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Testing the Light Acclimatization Potential of *Chrysalidocarpus lutescens* Wendl.

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Abstract. **This experiment was conducted to evaluate the interior performance of *Chrysalidocarpus lutescens* grown for 8 months under 481, 820, and 1241 μmol·m^{-2}·s^{-1} and fertilized weekly with a 20N–4.7P–16.6K soluble fertilizer at 440, 880, and 1660 mg/pot. Afterwards, plants were placed indoors and maintained at 20 μmol·m^{-2}·s^{-1} for 12 h daily at 21 ± 1C and a relative humidity of 50% ± 5% for 3 months. At the end of the production phase, light compensation point (LCP) varied from 243 μmol·m^{-2}·s^{-1} at the high irradiance level to 140 μmol·m^{-2}·s^{-1} at the lowest one. Chlorophyll concentration in the leaves was not affected by irradiance or fertilizer rate. Starch concentration in stems and roots were higher the lower the fertilizer rate applied during production and the higher the irradiance level. After 3 months indoors, LCP declined for all the treatments, but the lowest LCP reached, 126 μmol·m^{-2}·s^{-1}, was still too high if the plant has to survive an interior environment. After the interior holding period, a 45% to 55% reduction was observed on leaf, stem, and root soluble sugar concentrations, and stem and root starch concentrations decreased by 97%, and 62% to 72%, respectively, compared to the concentration at the end of production. The number of fronds increased in all treatments during the postproduction evaluation. However, the drastic carbohydrate concentration depletion during the interior holding period indicates that *C. lutescens* is not a species for extended use under very low interior light conditions.**

Chrysalidocarpus lutescens, the areca palm, native to semi-shade tropical forests in Madagascar, has been grown throughout the world in frost-free areas for its attractive ringed yellow-green bamboo-like stems and fine-textured, medium green, reflexed fronds. The visual impact of areca palm exceeds most plants in the same size container (McConnell et al., 1989) but it requires high interior light levels.

Poole and Conover (1975) studied the effect of media, shade, and fertilizer on production of *C. lutescens*. They reported that areca palms grew best under 40% shade, in a mix of 3 peat : 1 sand when fertilized with surface applications of 14.7 g 18N–6P–12K Osmocote, a slow-release fertilizer, every 4 to 5 months. Cultural practices affect the interior performance of numerous potted foliage plants (Batson and Blessington, 1983; Braswell et al., 1982; Conover and Poole, 1984). Interior performance of areca palm is poor (unpublished) and research has not been conducted to identify cultural practices or physiological adaptations that improve the interior performance of *C. lutescens*. This research was conducted to study the influence of irradiance level and fertilizer rate on light compensation point, chlorophyll and carbohydrates concentration at the end of production, and its relation to the interior performance of *C. lutescens*. Our objective was to determine if *C. lutescens* acclimates to low irradiances by physiological and anatomical changes similar to those of dicots and *C. elegans* Mart., a palm that performs well indoors.

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Material and Methods

A 3 × 3 factorial experiment in a split-plot design with three replications was initiated 30 Aug. 1991 with two plants per experimental unit. Six-month-old *C. lutescens* plants were planted in 6.25-L (23-cm) plastic pots containing a 6 peat : 3 bark : 1 sand mix and 4 kg of dolomite per cubic meter. Micronutrients (Micromax; Scotts, Marysville, Ohio) were incorporated initially and every 3 months at 450 g·m^{-3}. Plants were placed on the ground in a polyethylene-covered, fan- and pad-cooled greenhouse in Gainesville, Fla., and grown for 8 months.

Irradiance levels taken at noon with a LI-185A quantum sensor (LI-COR, Lincoln, Neb.) were 481, 820, and 1241 μmol·m^{-2}·s^{-1}. Fertilizer was applied weekly at 440, 880, and 1660 mg per pot from a 20N–4.7P–16.6K soluble fertilizer. Plants were watered as needed at other times.

The production phase ended 2 May 1992, and one plant per experimental unit was moved to an interior room for 3 months, and the other was used for analysis. Plants were maintained at 20 μmol·m^{-2}·s^{-1} from cool-white fluorescent lamps for 12 h daily at 25 ± 1 C with 50% ± 5% relative humidity.

Light compensation point (LCP), dry weight (DW) of shoots and roots, number of fronds, nonstructural carbohydrates (soluble sugar and starch concentrations of roots, stems, and leaves), and chlorophyll concentration (Chl) were determined at the end of the production period and after interior holding. Recently mature fronds were microscopically examined at the end of the production phase.

The light compensation point was determined by placing single plants into a 1-m^2 Plexiglas chamber. A closed gas-exchange system with an infrared gas analyzer (model AR-600R; Anarad, Santa Barbara, Calif.) monitored CO_2 changes. LCP was recorded at the top of the plant canopy when no CO_2 changes were observed for at least 10 min.

Soluble sugars were extracted from ground dry tissue boiled in 80% ethanol and filtered. Concentration was estimated following the phenol-sulfuric method (Dubois et al., 1956) and expressed in milligrams of glucose per gram of dry weight. For starch measurement, the resulting pellet was digested using α-amylase and amyloglucosidase. The resulting sugars concentration was estimated as described above and also expressed in milligrams of glucose per gram of dry weight. Total chlorophyll concentration (Chl; mg·cm^{-2}) was determined following Bruisnma (1963). Samples for microscopic examination taken from recently mature leaves were killed in formalin, acetic acid, and alcohol (FAA), dehydrated in tertiary butyl alcohol, embedded in paraffin, sectioned at 10 μm, and stained with toluidine blue. Sections were analyzed with a Wild Heerbrugg (model 368025; Datco, Clearwater, Fla.) light microscope.

Data were subjected to analysis of variance procedure, and orthogonal comparisons were to used to examine differences between treatment means.

Results

Light compensation point and chlorophyll. LCP of *C. lutescens* at the end of production varied from 243 μmol·m^{-2}·s^{-1} at the highest irradiance level to 140 μmol·m^{-2}·s^{-1} at the lowest one, but was not affected by fertilizer rate (Table 1). After 3 months indoors, LCP had decreased by 10%, 22%, and 38% for plants grown under 481, 820, and 1241 μmol·m^{-2}·s^{-1}, respectively, compared to LCP levels at the end of production, but the differences among them were not significant (Table 1).

Neither irradiance level nor fertilizer rate affected total chlorophyll concentration (0.059 to 0.070 mg·cm^{-2}) of leaves of *C. lutescens* at the end of the production period. After 3

months indoors, chlorophyll concentration had increased with fertilizer rate in plants grown under 481 μmol·m^{-2}·s^{-1}, but the reverse occurred with plants grown at 1241 μmol·m^{-2}·s^{-1} (Table 1). The total number of fronds recorded at the end of production (76 to 109) was not affected by irradiance level or fertilizer rate. However, the higher the irradiance level, the larger the number of damaged fronds in the plants, which were removed before placement in interior conditions (Table 1). Soluble salts increased linearly with fertilizer (data not shown). The effect of increased salt levels in the medium was more evident on plants grown under the highest irradiance tested and is probably directly related to the number of damaged fronds. This problem may be minimized by increasing irrigation frequency to leach excess soluble salts from the medium or reducing the fertilizer levels. After 3 months in the interior environment, the total number of fronds was higher the lower the fertilizer rate applied in production (Table 1).

Soluble sugars concentration. An interaction between irradiance level and fertilizer rate affected stem and root soluble sugar concentrations at the end of the production period and leaf soluble sugars concentration at the end of the holding period (Table 2). At the end of production, the concentration of soluble sugars in the stem was higher in plants exposed at 820 μmol·m^{-2}·s^{-1} and medium fertilizer rate, and decreased linearly the higher the fertilizer rate in plants grown at the 481 and 1241 μmol·m^{-2}·s^{-1} irradiance. In the roots, the concentration of soluble sugars also decreased the higher the fertilizer rate in plants grown under the highest irradiance, but there were no differences at the two other irradiances tested (Table 2). After 3 months in an interior environment, leaf soluble sugars concentration increased linearly the higher the fertilizer rate in plants grown under the intermediate irradiance, and showed a quadratic response to fertilizer at the lowest one. Stem and root soluble sugars decreased the higher the fertilizer rate applied during production (Table 2) and were not affected by irradiance level. During the interior holding period, leaf, stem, and root soluble sugars concentration decreased 45% to 55%.

Starch concentration. At the end of the production period, leaf starch concentration was higher when plants were fertilized with the medium fertilizer rate at the lowest irradiance level, but was not affected by fertilizer rate at the other two irradiance treatments (Table 3). In the stem, starch concentration decreased the higher the fertilizer rate applied. The concentration of starch in the roots was highest at the intermediate irradiance and fertilizer level, and decreased linearly at the high irradiance the higher the fertilizer rate. After the interior holding period, leaf, stem and starch concentration were drastically reduced compared to levels at the end of production (Table 3). Depletion was ≈97% for stem starch content in all treatments. Root starch concentration was reduced 62% in plants grown under the lowest irradiance level and 72% in plants grown under the highest irradiance.

Anatomical features. The greatest anatomical differences between high- and low-irradiance grown leaves were leaf and cuticle thickness and palisade cell size. Leaves developing under the high irradiance level had elongated, columnar palisade cells in one or more layers, which resulted in increased leaf thickness (Fig. 1, top). A thicker cuticle was also observed in leaves grown under the high irradiance level. Similar observations have been reported for

Table 1. Effect of irradiance (I) and fertilizer (F) rate during production on light compensation point (LCP), number of damaged fronds of *Chrysalidocarpus lutescens* at the marketable stage, and on LCP, total number of fronds, and chlorophyll concentration (C) after 3 months indoors under an irradiance of 20 μmol·m^{-2}·s^{-1}.

			After 3 months indoors				
				C (mg·cm^{-2})			
	Production			Irradiance (μmol·m^{-2}·s^{-1})			Fronds
Variable	LCP (μmol·m^{-2}·s^{-1})	Damaged fronds[z]	LCP (μmol·m^{-2}·s^{-1})	481	820	1241	(no.)
Fertilizer (F) (mg/pot weekly)							
440	165	32.8	143	0.075	0.078	0.093	128
880	204	34.0	131	0.079	0.087	0.089	109
1660	206	50.5	149	0.095	0.083	0.070	87
Significance							
Linear	NS	NS	NS	*	NS	**	**
Irradiance (I) (μmol·m^{-2}· s^{-1})							
481	140	27.9	126				114
820	192	33.2	149				114
1241	243	56.3	149				97
Significance							
Linear	**	**	NS				NS
Interaction (F × I)	NS	NS	NS		*		NS

[z]Number of damaged fronds removed from the plants prior to placement indoors.
NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively, n = 3. Quadratic relationships were nonsignificant.

Table 2. Interaction effect of fertilizer rate (F) and irradiance level (I) on stem and root soluble sugars concentration of *Chrysalidocarpus lutescens* at the end of the production and on leaf solubles sugars after 3 months indoors. Effect of fertilizer rate as a main factor on leaf soluble sugars concentration at the end of production and on stem and root soluble sugars concentration after 3 months indoors. Soluble sugars concentration is expressed as glucose, mass basis.

	Soluble sugars (mg·g^{-1})											
	Production							After 3 months indoors				
	Leaf[z]	Stem			Root			Leaf			Stem[z]	Root[z]
		Irradiance (μmol·m^{-2}·s^{-1})			Irradiance (μmol·m^{-2}·s^{-1})			Irradiance (μmol·m^{-2}·s^{-1})				
Fertilizer (mg/pot weekly)	---	481	820	1241	481	820	1241	481	820	1241	---	---
440	48	48	41	55	47	43	55	21	17	23	32	28
880	37	40	52	44	44	47	45	26	18	19	23	19
1660	44	38	37	34	43	39	42	18	22	19	17	14
Significance	NS											
Linear		**	NS	**	NS	NS	**	NS	**	NS	**	**
Quadratic		NS	**	NS	NS	NS	*	*	NS	NS	**	**
Interaction (F × I)	NS		**			**			**		NS	NS

[z]Irradiance level did not significantly affect these variables.
NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively, n = 3.

other species (Chabot and Chabot, 1977; Dengler, 1980; Friend and Pomeroy, 1970). Under the low irradiance level, leaves were thinner, and had a poorly developed palisade layer, characteristic of shade-grown leaves. However, we did not find important differences in chloroplast size, distribution, or orientation of *C. lutescens* based on irradiance level. Chloroplasts of shade-grown leaves are usually large, with grana stacks highly developed, and chloroplast orientation tends to maximize exposure of total chloroplast area, further enhancing light interception (Haupt, 1973; Fails et al., 1982a; Reyes et al., 1996).

Discussion

The success of foliage plants in an interior environment depends on their ability to survive under low light conditions (Conover and Poole, 1984). Photosynthetic acclimation to differing light conditions has been demonstrated for a wide range of plant species (Boardman, 1977). LCP has been used extensively as an indicator of acclimatization, since quality loss indoors is thought to result from interior irradiance below LCP. Acclimatized *Philodendron scandens* Koch and Sello, *Epipremnum aureum* Bunt, *Brassaia actinophylla* Endl., and *Dracaena sanderana* Hort. after 15 weeks at 27 $\mu mol \cdot m^{-2} \cdot s^{-1}$ exhibited light compensation points of 7, 6, 4, and 15 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively (Fonteno and McWilliams, 1978). *Ficus benjamina* L. grown under 75% light exclusion showed a LCP of 6 $\mu mol \cdot m^{-2} \cdot s^{-1}$ after 12 weeks in a simulated interior environment (Fails et al., 1982b). LCP in *Ficus benjamina* significantly decreased in plants grown under 47% light exclusion (Johnson et al., 1979; Joiner et al., 1980). Another palm, *Chamaedorea elegans* Mart. grown under 162 $\mu mol \cdot m^{-2} \cdot s^{-1}$, had a LCP of 20 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at the end of production (Reyes et al., 1996). The LCP of *C. lutescens* grown at the lowest irradiance level was 126 $\mu mol \cdot m^{-2} \cdot s^{-1}$ after 3 months indoors, at 20 $\mu mol \cdot m^{-2} \cdot s^{-1}$. This value was still considerably higher than the minimum light requirement reported in the literature for acclimatized foliage plants.

Chlorophyll concentration is higher in leaves of shade plants than in plants growing in full sun (Anderson et al., 1973). Sun-grown *Dracaena marginata* had chlorophyll levels of 0.055 $mg \cdot cm^{-2}$, and 0.081 and 0.100 $mg \cdot cm^{-2}$, respectively in those grown under 40% or 80% shade for 8 months. Similar results were obtained by Milks (1977) in *Ficus benjamina* and Reyes et al. (1996) in *Chamaedorea elegans*. In this study, chlorophyll content of *C. lutescens* was not significantly affected by irradiance levels in production.

Batson and Blessington (1983) speculated

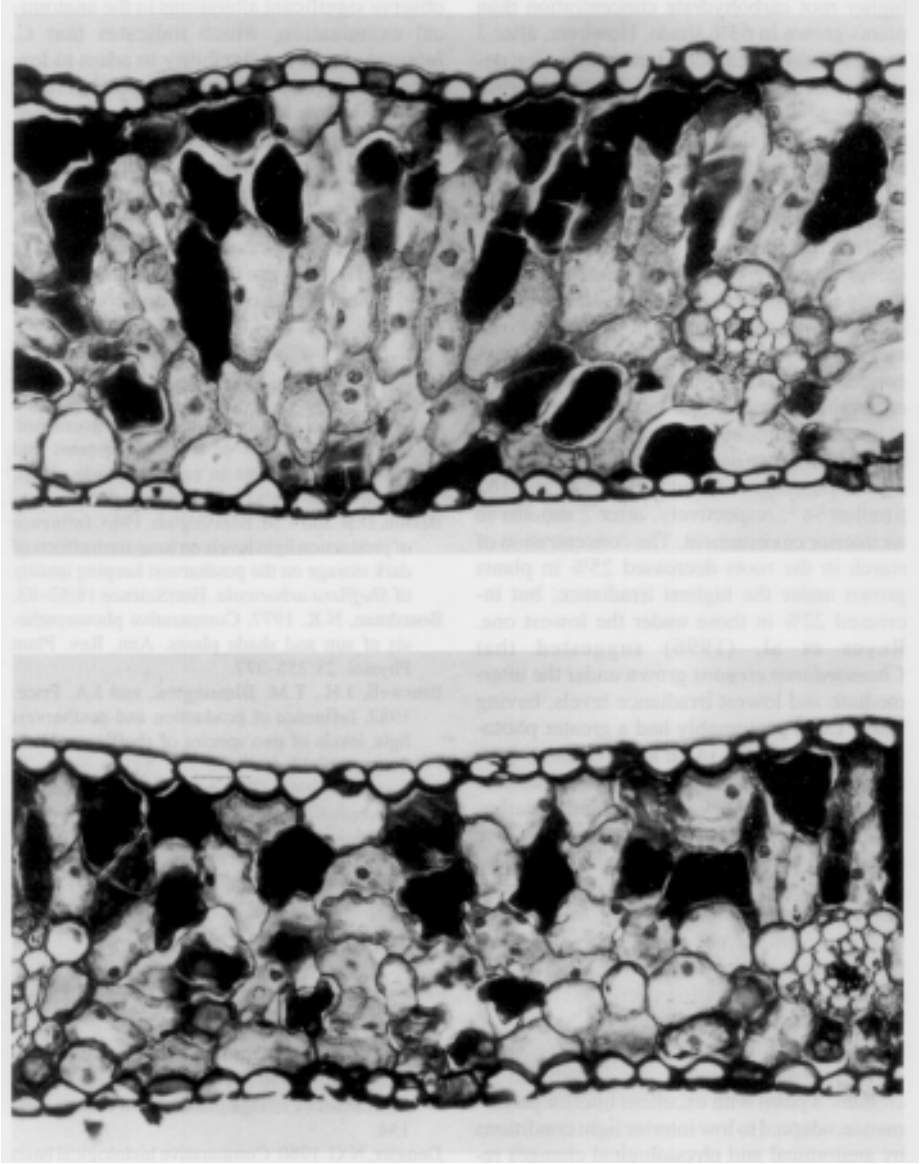

Fig. 1. Light microscope micrographs (400×) showing leaf cross section of *Chrysalidocarpus lutescens* grown at 1241 (**top**) and at 481 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (**bottom**).

Table 3. Interaction effect of fertilizer rate (F) and irradiance level (I) on leaf, stem and root starch concentration of *Chrysalidocarpus lutescens* at the end of the production and on stem and root starch after 3 months indoors. Effect of fertilizer rate as main factor on leaf starch concentration after 3 months indoors. Starch concentration is expressed as glucose, mass basis.

	Starch ($mg \cdot g^{-1}$)															
	End of production									After 3 months indoors						
	Leaf			Stem			Root			Leaf[z]	Stem			Root		
Fertilizer (F)	Irradiance (I) ($\mu mol \cdot m^{-2} \cdot s^{-1}$)															
(mg/pot weekly)	481	820	1241	481	820	1241	481	820	1241	---	481	820	1241	481	820	1241
440	4.2	8.2	4.7	207	223	251	107	51	119	0.7	4.0	3.8	3.5	42	43	39
880	7.1	2.1	5.6	188	149	178	82	118	76	1.2	6.0	3.1	4.9	58	25	18
1660	3.4	4.2	11.2	164	104	114	115	46	48	1.6	3.5	5.3	4.0	18	16	13
Significance																
Linear	NS	NS	NS	*	**	**	NS	NS	**	**	NS	*	NS	*	**	*
Quadratic	**	NS	NS	NS	NS	NS	NS	**	NS	*	*	**	NS	*	NS	NS
Interaction (F × I)		**			**			**		NS		**			**	

[z]Irradiance did not affect this variable.

[NS, *, **]Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively, n = 3.

that reduction in quality of *Shefflera arboricola* Hayata ex. Kanehira after simulated dark storage and 12 weeks in an interior environment was due to loss of carbohydrates during the dark storage period. Milks et al. (1979) found that sun-grown *Ficus benjamina* had 29% higher root carbohydrate concentration than plants grown in 63% shade. However, after 3 months indoors, carbohydrate production decreased for all treatments and the stored carbohydrate was used for plant growth. Indoor performance of shade-grown plants was superior to plants grown under full sun even though total carbohydrate levels were lower. In contrast, Fails et al. (1982b) found that root carbohydrate reserves were used to produce new leaves on sun-grown *F. benjamina* at a rate nearly five times higher than in shade-grown or acclimatized plants. In *Chamaedorea elegans* (Reyes et al., 1996), the soluble sugars concentration after placement in an interior environment was similar to the concentration at the end of production. The concentration of starch in the stem decreased by 43%, 10%, and 5% for plants grown under 564, 306, and 162 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively, after 2 months in an interior environment. The concentration of starch in the roots decreased 25% in plants grown under the highest irradiance, but increased 22% in those under the lowest one. Reyes et al. (1996) suggested that *Chamaedorea elegans* grown under the intermediate and lowest irradiance levels, having lower LCP, presumably had a greater photosynthetic efficiency in the low irradiance interior environment. Thus, plants were able to produce new fronds without depleting carbohydrate reserves. In the present study, we found a 45% to 55% decrease in leaf, stem and root soluble sugars concentration in *C. lutescens* after 3 months indoors. Moreover, a 97% depletion was observed on the concentration of starch in the stem in all treatments, and root starch concentration decreased 62% and 72% for plants growing under the lowest and highest irradiance, respectively.

In previous research, we found that *C. elegans*, a palm with excellent interior performance, adapted to low interior light conditions by anatomical and physiological changes resulting in a LCP as low as 18 $\mu mol \cdot m^{-2} \cdot s^{-1}$ after 2 months indoors (Reyes et al. 1996). LCP of *C. lutescens* never decreased below 126 $\mu mol \cdot m^{-2} \cdot s^{-1}$ after 3 months indoors; chlorophyll concentration was not higher in plants grown under low irradiance, and we did not observe significant alterations in the anatomical examination, which indicates that *C. lutescens* lacks the flexibility to adapt to low irradiance levels. *Chrysalidocarpus lutescens* grew in the low levels of the interior environment at the expense of reserved carbohydrates regardless of the treatments imposed during production. The drastic carbohydrate depletion observed in *C. lutescens* during the holding period suggests that this is not a species for extended interior use under the low irradiance level characteristic of homes and commercial offices.

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