The Effect of Short-term Intermittent Light Exposure on Total Carbon Content and Quality of Dark-stored Ornamental Chilli Plants

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ABSTRAK

Tanaman cili (Capsicum frutescens *L.*) *telah digunakan sebagai tanaman model di dalam kajian ke atas analisa imbangan karbon. Ianya bertujuan untuk menentukan potensi menggunakan pendedahan kepada cahaya yang mengcukupi buat 2-3 jam sehari bagi mengekalkan kualiti tanaman yang disimpan selama 16 hari. Nisbah karbon bekalan/penggunaan telah ditentukan melalui analisa karbon yang hilang semasa respirasi berbanding dengan yang dihasilkan menerusi proses fotosintesis. Penggantian sebanyak lebih kurang 95% daripada jumlah karbon yang hilang semasa respirasi dengan pendedahan tersebut di dapati mengcukupi untuk mengekalkan ciri-ciri pertumbuhan (iaitu ketinggian pokok, keluasan daun, berat kering daun, batang, akar dan keseluruhan pokok).*

ABSTRACT

Using ornamental chilli (Capsicum frutescens *L.*) *as a model plant, a study was conducted on carbon balance analysis to determine the potential of using 2-3 hours of intensive light exposure per day to maintain the plant quality during 16 days storage period. Carbon input/output ratios were ascertained by measuring respiratory carbon losses and photosynthetic carbon inputs. Replacement of respiratory carbon losses (i.e. approx. 95%) using 2-3 hours of light exposure was sufficient to maintain growth attributes (i.e. plant height, leaf area, leaf, stem, root and total dry weight).*

INTRODUCTION

In the horticultural trade, during postharvest handling, storage and marketing, intact indoor ornamental pot plants are subjected to reduced light intensity and/or darkness for varying lengths of time. Transport of plants under these conditions is currently the most practical method of shipping (Nell 1993) but it puts them under photo stress. Normally, photo stress is caused by insufficient light, although in some cases the opposite is true. As the length of time in the marketing process increases, the period of photo stress is often extended and so the plant becomes acclimatized to conditions of insufficient light.

When normal plants are placed in darkness or reduced light for a sufficient duration they undergo distinct changes. Generally, there is a significant loss of chlorophyll (Conover and Poole 1977) and dry matter (Milks *et al.* 1979). Depending upon species, there may also be substantial leaf shedding (Poole and Conover 1979) and a reallocation of dry matter within the plant (Biran and Kofranek 1981). The net effect is a reduction in quality and in extreme cases, death of the plant. Acclimatization of intact plants, through growth under conditions of reduced light intensity prior to harvest, can improve the retention of quality during and after storage (Conover and Poole 1975). Accli-

matization appears to result in changes in both respiratory losses and the light compensation point of the plant (Fonteno and McWilliams 1978). This allows the plant to decrease losses of carbon while enhancing fixation under reduced light conditions.

Acclimatization requirements and/or the postharvest effect of dark or reduced light have been established for several plant species of precise size and condition (Conover and Poole 1975; Conover et al. 1975; Conover and Poole 1977; Fonteno and McWilliams 1978).

While the physical manifestations of reduced light have been documented, the interrelationship between intensity and duration has not been adequately investigated in relation to changes in the basic physiological and biochemical processes that are operative.

The acquisition and storage of energy and the utilization of this energy during dark storage are two of the central processes controlling the overall metabolism and quality of stored plants. Because of this, we chose to monitor the carbon balance, photosynthetic energy inputs versus respiratory losses, in relation to postharvest quality changes. It also tested the potential of short-term intermittent light exposure to maintain quality in otherwise dark storage.

MATERIALS AND METHODS

Ornamental chilli plants (*Capsicum frutescens* L. cv. Hungarian Hot Yellow Wax) were used as the test plants. The plants were watered daily and fertilized weekly with a 200 ppm (N) 20-20-20 (N,P,K) soluble fertilizer solution. A single application of aldicarb (Temik) (0.5 g pot^{-1}) was made following transplanting into 10-cm pots. Foliar sprays of dinocap (Karathane) (2.5 g $litre^{-1}$) and pirimicarb (Pirimor) (1.5 g $litre^{-1}$) were applied as needed for insect control.

Plants at 30 days after transplanting with approximately 6-8 fully expanded leaves and 12-14 young leaves with 6-8 flower buds were used. At the beginning of the storage period, 40 plants selected for uniformity were divided into two equal groups for the dark and light treatments. Two representative plants in their pots from each group were placed in specially constructed glass chambers (26 x 26 x 38 cm) for CO_2 exchange measurements. The root system was separated from the above ground portion of each plant using a sub-chamber (12 x 12 x 8.5 cm) within the large chamber. To minimize the

CO_2 contribution from microbial organisms present in the soil, the Cornell mix used as the planting media was first steam sterilized before being used to fill the pots. Both aerial and root system chambers were aerated with humidified air (60-70% RH, 25 ± 2°C) containing approximately 300 µl CO_2 l^{-1} at a flow rate of 2 l min^{-1} for the aerial portion and 0.5 l min^{-1} for the root system. Each chamber also contained a small circulating fan and thermocouples. The difference in the CO_2 concentration (±1 µl l^{-1}) entering and leaving each chamber was measured throughout each 24-hour period using a Beckman model 865 infrared CO_2 analyser with output recorded on a Linear Instruments Corp, model 285 strip chart recorder. This allowed monitoring of both the net rate of carbon fixation during the light exposure treatments and respiration during the dark phase. Thus, the precise carbon input/output balance could be assessed and the supplemental light treatments adjusted during each 24-h period. To reduce heat build-up, a 2-cm deep layer of circulating cooled water in a transparent plexiglas tray separated the lamp from the chambers.

Half the plants (20 plants) were exposed to light at an intensity of approximately 1200 µmol $m^{-2}s^{-1}$ from 400-W metal halide high intensity discharge lamps for a sufficient duration (depending upon the change in the respiration rate) within each 24-h period to replace the amount of carbon lost due to respiration during the dark period. The remaining 20 plants were held in continuous darkness.

All plants were placed on lab benches covered with black plastic during the dark phase. The plants were also aerated with humidified air (approx. 60-70% RH) and held at 25 ± 2°C. The air rate flowing into the system was of a sufficient velocity to prevent the build-up of ethylene within the storage enclosure.

Changes in elongation of the aerial portion of the plants were determined by measuring the same set of plants throughout the course of the experiment. The heights were taken from the soil line to the most apical leaves.

The number of abscised leaves were recorded at the end of each storage period (0, 4, 8, 12 and 16 days) with the data presented as the percentage of leaf drop (i.e. number abscised/total number x 100). Leaf area was also determined on the sampled plants (4 plants) by removing the leaves and measuring the area

using a leaf area meter (Li-Cor, Nebraska, USA, model LI-3000).

Each plant sampled was divided into three component parts: leaves, stems and roots, and oven-dried at 60°C until constant weight. Dry weight was determined using a Mettler PL-1200 balance. Abscised leaves were included in the determination of leaf area and plant fresh and dry weights.

The experiment was a 2 x 5 factorial in a completely randomized design (CRD) with four replications used to test two storage treatments (continuous dark and sufficient light every 24 h to maintain an input-output balance for carbon) and five storage durations (0, 4, 8, 12 and 16 days). The results were subjected to analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) procedure (Steel and Torrie 1960).

RESULTS AND DISCUSSION

Carbon balance measurements were carried out daily over the 16-day test period. The average carbon input/output ratio throughout the experimental period was found to be about 0.96. On a daily basis, the respiratory carbon losses from the above and below ground portions of the test plants were calculated. Losses were then compensated with a sufficient photosynthetic carbon input. An example of carbon input/output balance sheet from a typical plant is presented in Table 1. Based on the carbon balance analysis, a daily light exposure duration of approximately 2-3 hours was required to compensate for carbon losses due to dark respiration. This suggests that approximately 95%

of the respiratory carbon losses were replaced daily by exposure to light for 2-3 hours. In the dark treatment (i.e. plants stored under continuous darkness), the total amount of carbon lost throughout the 16-day test period was estimated to be about 290 mg C (1075 mg CO_2). Based on the total dry weight, the actual C loss (difference between day 0 and 16) from the plant calculated using the conversion factor of 0.39 g C g^{-1} dry weight (McCree and Troughton 1966) was found to be about 0.2 g. This light exposure and carbon replacement maintained the quality of the plants under otherwise dark storage.

Carbon demand by the plant can be separated into that utilized for growth and maintenance and that lost due to a less than 100% conversion efficiency (McCree and Kresovich 1978). Therefore, if a leaf is to benefit a plant, its carbon gain must exceed the carbon costs of its construction, maintenance and protection (Salisbury and Ross 1992). The amount of carbon used for growth and maintenance can be estimated using the mathematical model proposed by Thornley (1976).

Plant height for both treatments (light and dark) increased for the first four days, after which those plants exposed to sufficient light (2-3 hours during the 24-h cycle) during storage for replacing respiratory losses of carbon did not show any significant increase in plant height (*Fig. 1*). Plants kept in total darkness were of about the same height as at the beginning of the experimental period.

Light treatment had a significant ($p<0.05$) effect on the leaf area (*Fig. 2*) with a greater

TABLE 1

Representative carbon balance data for chilli plants over the 16-day storage period

Storage duration (day)	Respiration (mg CO_2 h^{-1} plt^{-1})			Length of dark period (h)	Total carbon loss during dark period/day (mg)*	Photosynthetic rate during light exposure (mg CO_2 $h^{-1}plt^{-1}$)	Total carbon input/day (mg)
	Top	Root	Total				
1	1.37	1.31	2.68	22.0	15.9	28.5	15.4
5	1.72	0.61	2.33	22.0	13.9	25.0	13.5
8	2.63	1.20	3.83	21.0	21.7	26.0	21.1
9	2.13	1.15	3.28	21.5	19.0	25.0	16.9
12	1.16	0.88	2.49	22.0	14.8	28.5	15.4
16	1.65	1.07	2.72	22.0	16.2	27.0	14.6
SD	0.45	0.25	0.56	-	2.91	1.60	2.67

* The calculated CO_2 exchange rate (CER) was converted to mg C h^{-1} Plt^{-1} by a factor of 0.27(the proportion of C in CO_2)
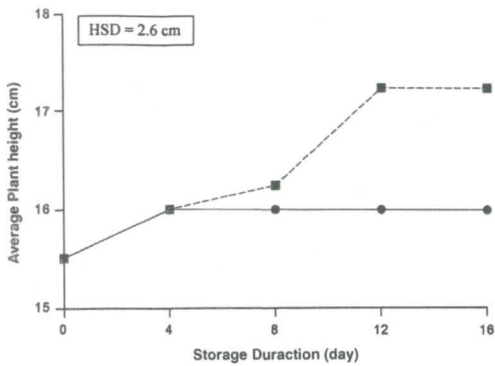
Fig. 1. *Effect of daily replacement of respiratory carbon losses and storage duration on average plant height ■ light treatment ● dark treatment*
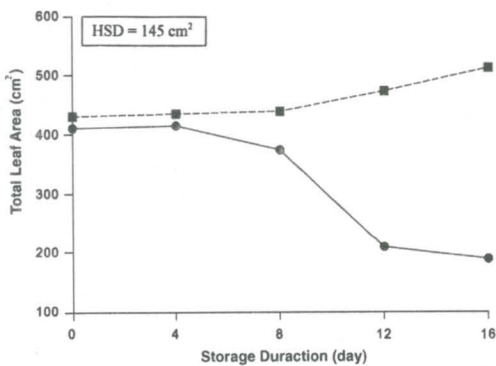

Fig. 2. *Effect of daily replacement of respiratory carbon losses and storage duration on total leaf area.* ■ *light treatment ● dark treatment*
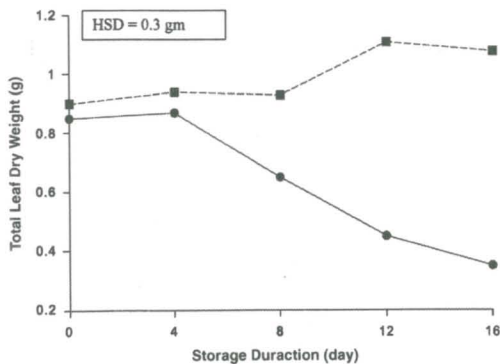

Fig. 3. *Effect of daily replacement of respiratory carbon losses and storage duration on total leaf dry weight per plant* ■ *light treatment ● dark treatment*

total leaf area for plants exposed to light during storage than those held in continuous darkness. For the plants under complete darkness, rapid decrease in leaf area only occurred after 4 days

of storage. As expected, replacement of respiratory losses of carbon during storage had a significant ($p < 0.05$) effect on the leaf dry weight per plant (*Fig. 3*). Light exposure gave a higher total leaf dry weight, and differences between the light and dark treatments increased progressively with increasing storage time. As with leaf area, decrease in dry weight of the dark treatment occurred only after the 4th day in storage. The trend for both the total leaf dry weight per plant and the total leaf area was similar with all treatments.

Plants stored in total darkness displayed the greatest abscission of leaves. Abscission began after the 4th day in storage and coincided with changes in the total dry weight of leaves per plant (*Fig. 3*). The percentage of leaf drop for the dark stored plants was 29, 43 and 55% for the 8-, 12- and 16-day storage durations, respectively. However, fewer leaves abscised from plants given even the minimum daily light exposure treatment.

Root dry weight per plant was not affected by the intermittent exposure to light during storage. There did not appear to be a recycling of carbon from the root system to support respiratory demand during the 16-day test period (*Fig. 4*). By the 16th day, the root dry weight of the dark stored plants had begun to decline; however, differences were not statistically significantly.

Daily replacement of respiratory carbon losses using exposure to light during dark storage had a significant effect on the stem dry weight. That of light treated plants increased with increasing storage duration (*Fig. 5*). Dry weight declined in plants held under continuous darkness, especially after the 8th day of storage. By this time, significant differences between light and dark treatment plants were found in stem dry weight.

Replacement of respiratory carbon losses using exposure to light was found not to have a significant effect on the total dry weight per plant. Even though light-treated plants had an increase in dry weight with increasing storage duration (*Fig. 6*)–by the 16th day, the plants had increased in dry weight by 30%–whereas plants stored in continual darkness displayed a 35% decline in dry weight. The increase in total plant dry weight indicates that the 2-3 hours of light exposure was in excess of that required for the replacement of respiratory losses of carbon. Fail-
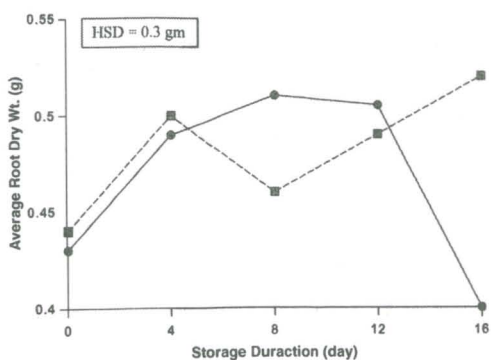
Fig. 4. Effect of daily replacement of respiratory carbon losses and storage duration on average root dry weight per plant
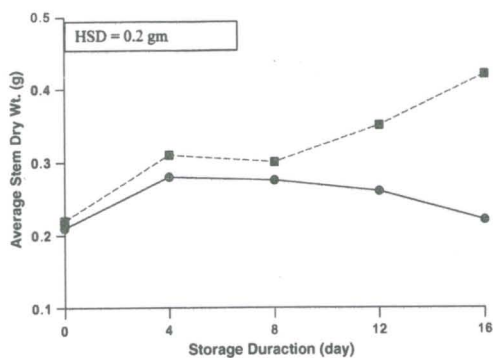■ *light treatment* ● *dark treatment*

Fig. 5. Effect of daily replacement of respiratory carbon losses and storage duration on average stem dry weight per plant
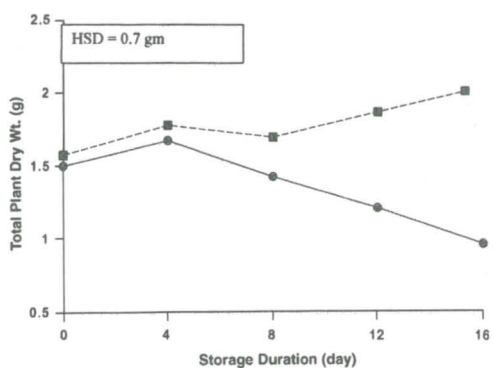■ *light treatment* ● *dark treatment*

Fig. 6. Effect of daily replacement of respiratory carbon losses and storage duration on total plant dry weight
■ *light treatment* ● *dark treatment*

ure in supplying supplemental light to replace carbon losses under dark storage conditions results in undesirable alterations in plant quality

characteristics. At a plant morphological level, these quality losses are typically expressed as the abscission of leaves such as in *Dracaena marginata* (Wijeratnam *et al.* 1995) and changes in height and leaf chlorophyll content. During storage, the plant materials containing chlorophyll undergo changes or loss of colour similar to that occurring in senescing plants. Chlorophyll loss during senescence is, at least in part, the result of direct photochemical degradation of the pigment (Gross 1991). In addition, losses occur in the leaf, root and total dry weight (Biran and Kofranek 1981) and plant grade or overall quality (Ben-Jaacov *et al.* 1984; Fjeld 1990). These detrimental effects of dark storage could be attributed to increased endogenous ethylene evolution during the postharvest period (Serek 1991). Ethylene is involved in leaf senescence (Aharoni and Lieberman 1979), which was also found to promote chlorophyll loss in oat leaves (Gepstein and Thimann 1981). The sensitivity of these characteristics to adverse light conditions varies with the plant part in question and the storage environment. With chilli plants, the most sensitive physiological parameter altered by continuous dark storage was leaf abscission, which was the first to be observed. After the 8th day in storage, 29% of all leaves had abscised and this increased, as the storage duration increased until the end of the experimental period.

CONCLUSION

The daily carbon input from photosynthesis during 2-3 hours of light exposure was based on the carbon input/output analysis. This exposure duration was found to be sufficient for the maintenance of plant quality. Therefore, the possibility of using this exposure time for maintenance of plants in transit is promising. However, the light quality used should also be taken into consideration. Intensity of about 650-700 (μmol $m^{-2}s^{-1}$ is recommended. This intensity approximated the light saturation point for chilli (Mahmud 1986).

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