±0.19b

Table 3: Effect of shading on chlorophyll a, chlorophyll b, total chlorophyll and carotenoids of cucumber transplants during the summer season

Treatment	Chlorophyll a (mg g-1FW)	Chlorophyll b (mg g-1FW)	Total Chlorophyll (mg g-1FW)	Carotenoids(mg g-1 FW)
Summer Cucumber Exp. (1)				
Shade 75%	0.66±0.02a	0.57±0.03a	5.40±0.22a	0.14±0.00a
Shade 63%	0.67±0.04a	0.56±0.04a	5.58±0.45a	0.13±0.02a
Shade 50%	0.56±0.03b	0.44±0.02b	5.03±0.30a	0.13±0.01a
Shade 25%	0.59±0.03ab	0.50±0.02ab	4.73±0.24b	0.10±0.01b
Summer Cucumber Exp. (2)				
Shade 75%	0.69±0.03a	0.46±0.02a	4.61±0.18a	0.10±0.01a
Shade 63%	0.61±0.04ab	0.40±0.02ab	4.22±0.23a	0.06±0.00b
Shade 50%	0.54±0.02bc	0.37±0.04b	3.55±0.18b	0.04±0.01c
Shade 25%	0.50±0.03c	0.30±0.01c	3.21±0.15b	0.04±0.00c

Table 4: Effect of shading on chlorophyll a fluorescence (Fv/Fm, Fv/F0, and PI) of cucumber transplants during the summer season

Treatment	Fv/Fm	Fv/F0	PI
Summer Cucumber Exp. (1)			
Shade 75 %	0.81±0.00a	4.38±0.06 a	4.20±0.22a
Shade 63 %	0.78±0.01ab	3.61±0.23 b	2.43±0.23b
Shade 50 %	0.73±0.03b	3.33±0.38 b	1.97±0.22b
Shade 25 %	0.66±0.03c	2.04±0.28 c	1.87±0.51b
Summer Cucumber Exp. (2)			

Shade 75 %	0.79±0.00a	3.74±0.10ab	2.52±0.17ab
Shade 63 %	0.79±0.00a	3.76±0.11a	2.54±0.26a
Shade 50 %	0.77±0.01b	3.24±0.14b	1.26±0.16bc
Shade 25 %	0.75±0.01c	2.42±0.27c	0.78±0.11c

Chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, and chlorophyll a fluorescence (Fv/Fm, Fv/F0, and PI) increased, in both experiments, with increased shade level (Table 3 & 4). Chlorophyll a, chlorophyll b, total chlorophyll were significantly higher for shade 75% and/or shade 63% in both experiments, followed by shade 50%, and shade 25%. Total chlorophyll was highest (p=0.02 and p<0.001 and for exp. 1 and 2 respectively) for shade 75% followed by shade 63%, shade 50%, and shade 25%. Similar trends were observed, in both experiments, for carotenoids (Table 3). Carotenoids were highest (p<0.01), in both experiments, for shade 75% followed by shade 63%, shade 50%, and shade 25%.

Chlorophyll a fluorescence (Fv/Fm, Fv/F0, and PI) reduced with the increase of solar radiation levels (Table 4). Significant differences were observed in Fv/Fm, and Fv/F0 of plants grown under shade 75% and/or shade 63% compared to those plants grown under shade 50%, and shade 25%. Fv/Fm and Fv/F0 were highest (p<0.001) in both experiments for shade 75% followed by shade 63%, shade 50%, and shade 25%. Similarly, plants grown under shade 75% and/or shade 63% significantly (P<0.001) resulted in higher PI than under shade 50%, and shade 25% (Table 4). Values are means ± SE (n =6). Mean values in each column followed by a different lower-case-letter are

significantly different by Fisher's least-significant difference test (LSD) at P ≤ 0.05. Values are means ± SE (n =10). Mean values in each column followed by a different lower-case-letter are significantly different by Fisher's least-significant difference test (LSD) at P ≤ 0.05.

Free proline, soluble sugars, and total free amino acids decreased, in both experiments, with increased shade level (Table 5). Significant differences were observed in the concentrations of free proline of plants grown under shade 75%, shade 63%, and shade 50% compared to those plants grown under shade 25%. Concentrations of free proline were highest (p<0.001) in both experiments for shade 25% followed by shade 50%, shade 63%, and shade 75%. Similar trends were observed, in both experiments, for soluble sugars and total free amino acids (Table 5). A soluble sugar was highest for shade 25% followed by shade 50%, shade 63%, and shade 75%. Total free amino acids was significantly highest (p=0.039 and p=0.005 for exp. 1 and 2 respectively), in both experiments, for shade 25% followed by shade 50%, shade 63%, and shade 75%. Values are means±SE (n =6). Mean values in each column followed by a different lower-case-letter are significantly different by Fisher's least-significant difference test (LSD) at P ≤ 0.05.

Table 5: Effect of shading on free proline, soluble sugars, and total free amino acids of cucumber transplants during the summer season

Treatment	Free Proline (mg g ⁻¹ DW)	Soluble Sugars (mg g ⁻¹ DW)	Total Free Amino Acids (mg g ⁻¹ DW)
Summer Cucumber Exp. (1)			
Shade 75 %	0.26±0.03b	0.978±0.05b	0.0940±0.01b
Shade 63 %	0.32±0.02b	1.048±0.11b	0.1240±0.02b
Shade 50 %	0.35±0.01b	1.096±0.08b	0.1360±0.02b
Shade 25 %	0.60±0.07a	1.316±0.03a	0.1840±0.03a
Summer Cucumber Exp. (2)			
Shade 75 %	0.28±0.02c	1.48±0.15a	0.15±0.02b
Shade 63 %	0.31±0.03c	1.54±0.26a	0.14±0.01b
Shade 50 %	0.40±0.02b	1.62±0.12a	0.16±0.01b
Shade 25 %	0.57±0.02a	1.68±0.16a	0.21±0.01a

Plant water status and leaf mineral nutrients

Data shown in Table 6 reveal that relative water content (RWC), membrane stability index (MSI), and electrolyte leakage (EL) of cucumber transplants were significantly affected, in both experiments, by shade level. Cucumber transplants grown under shade 75% and/or shade 63% revealed a significant increase in dehydration tolerance in terms of increased RWC and MSI and reduced EL compared to those plants grown under shade 50%,

and shade 25%. RWC was significantly highest (p=0.02 and p<0.001 for exp. 1 and 2 respectively), in both experiments, for shade 75% followed by shade 63%, shade 50%, and shade 25%. MSI was also significantly highest (p<0.001 and p=0.012 for exp. 1 and 2 respectively), in both experiments, for shade 75% followed by shade 63%, shade 50%, and shade 25%. In contrast, EL were highest (p<0.001) in both experiments for shade 25% followed by shade 50%, shade 63%, and shade 75%.

Table 6: Effect of shading on relative water content (RWC), membrane stability index (MSI), and electrolyte leakage (EL) of cucumber transplants during the summer season

Treatment	RWC (%)	MSI (%)	EL (%)
Summer Cucumber Exp. (1)			
Shade 75%	65.56±2.62 a	46.54±1.57 a	87.90±1.22 b
Shade 63%	58.41±4.99 ab	35.69±2.09 b	87.81±2.34 b
Shade 50%	55.55±2.03 b	28.86±1.93 c	93.56±1.08 a
Shade 25%	52.37±1.39 b	25.85±1.09 c	95.86±0.89 a
Summer Cucumber Exp. (2)			
Shade 75%	71.02±3.00a	50.86±2.49 a	91.05±1.36 b
Shade 63%	55.10±3.13 b	49.90±1.77 ab	92.93±1.07 ab
Shade 50%	52.12±3.17 b	44.89±2.65 bc	94.01±0.81 ab
Shade 25%	40.91±1.62 c	42.07±1.39c	94.36±0.61 a

Table 7: Effect of shading on leaf N, P, and K concentrations of cucumber transplants during the summer season.

Treatment	N	P	K
Summer Cucumber Exp. (1)			
Shade 75 %	9.80±0.09a	0.16±0.01a	1.42±0.02a
Shade 63 %	9.05±0.10b	0.10±0.02b	1.27±0.01b
Shade 50 %	8.70±0.14b	0.09±0.01bc	1.19±0.05c
Shade 25 %	8.63±0.19b	0.07±0.01c	1.04±0.01d
Summer Cucumber Exp. (2)			
Shade 75 %	9.68±0.09a	0.15±0.03a	1.39±0.05a
Shade 63 %	9.44±0.12a	0.13±0.04a	1.22±0.10ab
Shade 50 %	9.29±0.15a	0.10±0.01b	1.15±0.02b
Shade 25 %	8.49±0.13b	0.07±0.02c	0.91±0.04c

Shade level affected leaf mineral nutrient concentration but the effect differed among nutrients. Leaf N, P, and K concentrations increased with shade level (Table 7). Concentrations of leaf N, P, and K were significantly highest in both experiments for shade 75% followed by shade 63%, shade 50%, and shade 25%. Leaf N concentration was significantly highest ($p < 0.001$ and $p = 0.007$ for exp. 1 and 2 respectively), in both experiments, for shade 75% followed by shade 63%, shade 50%, and shade 25%. P concentration was also significantly highest ($p = 0.004$ and $p < 0.001$ for exp. 1 and 2 respectively), in both experiments, for shade 75% followed by shade 63%, shade 50%, and shade 25%. Similarly, K were highest ($p < 0.001$) in both experiments for shade 25% followed by shade 50%, shade 63%, and shade 75%. Values are means \pm SE ($n = 6$). Mean values in each column followed by a different lower-case-letter are significantly different by Fisher's least-significant difference test (LSD) at $P \leq 0.05$. Values are means \pm SE ($n = 6$). Mean values in each column followed by a different lower-case-letter are significantly different by Fisher's least-significant difference test (LSD) at $P \leq 0.05$.

Discussion

Shading nets are intended to reduce solar radiation in order to reduce heat stress especially during summer inside greenhouses.

Significant amount of work has been done on the effect of shading materials including shade clothes with varying degree of shading, shade nets, and partially shade screens [5,12,30,31] to reduce the photo inhibition and/or high temperature caused by light. Our studies show that solar radiation and temperature have been strongly affected by shading level. Over the two repeats of summer cucumber experiments in which transplants were grown under different shade levels, solar radiation decreased with increased shading levels (Figure 1 & 2). Also, temperatures have been strongly affected by shading level, but the effect differed among experiments. Over the two repeats of summer cucumber, temperature decreased with increased shading levels (Figure 3 & 4).

Our results are consistent with previous reports that show that shading reduces solar radiation and air temperature [32-34]. A 30% black shading cover was found to reduce solar radiation and wind speed but did not significantly alter maximum daily air temperature as compared with open field conditions [35]. Heavy shading (75%) on basil, strongly reduce photosynthesis rate and, effectively reduce leaf temperature when air temperature was less than 30 °C [36]. Light quality modification by colored shade nets efficiently decreases temperature compared with

black shading. This might be due to the higher content of scattered/diffuse light [5]. The reduction in air temperature during the summer experiments under higher shade levels could be attributed to the light diffusive characteristics and the shaded environment of the black nets.

A significant reduction in air temperature due to shading was also reported in a greenhouse study on strawberry, tomato, and sweet pepper even though a different type of shading was used compared to the current study [33,37]. Overall this study showed that vegetative growth characteristics i.e., leaves number, leaf area, shoot length, stem diameter, shoot FW, and shoot DW, increased when shade level increased (Table 1 & 2). Under shade condition, plants undergo morphological changes to maximize light use. Modification of the light spectrum quality and quantity via black and/or colored shade nets can act as a physiological tool to modify the crop micro-climate and enhance plant growth and productivity [5]. Plants adapted to shade have greater foliar surface and specific leaf area, thinner leaves, and taller stems compared with plants adapted to strong light [38]. Our results agree with studies showing that shaded bell peppers and tomato plants have longer internodes, larger leaves, greater whole-plant leaf area, and thinner leaves [32,34]. Results are also consistent with a cucumber and tomato study, in which shaded plants grow taller than unshaded plants, and produce a greater average internode length [38,39]. Plants grown in the shade tend to have a larger leaf area because cells expand more under low light intensities in order to receive light for photosynthesis [40].

At high sunlight intensities, chlorophyll degradation rate in plant leaves is higher than the synthesis rate, leading to a decrease in chlorophyll concentration as a result of chloroplast formation inhibition. Accordingly, shade leaves in comparison with sun leaves tend to show higher chlorophyll concentrations per unit of leaf weight [41]. Although the formation of carotenoids in mature fruits does not require induction by light, shaded fruits have lower content of carotenoids [42]. The carotenoid content was lowest in plants from open fields and highest in plants covered by black nets [43]. This study clearly showed that Chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids increased with increased shade level (Table 3).

Although shade-grown plants are not directly exposed to sunlight, they produce additional chlorophyll a and b to capture diffuse radiation to produce the carbohydrates needed for the plant to grow, as supported by the results of [44]. Shaded lettuce leaves showed higher total chlorophyll (chlorophyll a and b) content than leaves from unshaded control plants [43]. Minimal chlorophyll fluorescence (F₀) has been reported to increase with the increase of the irradiance. Reduction in the maximum photochemical efficiency of PSII (F_v/F_m) under excessive photosynthetic photon flux density (PPFD) is a widely reported phenomenon in plants [45]. F_v/F_m reduced with the increase of photosynthetic photon flux density (PPFD) levels [46]. Other

studies have found F_v/F_m to be similar [47] and occasionally higher [47] in shaded plants. These results are consistent with the result of the current study (Table 4), indicating that shading increases chlorophyll a fluorescence (F_v/F_m, F_v/F₀, and PI), which can serve as an indicator of the plant's photosynthetic efficiency.

When plants are exposed to the direct sunlight irradiance, they could induce some protective mechanisms such as the increases in proline, sugars, and the activity of antioxidant enzymes as reported [48]. We have observed clear decreases in free proline, soluble sugars, and total free amino acids with increased shade level (Table 5). Sugar accumulation in vegetables is mainly affected by light intensity and temperature. Consequently, exposing fruit to higher temperatures, especially during ripening, leads to an increase in the total soluble solids content (SSC), mainly due to an increase in carbohydrate biosynthetic enzyme activity and increased transpiration [49]. Pepper fruits grown in plastic shade nets had significantly lower TSS content when compared with unshaded fruits [43]. Conversely, lettuce grown under pearl (and yellow shading nets) showed the highest soluble sugar content [50]. The higher blue light transmittance during the production of tomato under pearl shading nets showed higher SSC/TA ratios [51].

Our studies show that cucumber transplants grown under higher shade levels (63 and 75 %) showed a significant increase in dehydration tolerance in terms of increased RWC and MSI and reduced EL compared to those plants grown under lower shade and/or unshaded conditions (Table 6). As a measure of plant water status, RWC reflects the metabolic activity in plant tissues, and used as a most meaningful index to identify the legumes with contrasting differences in dehydration tolerance [52]. Moderate shade alleviated the drought stress of *P. cathayana* not only by improving the leaf RWC but also by maintaining the positive carbon balance [53].

Over the different repeats of the experiments in which transplants were grown under different shade levels, lower shade conditions invariably caused significant reductions in leaf mineral nutrient i.e., N, P, and K (Table 7). This was consistent with the report [54] who showed that tissue N, P, and K levels were increased with increasing shading level [55] studied the effect of different shading levels on tomato leaves nutrient contents, especially N, P and K. their results showed that shading had no effect on total leaf N, P and K contents at the early and peak flowering stages. However, leaf N, P and K contents of 40% shaded plants at the later flowering stage were significantly increased. There were no difference in leaf N and K contents between 40% and 75% shading treatments

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