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Effects of leaf aging and light duration on photosynthetic characteristics in a cucumber canopy

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ABSTRACT

Photosynthetic characteristics, chlorophyll index and leaf area were examined in selected leaves of cucumber (*Cucumis sativus* L. cv. Euphorbia). In the first experiment, plants of cucumber were grown horizontally at a lighting period of 20 h day^{-1}. Photosynthetic measurements in horizontally growing cucumbers showed that there was no decline in photosynthetic capacity when cucumber leaves are developing under good light conditions. In a second experiment, plants were grown in a traditional high-wire cultivation system under 20 h day^{-1} lighting period until they reached final height and then exposed to different lighting periods (20 and 24 h day^{-1}) for 3 weeks. In stands of cucumber plants photosynthetic measurements showed that the lower leaves have a significant reduction in photosynthetic capacity due to reduced light conditions. Three weeks exposure to 24 h day^{-1} lighting period reduced leaf area by 20%. Plant grown under continuous light had also lower chlorophyll index compared to plants grown under 20 h day^{-1} lighting period.

1. Introduction

Year-round production of cucumbers in northern latitudes requires intensive use of supplementary lighting to obtain good yields. With intensive crop cultivation and use of high amounts of supplementary lighting, growers have obtained remarkably high yields in the recent years. Cucumbers cultivated using the high-wire method and supplementary lighting with an installed effect of >200 W m^{-2} can yield between 160 and 180 kg fresh weight m^{-2}. The cultivation method and high plant density cause most of the light to be captured in the upper part of the plant canopy. In a high-wire system, plants are lowered two or three times per week, and the oldest leaves are removed, keeping approximately 25 leaves on the plant. A cucumber plant develops in average one new leaf per day when grown under optimal growth conditions. High planting density and tall crop stands favour development of upper leaf layers to maximize interception of light incident at the top of the foliar canopy.

Dicot leaf development is characterized by a phase of increasing photosynthetic rates, usually coincident with leaf expansion, a phase of maximal rates and, finally, by a prolonged senescence phase of declining photosynthetic rates. Premature leaf senescence is associated with competition for light within the canopy during intensive crop cultivation (Rousseaux et al., 1996). Whether leaf age and/or environmental conditions trigger natural senescence in cucumber is poorly understood. In cotton it was found that changes in leaf photosynthetic responses to light environment during leaf aging were solely the result of physiological changes within the senescing leaf and not the result of differences in light environment (Sassenrath-Cole et al., 1996). In cucumber, however, leaves will normally be removed before leaves have reached maturity, due to the culture practice of lowering the plants.

Use of supplementary lighting and prolonged photoperiod has given increased growth and yield for many species, and is a widely used technique in greenhouse production (Fierro et al., 1994; Koontz and Prince, 1986; Warrington and Norton, 1990; McAvoy and Janes, 1984; Logendra et al., 1990; Dorais et al., 1996; Demers et al., 1998). Several experiments have focused on light levels while only a few have studied the photoperiod effects, especially effects of extending the photoperiod to more than 20 h day^{-1}.

Due to low outside temperatures in winter time, growers occasionally need to apply supplementary lighting continuously to avoid a temperature drop. This practice has been reported to have harmful effects in cucumber crops. If continued for weeks, reduced fruit yield and leaf photosynthesis has been observed (Wolff and Langerud, 2006).

The aim of this study was to investigate how leaves respond to changes in light environment in a cucumber canopy, and examine how extending the lighting period from 20 to 24 h day^{-1} affects photosynthetic characteristics in mature cucumber plants.

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2. Materials and methods

2.1. Plant materials and treatments

Seeds of cucumber (*Cucumis sativus* L. cv. Euphorbia) were soaked in water for 24 h before sowing individually in 12 cm pots filled with sphagnum peat. Three weeks after germination, and after the appearance of the fifth true leaf, transplants were transferred into 25 L boxes filled with limed and fertilized sphagnum peat (Floralux). Two plants were planted in each box with a spacing of approximately 25 cm.

The plants were manually watered twice daily using a complete nutrient solution. The electrical conductivity (EC) of the feeding solution ranged from 2.4 to 2.6 mS cm^{-1}. The pH in the growing media was kept between 5.5 and 6.0. The day/night air temperature was set at 21 (±0.5) °C and ventilation temperature was set at 24 °C. Relative humidity (RH) was set at 75% and the air was moistened by water from high pressure nozzles placed above the canopy. Supplementary lighting was provided using 400 W high pressure sodium (HPS) lamps (GE lucalox HO 400W, GE lighting) in Gavita armatures. Light distribution and intensity was measured using a Li-Cor model LI-190 light meter (Li-Cor Co., Lincoln, NE, USA). The microclimate in the greenhouse was controlled and recorded by a PRIVA environmental computer. During cultivation all side-shoots were removed and one singular fruit per leaf was allowed to develop.

2.1.1. Experiment one—horizontally grown cucumbers

The boxes with plants were placed in a row near the outer wall of a greenhouse compartment (12 m^2). A frame of steel bars was constructed to allow plants to grow horizontally across the compartment at a height of 0.5 m above the ground. To direct the plant growth on the frame each plant was regularly twined around nylon thread. Distance between plants was approximately 30 cm. A total of 10 plants were used in the experiment.

Light intensity at plant height (main stem) was 150 $\mu mol\ m^{-2}\ s^{-1}$ (±10%). The lamps were turned on from 04:00 to 00:00 to provide 20 h photoperiod. The experiment was conducted from October to December.

2.1.2. Experiment two—high-wire grown cucumber

The boxes with plants of 30 cm length were placed in greenhouse compartments (24 m^2) and connected to a string (high-wire method).

In each compartment the plants were placed in two rows of 10 plants each. Distance between rows was 0.80 m. Supplementary lighting was provided as traditional top lighting with an installed effect of 230 W m^{-2}.

One week after the plants had reached final height of approximately 2.30 m, they were subjected to the following treatments:

- 20 h light period (20 h LP)
- 24 h light period (24 h LP)

During the experimental period plants were lowered two to three times per week, keeping the top of the plants approximately at a constant distance (at least 50 cm) from the lamps. The oldest leaves were removed after lowering the plants, leaving at least 25 leaves on each plant. Pure liquid CO_2 from a central supply was used to enrich the atmosphere of the greenhouse compartments to a concentration of 800 $\mu l\ L^{-1}$ during the photoperiod when the ventilators were closed. The experiment was carried out from January to April.

Leaf area was measured two times during the experiment; before start of treatments and 3 weeks after start of treatments, using a leaf area meter (Li-Cor, Li-3000). A total of three plants per treatment were used for the leaf area measurement.

Chlorophyll index was measured on the fifth, 10th, 15th, 20th and 25th leaf (from the youngest one) before start of treatment and 3 weeks after start of treatment. Chlorophyll index was measured as absorption using a chlorophyll content meter (Hansatech Instruments, Model CL-01). A total of 10 measurements were taken on individual leaves. Light intensity was measured at each leaf position. The sensor was positioned horizontally at the leaf tip at each leaf position, and data are presented as an average of three measurements at each leaf position. All measurements were conducted on leaves in defined positions on the plants. Leaves were counted from the top of the plant, and leaf number one was defined as the youngest leaf separating from the shoot tip. Typical size of the first leaf was approximately 3 cm in length. All measurements were conducted on fifth, 10th, 15th, 20th and 25th leaf.

2.2. Gas-exchange measurements

Photosynthesis was measured with a CIRAS 2 portable photosynthesis system attached to a Parkinson leaf cuvette (PLC6) (PP systems, Hitchin, UK) and was carried out between 0800 and 1800 HR. Gas-exchange measurements were conducted on leaves at all defined positions before start of treatment. After subject to treatments the same measurements were conducted after 3 weeks on leaves at the same positions. A minimum of four measurements were done in each leaf position for both light response curves and A/C_i curves.

2.3. Light response curves

When measuring photosynthetic light response curves, the temperature inside the leaf cuvette was set to 25 °C, and [CO_2] was set to 370 $\mu mol\ mol^{-1}$ in experiment one and to 800 $\mu mol\ mol^{-1}$ in experiment two. Leaves were kept in the cuvette until steady-state conditions were reached before recording measurements. Then, light intensity was decreased (from 2000 to 0 $\mu mol\ m^{-2}\ s^{-1}$) in 13 steps using the light source in the sensor head, waiting at least 3 min before another measurement was made. The built-in temperature controller maintained leaf temperature at 25 °C. The photosynthetic light response curves were fitted using a least-square solution to a non-rectangular hyperbola (Ögren and Evans, 1993):

$$\theta P^2 - (\Phi I + P_{max})P - \Phi I P_{max} = 0$$

where P is photosynthetic rate, I is the PAR ($\mu mol\ m^{-2}\ s^{-1}$), P_{max} is the maximum light saturated photosynthetic rate ($\mu mol\ m^{-2}\ s^{-1}$), θ is the curvature, and Φ is the maximum quantum yield (mol CO_2 mol $photon^{-1}$). The three parameters of P_{max}, θ, and Φ, which reflect C3 plant leaf photosynthesis properties, were obtained by nonlinear regression. Values of leaf dark respiration rates (R_d) ($\mu mol\ m^{-2}\ s^{-1}$) and light compensation points (LCP) ($\mu mol\ m^{-2}\ s^{-1}$) were obtained by linear regression of the first four light intensities (PAR: 0, 25, 50 and 100 $\mu mol\ m^{-2}\ s^{-1}$) and associated gas-exchange rates.

2.4. A/C_i curves

A/C_i curves (photosynthesis plotted against intercellular CO_2 concentration) were generated to investigate specific characteristics of photosynthesis and to estimate potential photosynthetic capacity. The response of A_{sat} ($\mu mol\ m^{-2}\ s^{-1}$) to variation in C_i ($\mu mol\ mol^{-1}$) was determined under standardized conditions, using a fully controlled microenvironment cuvette (PCL6) incorporated into an open gas-exchange system (CIRAS-2; PP Systems, Hitchin, UK).