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Year-round Production of Flowering *Calathea crocata:* Influence of Light and Carbon Dioxide

Johan M. Van Huylenbroeck[1] and Pierre C. Debergh
Faculty of Agricultural and Applied Biological Sciences, Department of Plant Production, Laboratory of Horticulture, University of Gent, Coupure links 653, B-9000 Gent, Belgium

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Abstract. **Programmed flower induction of Calathea crocata Morr. et Joris is possible under the controlled environmental conditions of a multilayer growing room. A photoperiod of 10 hours for 9 weeks, growth at 18C, and a photosynthetic photon flux density (PPFD) of 71 µmol·s^{-1}·m^{-2} induced flowering in more than 95% of the plants and in 50% to 80% of the shoots. In the meantime, none of the plants under natural conditions was induced. Significantly more flowers were induced when PPFD during the short-day treatment was 71 rather than 56 µmol·s^{-1}·m^{-2}. Flowers became visible 14 to 16 weeks after the start of the inductive treatment. Moreover, raising the CO_2 concentration to 900 ppm for 5 months increased the leaf area and dry weight by 40%, and resulted in darker leaf color, longer flower stalks, and significantly accelerated flowering (10 days).**

Many Marantaceae, mainly those belonging to the genera *Calathea* and *Maranta,* are common houseplants, valued for their variegated leaf color. Only *Calathea crocata* is cultivated commercially as a flowering potted plant. Leaf blades are 10 to 15 cm long, ovate-lanceolate, and somewhat undulate. Leaves are dark green adaxially and rose-purple abaxially. The capitate inflorescence is a short spike with bright saffron-yellow bracts (Bailey, 1950; Kennedy, 1977; Schumann, 1902).

Under northern European conditions, *C. crocata* flowers during winter; therefore, the sales period is limited from December until March. Flowering depends on daylength and temperature. Flower induction requires a photoperiod of ≈8 to 11 h·day^{-1} and temperatures between 18 and 21C. Maximum daylength decreases as temperature increases (15 h at 18C and 14 h at 21C) (Vonk-Noordegraaf, 1980; Zimmer, 1976). Consequently, excellent control of environmental conditions would be required for commercial year-round production of *C. crocata.* Such control is difficult to realize in a greenhouse during spring and summer. Therefore, the use of a multilayer growing room (MGR), as used by Pieters et al. (1989), where optima1 environmental control was combined with optimal use of the available space, was evaluated for summer production. In preliminary work, Pieters et al. (1989) demonstrated that an MGR could be used for flower induction and that it was a competitive alternative for natural circumstances during winter. Up to 75% of the plants were induced after 9 weeks of short-day treatment (SDT) (photoperiod 10 h, temperature 18C). Light quality in the cells during the induction phase was important: changing the red : far red ratio by adding incandescent lamps to fluorescent lamps improved flowering.

Here we present the results of two experiments, conducted under summer conditions, that evaluated the possibility of producing out-of-season, flowering *C. crocata* in an MGR. We determined the effect of light and CO_2 during different growth phases, and we propose a production system for year-round culture of *Calathea* with the help of an MGR.

Commercially micropropagated plants of two clones (G and S) were used in the experiments. Plants of G were ≈30 cm tall, and the inflorescence was ≈4 cm long. Clone S was more compact and had shorter inflorescences (≈3 cm). After transplanting to the greenhouse, the micropropagated plants were multiplied once by vegetative division and planted in 0.81-liter (13-cm) pots for G types and in 0.38-liter (lo-cm) pots for S types. At the start of the experiments, plants were 10 (S clone) or 14 (G clone) months old. Potting medium was coarse ST 400-Finnpeat (DEGA potgrond, Delft, Netherlands; electrical conductivity = 1.0 dS·m^{-1} and pH = 5.5). Flowering during Winter 1988 and 1989 was prevented by extending the natural photoperiod to 16 h·day^{-1} with high-pressure mercury-iodide lamps [Philips HPI-T400W; photosynthetic photon flux density (PPFD) = 50 µmol·s^{-1}·m^{-2} at plant level]. Plants were fertilized regularly with Flory 3 (Planta, Regenstauf, Germany) at 1 g·liter^{-1} (15N-11P-15K + 1) and treated for red spider mite control.

Flower induction took place in four MGR (2.90 x 5.60 x 2.90 m high). Each room had four levels (4.07 x 1.37 m), and the distance between the levels was 67.5 cm. Light in the MGR was provided by fluorescent lamps (Philips TL´D 83) in combination with incandescent lamps (Osram 60 W). The SDT, based on experiments by Pieters et al. (1989), lasted 9 weeks. Photoperiod was 10 h, relative humidity fluctuated between 65% and 80%, and the day/night cycle was 18/17 ± 1C. Before and after induction, plants were placed in a standard greenhouse at 21C.

Type G plants were used in Expt. 1. The SDT was given from 8 Aug. to 11 Oct. 1989. We investigated the influence of PPFD (56 or 71 µmol·s^{-1}·m^{-2}) and CO_2 concentration (400 or 800 ppm) during the SDT. Before and after the SDT, the plants were placed in a greenhouse at a normal CO_2 concentration, and the photoperiod was extended to 16 h·day^{-1} with high-pressure mercury-iodide lamps (PPFD = 50 µmol·s^{-1}·m^{-2} at plant level).

Type G and S plants were used in Expt. 2. The SDT was given from 10 July to 11 Sept. 1990. During the SDT, PPFD was 71 µmol·s^{-1}·m^{-2}. We examined the influence of increased CO_2 concentration (400 or 900 ppm, starting 10 June) on growth and flowering, and the effect of additional light after the SDT. Additional light was provided by high-pressure mercury-iodide lamps (PPFD 50 µmol·s^{-1}·m^{-2} at plant level) from 0300 to 0900 HR and from 1700 to 2130 HR during Sept. and Oct. 1990. The daily light sum for plants grown under additional light was ≈30% higher than for those grown under natural conditions. Before the SDT, the experimental plants were maintained under a 16-h photoperiod for all treatments.

Table 1. Effects of photosynthetic photon flux density (PPFD) and CO_2 concentration during short-day treatment (SDT) on flowering of *Calathea crocata* clone G (Expt. 1).

PPFD during SDT (µmol·s^{-1}·m^{-2})	CO_2 level during SDT (ppm)	Inflorescences/plant (no.)	Flowering plants (%)	Flowering shoots (%)	Flowering date[z]
56	400	3.0 ± 0.2[y]	94 ± 3	56 ± 4	104 ± 1
	900	3.5 ± 0.2	97 ± 3	71 ± 4	96 ± 1
71	400	3.7 ± 0.4	98 ± 1	69 ± 7	98 ± 1
	900	4.2 ± 0.1	100 ± 0	74 ± 1	93 ± 1
Significance					
Light		*	NS	NS	**
CO_2		NS	NS	NS	**
Light × CO_2		NS	NS	NS	NS

[z]Days to flowering from start of SDT (8 Aug. 1989) for all treatments.
[y]Indicates SE.
NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01, respectively, using analysis of variance.

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[1]To whom reprint requests should be addressed.

Table 2. Effects of CO_2 concentration during culture [starting 1 month before short-day treatment (SDT)] and additional light after SDT on flowering of *Calathea crocata* clones G and S (Expt. 2).

CO_2 level (ppm)	Additional light[z]	Inflorescences/ plant (no.)	Flowering plants (%)	Flowering shoots (%)	Flowering date[y]	Peduncle length (cm)
			Clone G			
400	None	3.6 ± 0.4[x]	94 ± 6	69 ± 4	113 ± 1	26.3 ± 1.2
	Yes	3.2 ± 0.3	94 ± 6	79 ± 12	106 ± 1	31.1 ± 0.7
900	None	3.7 ± 0.6	100 ± 0	78 ± 13	100 ± 1	32.2 ± 0.8
	Yes	4.7 ± 0.7	94 ± 6	91 ± 5	99 ± 2	29.5 ± 1.1
Significance						
CO_2		NS	NS	NS	**	**
Light		NS	NS	NS	*	NS
CO_2 × light		NS	NS	NS	**	*
			Clone S			
400	None	0.8 ± 0.3	62 ± 12	15 ± 5	109 ± 5	22.6 ± 1.4
	Yes	2.1 ± 0.5	88 ± 6	40 ± 10	117 ± 6	22.4 ± 1.0
900	None	2.6 ± 0.4	94 ± 6	51 ± 7	100 ± 3	24.9 ± 1.5
	Yes	2.5 ± 0.5	94 ± 6	51 ± 9	97 ± 1	26.3 ± 1.4
Significance						
CO_2		*	*	*	**	**
Light		NS	NS	NS	NS	NS
CO_2 × light		NS	NS	NS	NS	NS

[z]Additional light from high-pressure mercury-iodide lamps (photosynthetic photon flux density = 50 µmol·s^{-1}·m^{-2} at plant level) from 0300 to 0900 HR and from 1700 to 2130 HR.
[y]Days to flowering from start of SDT (10 July 1990) for all treatments.
[x]Indicates SE.
[NS,*,**]Nonsignificant or significant at $P = 0.05$ or 0.01, respectively, using analysis of variance.

The following characteristics were scored: number of shoots, presence of visible flower buds, number of flowering plants, total number of flowers, and peduncle length. Additionally, in Expt. 2, the leaf areas and dry weights of type S plants were measured at the beginning (10 June 1990) and at the end (15 Nov. 1990) of the experiment. These latter data were obtained nondestructively, using image analysis (Sky Instruments, Powys, Wales; SI 700/705/710). Both experiments had a factorial design and four replicates with four plants per experimental unit. Data were tested by analysis of variance. During Expts. 1 and 2,16 control plants were grown under natural greenhouse conditions throughout the whole experimental period.

Almost 95% of the plants flowered after a SDT in the MGR (Tables 1 and 2), notwithstanding the low light intensities in the cells. Depending on the clone, 50% (S) to 80% (G) of the shoots were induced (Table 2). None of the control plants in the greenhouse was induced. When the PPFD during the SDT was 71 rather than 56 µpmol·s^{-1}·m^{-2} (Table l), the number of inflorescences per plant was significantly higher. Both light and CO_2 level during the SDT had a significant influence on earliness of flowering. Plants exposed to a PPFD of 71 µmol·s^{-1}·m^{-2} and 900 ppm CO_2 during the SDT flowered 10 days earlier than plants induced at low light and low CO_2 levels.

A higher CO_2 level during the culture period (Table 3) significantly stimulated plant growth. Increase in leaf area and dry weight of S-type plants was 40% higher after 5 months, while the number of shoots did not differ (Table 3). When grown at high CO_2 concentrations, both clones flowered 10 days earlier (Table 2) and had increased peduncle length, darker green leaves, and better plant quality. Van Dyk and Seydel (1985) mentioned similar positive effects. For clone S, CO_2 resulted in significantly more inflorescences per plant and increased the percentage of flowering plants and shoots (Table 2). For clone G, supplementary lighting after flower induction hastened flower development at natural CO_2 levels. The positive effect of supplementary lighting may be even more pronounced during winter.

Depending on the start of the induction period in the MGR, flowering started in October or December. During other experiments, nearly all plants had flowers in August and September (data not shown). During these periods, the supply of flowering *C. crocata* on the European market is very limited, because natural conditions are unfavorable for flower induction. From these results and others by Pieters et al. (1989), we conclude that year-round flower induction is possible. In combination with a year-round supply of new in vitro plants, a scheduled production system is possible as follows: 1) acclimated, in vitro plants are cultivated in a greenhouse; 2) 4 months before scheduled flowering, mature plants (at least 8 to 9 months old) are transferred to an MGR for 9 weeks at ≈ 18C and a 10-h photoperiod.

Temperature and daylength after induction are less important, and plants can be grown in a standard greenhouse. Carbon dioxide enrichment during the whole production schedule will accelerate vegetative development with positive effects on early flowering. By using an MGR for flower induction, optimal environmental control is combined with optimal use of space, thus reducing costs. In the commercial production of mushrooms *[Agaricus bisporus* (Lang) Sing.] and Belgian endive *(Cichorium intybus* L.), the use of such multilayer cells is common. Little is known, however, about the costs for using multilayer cells in commercial ornamental crop production.

Table 3. Effects of CO_2 concentration during culture [starting 1 month before short-day treatment (SDT)] and additional light after SDT on growth of *Calathea crocata* clone S (Expt. 2).

CO_2 level (ppm)	Additional light[y]	Shoots (no.)	Increase in leaf area[z] (cm^2)	Increase in dry wt[z] (g)
400	None	5.1 ± 0.3[x]	765 ± 178	6.3 ± 1.5
	Yes	5.6 ± 0.4	1101 ± 205	8.9 ± 1.7
900	None	5.0 ± 0.4	1188 ± 98	9.7 ± 0.8
	Yes	5.3 ± 0.6	1462 ± 204	11.9 ± 1.7
Significance				
CO_2		NS	*	*
Light		NS	NS	NS
CO_2 × light		NS	NS	NS

[z]Measurements at the beginning (10 June 1990) and at the end (15 Nov. 1990) of the experiment.
[y]Additional light from high-pressure mercury-iodide lamps (photosynthetic photon flux density = 50 µmol·s^{-1}·m^{-2} at plant level) from 0300 to 0900 HR and from 1700 to 2130 HR.
[x]Indicates SE.
[NS,*]Nonsignificant or significant at $P = 0.05$, respectively, using analysis of variance.

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