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Carbon balance and ethylene in the postharvest life of flowering hibiscus

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Abstract

The display life of potted flowering *Hibiscus rosa-sinensis* L. plants (held in a simulated interior environment) was terminated by depletion of their carbohydrate reserves, as determined by reduction in dry matter content of roots, stems, leaves, buds, and flowers. The substantial dry matter content of the short-lived flowers (0.2 g for singles, 0.6 g for doubles) was only partially recaptured when the flowers senesced. There was considerable variance in the low light compensation points for different hibiscus species and cultivars. Although the death of hibiscus flowers appears to be coordinated by ethylene, inhibition of ethylene action by treating the flowers with silver thiosulfate (STS) or 1-methylcyclopropene (1-MCP) had only a modest effect in extending flower life. Strategies for developing cultivars with improved display performance are discussed.

Keywords: *Hibiscus rosa-sinensis*; Photosynthesis; Postharvest; STS; 1-MCP

1. Introduction

Traditional potted flowering plants (chrysanthemum, poinsettia, kalanchoe, bulb flowers) are purchased at or near full bloom, and normally last in an interior environment for 1 week to 1 month. All of these species require special manipulation of photoperiod or temperature to induce flowering, and are therefore discarded after the blooms have faded. The popularity of foliage plants, and the expectation that they will continue to grow and flourish in the interior environment has provided a potential market for potted plants that continue to flower in the home. Such plants would need to be indeterminate, and continue flowering under the conditions of the interior environment.

The primary factors affecting the life of potted flowering plants are light, temperature, water supply, and ethylene (Nell, 1986; Fjeld, 1991; Serek,

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1991; Evensen and Olson, 1992; Serek and Reid, 1993, 2000). Light intensity and duration are of particular importance for potted plants that are intended as permanent additions to the décor (Nell, 1986, 1991; Serek, 1991). Unless there is sufficient light for net photosynthesis, the plants will be unable to provide the dry matter required for the production of new flowers.

The market for potted flowering plants that continue to grow and flower in the interior environment could be met by changing the strategies for selection of breeding material and commercial cultivars. We examine this hypothesis using, as an example, hibiscus (*Hibiscus rosa-sinensis*), a popular potted plant that some producers are advertising as 'a plant for life' (Graff, 1997). Horticultural cultivars of hibiscus have largely been selected for garden use in subtropical and tropical environments, and are therefore normally sensitive to chilling temperatures, and adapted to high light intensities (Dole and Wilkins, 1999). Selection has focused on large-flowered and even double-flowered varieties that maintain a large number of open blooms at any time.

The life of the individual blooms of hibiscus is typically short, although breeders note some variation among cultivars. Woodson et al. (1985) demonstrated involvement of ethylene in the senescence of the cultivar Pink Versicolor. They found that silver thiosulfate (STS) treatment of petals excised from opening buds extended petal life. Recently we have demonstrated the effectiveness of a gaseous ethylene inhibitor, 1-MCP (1-methylcyclopropene), in extending the life of cut and potted flowers that are sensitive to ethylene (Serek et al., 1994, 1995). We hypothesized that this material might be a very effective means for increasing the life of blooms on hibiscus.

We report here the changes in carbon balance in hibiscus plants following transfer to the interior environment and the effects of ethylene inhibition on life of the individual blooms. We measured low light compensation points of different species and cultivars to test the hypothesis that there might be useful variance in this characteristic. The results suggest strategies for developing new cultivars that will perform adequately in the interior environment.

2. Materials and methods

2.1. Plant material

A range of horticultural cultivars of *H. rosa-sinensis* were generously donated by Graff Kristensen A/S (Sabro, Denmark), transported to greenhouses at the Royal Veterinary and Agricultural University, and grown there under standard conditions (20/20 °C day/night temperatures, light 16 h per day from high-pressure sodium SON-T lamps, 80 μmol m^{-2} s^{-1}). Cuttings of hibiscus species were obtained from the collections at the Royal Veterinary and Agricultural University and the Royal Botanic Gardens Conservatory in Copenhagen, rooted, and grown to flowering under standard greenhouse conditions.

2.2. Measurement of flower life

Flowers were tagged at the 'opening bud' stage with paper tags, and observed at intervals to determine flower life.

2.3. Role of ethylene in flower life

Flowers were removed at the opening bud or full bloom stages, and placed either in a solution of 2 mM STS or in water in large (40 l) sealed aquaria. Some flowers were treated for various lengths of time with 200 nl l^{-1} 1-MCP released into the air of the aquarium. After treatment, the flowers were placed in another sealed aquarium for observation of vase life.

2.4. Carbon cost of flowering

The carbon cost of flowering in the different cultivars examined was determined by measuring the fresh and dry weight of flowers from a range of cultivars at four stages:

Stage −1	Bud 1 day before opening
Stage 0	Opening bud
Stage 1	Open flower
Stage 2	Senescent flower

Six species/cultivars were used for types of hibiscus with single-flowers, three for hibiscus types with double flowers. Dry and fresh weight of six flowers per species/cultivars was measured. All measurements were repeated twice.

2.5. Display life in the interior environment

Dry matter remaining in wilted flowers and flower production rate were determined in the greenhouse on a large group of plants of the 'Cairo Apricot' cultivar for 1 week. Half the plants were then placed in the interior environment (20 °C, 20 μmol m^{-2} s^{-1} for 12 h per day, ca. 60% R.H.), and flower production and wilted flower dry matter were determined daily on both groups until no new flowers were produced on the plants in the interior environment (28 days). The plants were then destructively sampled to determine dry matter distributions. Buds, leaves, and stems were dried and weighed individually. Roots were carefully separated from the growing medium under running water, dried and weighed.

2.6. Photosynthesis in the interior environment

Gas exchange parameters were determined on the middle of the lamina of several leaves of the different species and cultivars using a portable differential CO_2/H_2O infrared gas-analysis system (CIRAS-1 with a Parkinson narrow leaf cuvette, 9 cm^2, PP-Systems, UK). Standard calibration with CO_2 was performed before the measurements. The CO_2 in the leaf chamber was adjusted to 36 Pa. Within the cuvette, leaf temperature was 18–25 °C, depending on the treatment. Measurements were conducted in a high and low light interior environment, and in a greenhouse under high and low light conditions. The cuvette was held perpendicular to the light source.

2.7. Statistics

Statistical procedures were performed using the PC-SAS software package. Differences between means were determined using Student's *t*-test.

3. Results

3.1. Life and carbon cost of hibiscus flowers

For the cultivars tested, effective flower life was 1 day (data not shown). The mean fresh and dry weights for flowers of a range of commercial hibiscus cultivars are shown in (Table 1). Buds of single-flowered varieties, 1 day before opening, contained 0.18 g dry matter. Dry matter increased to about 0.3 g for open flowers, and fell again during senescence, so that the abscised senescent flowers had a mean dry matter content of 0.19 g. Double flowers, which had considerably higher fresh weight, also contained considerably more dry matter (0.59 g when open, and 0.44 g when senescent).

3.2. Role of ethylene in flower life

In initial experiments, open hibiscus flowers were treated with 200 nl l^{-1} 1-MCP for 6 h, a standard treatment with other species (Serek et al., 1994). This treatment had no effect on the life of the flowers. Subsequent tests demonstrated that the 1-MCP treatment was effective only when the flowers were held continuously in this material. Attempts to determine a 'window' of sensitivity, by treating during the first 15 h of bud opening,

Table 1
Fresh and dry weight of flowers (mg) from a range of species and cultivars at four stages

Flower type	Flowering range			
	−1	0	1	2
Fresh weight (mg)				
Singles	1.52	2.26	2.61	1.92
Doubles	3.45	4.98	6.20	4.38
Dry weight (mg)				
Singles	0.18	0.22	0.27	0.19
Doubles	0.35	0.51	0.59	0.44

Stage −1: bud 1 day before opening; Stage 0: opening bud; Stage 1: open flower; Stage 2: senescent flower. Six species/cultivars were used for types of hibiscus with single-flowers, three for hibiscus types with double flowers. Dry and fresh weight of six flowers per species/cultivars was measured. All measurements were repeated twice.

or the last 12 h of the display life were only partially successful (data not shown). Only continuous treatment with 1-MCP extended the life of hibiscus blooms. Treatment of open flowers with STS likewise was only partially successful. When we provided 1 μmol Ag^{+} per flower, their life was extended by 1 day (data not shown).

3.3. Flowering and dry matter changes in the interior environment

In the greenhouse, both tested cultivars produced an average of 1.5–2 flowers per day. After the plants were transferred to the interior environment (IE), flower production remained high for several days and then fell substantially, to a mean of one flower every 2.5–3 days (Fig. 1). The dry matter of the wilted flowers, which was around 0.3 g per flower in the greenhouse, fell rather steadily during the display period to about 0.2 g per flower at the end of the experiment (Fig. 1). The dry matter of plants from the greenhouse and plants from the IE was dramatically different at the end of the experiment. In addition to the much greater dry matter in their flowers and buds, the plants maintained in the greenhouse had 50% more dry matter in their stems and leaves, and 30% more dry matter in their roots (Table 2). There was no abscission of leaves from the plants in the IE.

3.4. Photosynthesis and photosynthetic light compensation point

Photosynthesis of both of the tested cultivars (Table 3) was above 3 μmol m^{-2} s^{-1} under high light greenhouse conditions (ca. 100 μmol m^{-2} s^{-1} PAR). In indoor lighting conditions, photosynthesis was very low (0.1–0.3 CO_2 μmol m^{-2} s^{-1}). The photosynthetic light compensation point for different species and cultivars varied substantially (Table 4) from a low of 1.9 μmol m^{-2} s^{-1} for 'Dark Casino' to a high of 5.4 for the 'Casanova Pink' cultivar. Photosynthetic light compensation point for the tested species fell between those of the two cultivars.

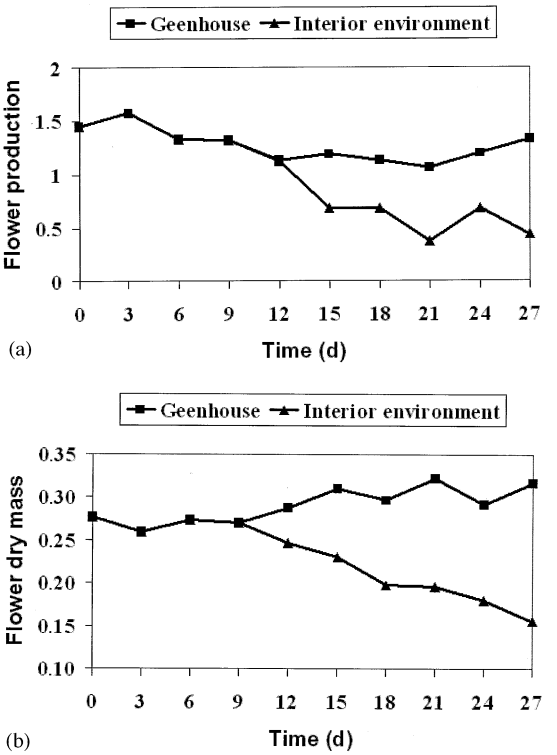

Fig. 1. Effect of transfer to the IE on production (a) and dry matter content (b) (g per flower) of flowers in *H. rosa-sinensis* 'Cairo Apricot'. Plants were grown in the greenhouse for a week, and then half of the plants were transferred to the IE. The number of open flowers and the dry matter of wilted flowers was determined each day until the plants in the IE stopped producing flowers. *Source of variation:* (a) greenhouse vs interior environment L** Q*; (b) greenhouse vs interior environment L*** Q^{ns}. ns, *, **, *** nonsignificant, significant at 0.05, 0.01 or 0.001, respectively.

4. Discussion

The data reported here indicate the crucial role of carbohydrates in the display life of hibiscus plants. The cost of each flower, in carbohydrate terms, can be estimated from the dry matter content of the senescent corolla (ignoring the small additional cost of the calyx and ovary, which remain on the plant after flower abscission). This cost, assuming a display effort of one flower per day, is about 0.2 g carbohydrate per day. In an IE with lighting similar to that used in the present experiments, photosynthesis by the cultivars tested here was, at most, 0.3 μmol m^{-2} s^{-1}. The

Table 2
Dry mass (g) of 'Cairo Apricot' plants kept in the greenhouse (GH) for 4 weeks or in the interior environment (IE) for 4 weeks after transfer from the greenhouse

Placement	Dry weight (g)				
	Leaves	Buds	Flowers	Stems	Roots
GH	24.84a	1.93a	0.46a	14.22a	8.13a
IE	17.32b	0.14b	0b	8.55b	4.92b

Experimental design: 2 repl. × 4 samples. Numbers followed by different letters in a column are statistically different at $P = 0.05$ by t-test probability values for the hypothesis H_0:LSM(i) = LSM(j).

leaf area on a typical plant was determined to be approximately 30 cm^2 (0.003 m^2). Assuming that the plants are illuminated for 12 h per day, the CO_2 fixed in a day would be 1.3 mmol, or about 90 mg of carbohydrate. This means that photosynthesis would provide less than half the carbohydrate necessary for flower production, even without considering the needs of maintenance and dark-period respirations.

Our data actually indicate that the rate of photosynthesis in the IE is insufficient to sustain the plants, let alone to support continued flowering. This is clearly indicated by the fact that the dry matter loss from the stems, leaves, and roots during the display life (mean of 15 g per plant) was greater than dry matter consumed in the production of flowers (10 g per plant). Our data also indicate, however, that there is substantial variation in the low light compensation point for different hibiscus species and even commercial cultivars, suggesting the possibility of genetic selection of cutlivars that would perform adequately in the IE.

This study points to criteria that must be considered in selecting plants for introduction as indoor flowering plants. Assuming that the goal is a plant that will continue to flower in the IE, and will truly be, as one breeder's advertising claims, 'a plant for life' (Graff, 1997), it will obviously need to be a species whose continued flowering is not dependent on environmental stimuli (vernalization or photoperiod). In addition to its ever-flowering nature, the plants will need to be a species or cultivar that is able to sustain itself in the IE, and synthesize sufficient additional carbohydrate to provide flowers. Since many foliage plants are able to grow successfully in the IE, selection for an adequate photosynthetic rate is an obvious next selection criterion. The challenge is therefore in identifying species with high low-light photosynthesis rates, and reduced maintenance respiration.

In addition, the life of a flowering plant in the IE can be partially improved by reducing the carbon cost of the flowers. Three possible strategies could be used, probably in combination, to dramatically reduce the carbon cost of the flowers. For example, extending the life of the individual blooms would provide an immediate reduction in carbon allocated to reproduction. If each hibiscus flower lasted for 5 days, the carbon cost per day would be reduced to 0.04 g per day. Our data with 1-MCP indicate the need for alternative technologies for overcoming the ethylene-mediated flower senescence. It would be worth testing molecular strategies such as driving the mutant ethylene response element *etr-1* with a

Table 3
Photosysnthesis of *H. rosa-sinensis* cv. 'Cairo Apricot', measured under various light conditions in the greenhouse (GH) or in the interior environment (IE), at 22 ± 2 °C

Placement/light (μmol m^{-2} s^{-1})	Photosynthesis (μmol m^{-2} s^{-1})
IE/high (26)	0.36a
IE/low (17)	0.13b
GH/high (99)	3c
GH/low (19)	0.36a

Experimental design: 3 repl. × 4 samples. Numbers with no letters in common are statistically different at $P = 0.05$ by t-test probability values for the hypothesis H_0:LSM(i) = LSM(j).

Table 4
Photosynthetic light compensation point for different cultivars and species of *Hibiscus*

Species and/or cultivar	Photosynthetic light compensation point ($\mu mol\ m^{-2}\ s^{-1}$)
Hibiscus acetosella	3.03
Hibiscus denisonii	2.63
Hibiscus pedunculatus	2.45
Hibiscus rosa-sinensis 'Dark Casino'	1.88
Hibiscus rosa-sinensis 'Casanova Pink'	5.35
Hibiscus waimeae	2.18

Plants were held in the IE for 10 weeks prior to measurement of light compensation points. Experimental design: 3 repl. $\times 4$ samples.

flower or senescence-specific promoter (Bleecker et al., 1988; Wilkinson et al., 1997). A second strategy for decreasing the carbon cost of the flowers would be a reduction in flower size. A 50% reduction in flower diameter would reduce the carbon cost to 25% of the cost in the cultivars that we studied. Now the carbon cost of the flowers would be a modest 0.01 g per day. The third strategy would be to improve remobilisation of resources from the corolla of the senescing flower. The 0.2 g of dry matter in the abscised hibiscus corolla includes substantial quantities of soluble sugars (Reid and Serek, unpublished), unlike daylily corollas, where the floral resources are extensively remobilised to the plant (Bieleski and Reid, 1992). This strategy might be achieved by selecting cultivars or species where floral abscission is delayed until remobilisation is complete.

These considerations indicate clear selection strategies for the ideal indoor potted flowering plant. Firstly, a photosynthetic rate under IE conditions sufficient to provide for maintenance of the plant and modest allocation of carbon to flowers. Secondly, long-lived flowers and production of limited numbers of flowers per week. Thirdly, selection of cultivars with moderate-sized flowers, and with abscission sufficiently delayed to allow maximum remobilisation of resources from the corolla.

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