

Effects of interlighting on yield and external fruit quality in year-round cultivated cucumber

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Abstract

The effects of interlighting and of the proportion of interlight on the yield and fruit quality of year-round cultivated cucumber (*Cucumis sativus* L. cv. Cumuli) were investigated for this study. Artificial lighting was provided by high pressure sodium (HPS) lamps and the lighting regimes included top lighting (TL), top + interlighting 24% (T + IL24) and top + interlighting 48% (T + IL48). In TL, all of the lamps were mounted above the canopy. In T + IL24 and T + IL48, top lamps covered 76 and 52% of the lighting, respectively, while 24 and 48% of the lighting came from interlighting lamps which were mounted vertically 1.3 m above the ground between the single plant rows. The outdoor daily light integral (DLI) varied greatly during the cultivation periods; the mean values were 36.8, 5.3 and 19.9 mol m⁻² day⁻¹ for the summer, autumn–winter and spring stands, respectively. Lighting regime affected both yield and external fruit quality. Interlighting increased first class yield and decreased unmarketable yield, both in weight and number. The increase in the annual first class yield in weight was 15% in the two T + IL regimes. Interlighting improved energy use efficiency in lighting, being for the whole year 120, 130 and 127 g total yield kW h⁻¹ in TL, T + IL24 and T + IL48, respectively. Interlighting increased the fruit skin chlorophyll concentration in all seasons, but had only a minor effect on the fruit dry matter concentration. The mean total chlorophyll concentration in fruit skin was 70.8, 76.7 and 82.2 µg cm⁻² in TL, T + IL24 and T + IL48, respectively. In addition, interlighting extended the post-harvest shelf life of cucumber fruits in spring. Besides interlighting *per se*, also the higher proportion of interlight tended to further improve the fruit quality. For example, the fruit skin chlorophyll concentration increased along with the higher proportion of interlighting. In general, the effects of lighting regime were more prominent in lower natural light conditions in winter and spring. It is concluded that interlighting is a recommendable lighting method in cucumber cultivation, especially in lower natural light conditions.

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1. Introduction

In Finland, supplemental lighting is essential for greenhouse cultivation during the winter months from November to February when the natural light levels are extremely low. Except in winter, supplemental light is also commonly used all year round in order to increase the yield and quality of many vegetables and ornamental plants. In 2006, for example, 23 and 20% of the total cultivation areas of cucumber and tomato, respectively, were cultivated under supplemental lighting in Finland (Anon, 2007). However, given the climbing energy prices, year-round greenhouse cultivation and supplemental lighting are nowadays challenged to be more efficient.

Plants are known to benefit from equal distribution of light throughout the canopy; e.g., increasing the penetration of natural light into the canopy enhances productivity (Aikman, 1989). Besides natural light, also artificial light has been successfully distributed more equally in experimental conditions since the late 1980s (Grimstad, 1987). However, in recent years, interlighting has raised interest not only among researchers but also among growers of greenhouse vegetables. Many species, such as soya bean (Stasiak et al., 1998), sweet pepper (Grodzinski et al., 1999; Hovi-Pekkanen et al., 2006) and cucumber (Hovi et al., 2004; Heuvelink et al., 2006) have been shown to benefit from interlighting or inner canopy lighting. For example, Grodzinski et al. (1999) found increased photosynthetic activity in sweet pepper canopy when side lighting was used jointly with top lighting. Hovi-Pekkanen et al. (2006) reported interlighting to increase the yield both in weight and number as well as, the energy use efficiency in

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lighting. However, only little is known about the impact of the proportion of interlight (i.e. the ratio between interlighting and top lighting).

Supplemental light has been shown to increase not only the amount of yield, but also the external and internal quality of many vegetable crops. For example, higher percentage of first class fruit and higher skin chlorophyll and dry matter content in cucumber (Hao and Papadopoulos, 1999), higher sugar content and ascorbic acid concentration in tomato (Dorais and Gosselin, 2002), and increased head firmness of lettuce (Gaudreau et al., 1994) have been reported as results of supplemental light.

In cucumber, the fruit skin chlorophyll content is an important quality factor, which strongly influences the keeping quality of the fruit. The post-harvest shelf life of cucumber is related to the location of the fruit in the canopy (Lin and Ehret, 1991) and to fruit greenness upon harvest (Klieber et al., 1993; Lin and Jolliffe, 1996). Cucumber fruits grown under low light conditions have lower chlorophyll concentration in the skin at harvest and they easily turn yellow during shelf life (Vonk Noordegraaf and Welles, 1995). High nutrient concentration and fruit thinning enhance fruit colour and thus extend the shelf life (Lin and Ehret, 1991). Moreover, cucumber shelf life has been found to decline with increasing fruit age at harvest (Kanellis et al., 1986).

To improve fruit greenness and shelf life, an open canopy structure (ensuring good light penetration into the canopy) has been suggested for cucumber cultivation (Klieber et al., 1993; Lin and Jolliffe, 1995, 1996). Shelf life can also be extended by using supplemental light (Lin and Jolliffe, 1995, 1996). Interlighting has been shown to increase irradiance in the high-wire canopy at the level where the fruits grow (Hovi et al., 2004), but there are no previous reports on the influence of interlighting on shelf life. This work was conducted in order to study the effects of interlighting and of the proportion of interlight on the yield and certain external quality factors of cucumber fruits grown at different times of the year. The distribution of fruit into different quality categories, fruit skin chlorophyll concentration, dry matter concentration in fruit skin and flesh, and the shelf life of the fruit were investigated. In addition, to further improve the interlighting methods, an attempt was made to even out the light conditions in the canopy and to reduce the electricity consumption, especially during the summer cultivation period, as suggested by Hovi et al. (2004).

2. Materials and methods

In 2003–2004 three cucumber stands (*Cucumis sativus* L. cv. Cumuli) were cultivated under supplemental light in Southern Finland (Piikkiö 60°23'N, 22°33'E). Seeds were sown in plastic pots filled with peat, and the seedlings were transplanted into peat boards (Kekkila Oyj, Finland) after 20–24 days on 23 May 2003 (summer stand), 25 September 2003 (autumn–winter stand) and 12 January 2004 (spring stand). The duration of the cultivation period was 115, 81 and 126 days from transplanting for the summer, autumn–winter and spring stands, respectively. The stands were grown in eight single rows (40 plants per row)

at a density of 2.3 plants m⁻² using the high-wire method (top wire at a height of 3.25 m from the ground). Six rows in the centre of the greenhouse were divided into two parts of three rows and the two parts were subdivided into three groups. The resulting six groups with three rows constituted the six blocks (24 plants) of the experiment. In practice, the three treatments were not completely randomized because of crop management purposes; the control treatment was always in the middle of the block, while the other treatments were randomized. The plant rows on either side of the greenhouse section, as well as four plants at each end of the rows and between the treatments along a row served as guards. In addition, treatments within one row were separated by white plastics which were hanged in the aisles. Owing to the lack of space in the experimental greenhouse section, the interaction of adjacent treatments could not be totally avoided, but on the basis of preliminary light measurements, they were estimated to neutralize each others' effect.

2.1. Light conditions

Supplemental lighting for 20 h day⁻¹ (between 04:00 and 24:00) was provided by 250 and 400 W HPS lamps (Master SON-T PIA Plus and Son-T Plus, Philips, Netherlands). After transplanting, the stands were subjected to the following lighting regimes (Fig. 1):

- (1) Top lighting (TL) (control): 100% of the lamps were top lamps (400 W), and they were automatically turned off once the outdoor global radiation exceeded 286 W m⁻².
- (2) Top + interlighting 24% (T + IL24): 76% of the installed capacity consisted of top lighting and 24% of interlighting. The top lamps and the interlighting lamps were automatically turned off once the outdoor global radiation exceeded 286 and 572 W m⁻², respectively.
- (3) Top + interlighting 48% (T + IL48): 52% of the installed capacity consisted of top lighting and 48% of interlighting. The lamps were used as in T + IL24. Treatments T + IL24 and T + IL48 are jointly referred to as T + IL.

The top lamps were mounted in the middle of the aisle 3.5 m above the ground (Fig. 1). The interlighting lamps were mounted vertically in the middle of the aisle between the single plant rows 1.3 m above the ground. For crop management purposes, the interlighting lamps were installed not more than in every other aisle. To even out the light conditions in the canopy along the aisle, as suggested in Hovi et al. (2004), smaller interlighting lamps (250 W) with special reflectors (Schetelig Oy, Finland) were used. The reflectors were designed to reduce straight irradiation to the nearest plants and reflect it further off along the plant row compared to a bulb without a reflector. In addition, irradiation along the centre of the aisle was prevented. As the interlighting bulbs were mounted vertically, very little amount of light was distributed to the floor. The installed capacity in TL and in T + IL was 170 and 163 W m⁻², respectively. According to Philips product catalogue (2004) the efficiency of the top light bulbs was

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