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Acclimatization of *Ficus benjamina* to temperature and irradiance conditions in indoor landscapes

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Summary

The present study examined the effects of temperature and light regimes as a means to acclimatize *Ficus benjamina* prior to plants being placed in a standard, interior environment. *F. benjamina* plants were exposed for six months to temperatures of 15, 20 and 25 °C combined with photon flux densities (PFD) of 40, 80 and 180 µmol $m^{-2}s^{-1}$. After treatments, plants were placed in an interior environment at 18 µmol $m^{-2}s^{-1}$ PFD and 20 °C and growth measured. During acclimatization the combination of 15°C and 180 µmol $m^{-2}s^{-1}$ is critical because leaf number is reduced and the typical leave gloss is lacking. Growth of *F. benjamina* in interior environment was affected by acclimatization parameters. After six month indoors, growth characteristics were nearly identical among acclimatization treatments. However, temperature and irradiance during acclimatization influenced internode length growth and carotenoid content after plants were placed in an interior environment.

1. Introduction

In recent years considerable interest has been generated to improve survival and quality of foliage plants used for indoor decoration of homes. Researchers have developed acclimatization procedures to reduce losses in quality when plants are placed in interior environments (CONOVER and POOLE, 1977; SVENSON, 2002) where irradiance and abscission are reduced (SAWWAN and GHUNEM, 1999). Plants preconditioned in low light adapt more successfully to low-light interior environments than non-preconditioned plants (FONTENO and MCWILLIAMS, 1978; JOINER et al., 1980).

Contrasting microclimates affect morphological characteristics (FAILS et al., 1982; GIANOLI, 2003) and leaf physiology (ANDERSON et al., 1991; MORTENSEN and OLSEN, 1987; CONOVER and POOLE, 1977). Plants grown in shade have thinner leaves (FAILS et al., 1982; SYVERTSEN and SMITH, 1984), greater leaf area (SAWWAN and GHUNEM, 1999), more chlorophyll (REYES et al., 1996; LANCE and GUY, 1992) and longer shoots than plants grown in full sun (COLLINS and WEIN, 2000). In addition, the temperature optimum for growth parameters decreased as irradiance decreased (BJÖRKMAN, 1980). High temperatures result in reduced light absorption because of thinner palisade parenchyma (ARMITAGE et al., 1981) and smaller leaf area (MARCELIS, 1993).

The most widely utilized tropical tree in the interior landscape industry is *Ficus benjamina*, a member of the family Moraceae indigenous to Southeast Asia. *F. benjamina* and its cultivars have been the focus of much of the foliage plant acclimatization research for the past 20 years because of their enormous popularity.

Presently *F. benjamina* is acclimatized for interior conditions at irradiances of 770-1170 µmol $m^{-2}s^{-1}$ PFD (CONOVER and POOLE, 1990). In the present study we determined the influence of temperature and low irradiance during acclimatization on plant growth when placed in interior environments.

2. Materials and methods

Plants of *Ficus benjamina* 'Danielle' were planted in 12 cm diameter pots and placed in a hydroponic substrate (Lecaton, Ø 4-8 mm). Initially, *F. benjamina* was separately exposed to three different photon flux densities (40 µmol $m^{-2}s^{-1}$, 80 µmol $m^{-2}s^{-1}$ and 180 µmol $m^{-2}s^{-1}$) combined with three temperatures regimes: 15 °C, 20 °C and 25 °C during light exposure in climate chambers for six months duration. During night (10 hours) temperature was lowered 2 °C in all treatments. Light for 14 hr day^{-1} was supplied by metal halide lamps (Osram, HQI-R, 250 W) located 1.20 m above the plants. Each chamber was set at a specific temperature but there were three PFD treatments in each chamber. Plant groups of nine were used as replicates. The different PFD in the climate chambers were created by shading the plants with white fleece. Tab. 1 gives the verification of PFD values among treatments within a chamber. Plants were moved twice weekly within each chamber to minimize PFD variation and maintained at 65 ± 5 % relative humidity. Temperature and relative humidity were programmed in climate chambers and controlled by external data loggers (Hobos, Onset Company). Airflow in the climate chambers was measured by thermo-anemometers and airflow sensors. In the growth chambers airflow increased from 0.09 m s^{-1} at 40 µmol $m^{-2}s^{-1}$ PFD to 0.20 m s^{-1} at 80 µmol $m^{-2}s^{-1}$ PFD and 0.26 m s^{-1} at 180 µmol $m^{-2}s^{-1}$ PFD. Differences in airflow were created by black cloth used to separate the different light regimes.

Tab. 1: Verification of PFD values among treatments within a climate chamber

Temperature [°C]	Verification of PFD values [µmol $m^{-2}s^{-1}$] 40	80	180
15	± 3.8	± 4.7	± 4.7
20	± 3.1	± 3.8	± 4.4
25	± 2.8	± 4.4	± 5.7

After six month of acclimatization, a total of 81 plants were transferred indoors at 18 ± 5.3 µmol $m^{-2}s^{-1}$ PFD for 14 hr day^{-1}. The air temperature was 20 ± 2 °C during light exposure and 18 ± 1 °C in darkness. *F. benjamina* were randomly distributed in two rooms with 0.30 m between plants. Variation in PFD was minimized by moving the plants randomly every seven days. The light source was from metal halide lamps (Philips, HQI-TS, 400 W) situated 2 m above the plants. Temperature and relative humidity were measured by a hydrothermograph. The average relative humidity was 45 ± 5 %. The average air flow was 0.03 m s^{-1} in interior environments.

The PFD was measured at nine different locations in each climate chamber during the acclimatization phase and at 15 locations indoors on the top of the plants by using a LI-COR-photometer with a quantum sensor. Plants were watered as needed and fertilized every four weeks

with 0.2 % Kristalon (19 % N, 6 % P_2O_5, 20 % K_2O, 3 % MgO; with no chloride).

After acclimatization and the subsequent six month indoor growing period the following data were collected: 1) shoot length; 2) internode length per shoot; 3) foliation per shoot; 4) leaf area; 5) dry mass; 6) chlorophyll a and b and carotenoid content, and 7) anatomical characteristics (leaf thickness, palisade and spongy parenchyma). Since the two youngest leaves were often not fully developed, we selected the third youngest leaf from the shoot apex for the analysis.

To determine dry mass, leaves from each plant were placed in petri dishes and dried at 105 °C for 36 hours. Chlorophyll and carotenoid contents were determined by a method described by METZNER (1982). To determine leaf and mesophyll thickness small, rectangular sections were cut at mid-lamina, preserved in formalin-acetic acid-alcohol and dehydrated in an ethanol series, and embedded in plastic (Technovit 7100 and hardener). Sections 4 µm in thickness were stained with toluidin blue according to BÖCK (1989).

All results were subjected to analysis of variance (ANOVA) using SPSS (Version 10.0) for windows. Data were tested for fit to a normal distribution and homogeneity of variances. The 5 % probability level was accepted to indicate significant differences. Normal distributed data with homogeneous variances were compared with Tukey's test. If data were not normally distributed the Kruskal-Wallis test and Nemenyi test were used. The correlation coefficients were calculated according to Pearson.

3. Results

3.1 Plant growth

Plants grown at 15 °C during acclimatization had significantly shorter internode length than plants at 20 °C and 25 °C. Internode length for plants grown at 20 °C and 25 °C were not different, regardless of PFD treatment. Leaf dry mass among treatments was highly variable but generally weights were lowest at low PFDs. In contrast, differences in leaf area were only detected at 15 °C/ 40 µmol $m^{-2}s^{-1}$ and 20 °C/80 µmol $m^{-2}s^{-1}$. Shoot length differed significantly among treatments acclimatized at 15 °C and higher temperatures, whereas shoots were generally shorter at 15 °C. However, shoot length at 20 °C and 40 µmol $m^{-2}s^{-1}$ PFD was the only exception and not different from 40 µmol $m^{-2}s^{-1}$ and 80 µmol $m^{-2}s^{-1}$ at 15 °C (Tab. 2). When plants were grown at 15 °C they developed significantly fewer leaves per shoot than when grown at 20 °C at 80 µmol $m^{-2}s^{-1}$ and 180 µmol $m^{-2}s^{-1}$ PFD as well as at 25 °C regardless of PFD treatment (Fig. 1). After six month exposure to interior conditions following acclimatization we noted differences in number of leaves per shoot between 15 °C/180 µmol $m^{-2}s^{-1}$ and 25 °C/ 180 µmol $m^{-2}s^{-1}$. Number of leaves, leaf area and leaf dry mass were similar for all treatments after six month under interior conditions (Tab. 3).

3.2 Chlorophyll and carotenoid content

The chlorophyll a and b content in leaves was variable among treatments. Chlorophyll a and b content in leaves was lower at 180 µmol $m^{-2}s^{-1}$ PFD when grown at 15 °C than at 20 °C and 25 °C (Tab. 4). After exposure to interior conditions for six months no differences were noted in chlorophyll content per leaf area among treatments. Temperature and irradiance during acclimatization did not influence chlorophyll content per leaf area in interior environments. The carotenoid ratio was variable after acclimatization treatments. However, after six month indoors no differences between chlorophyll a:b ratios were detected between treatments (Tab. 4).

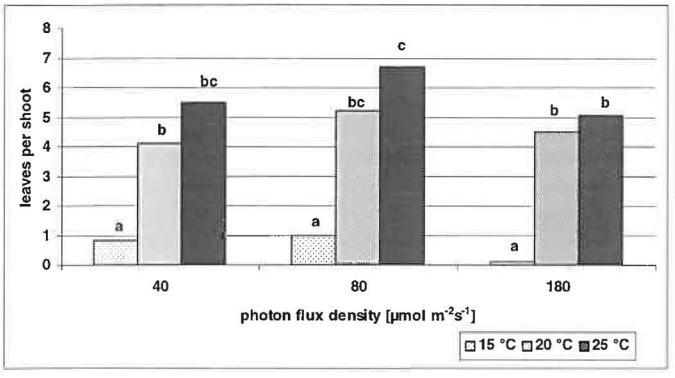

Fig. 1: The effect of temperature and photon flux density on the number of leaves per shoot of *Ficus benjamina* after six month acclimatization phase (Kruskal Wallis and Nemenyi test; $p < 0.05$; $n = 81$).

Tab. 2: Influence of temperature and photon flux density on growth of *Ficus benjamina* after six month acclimatization phase

temperature and PFD treatments [°C/µmol $m^{-2}s^{-1}$]	shoot length [cm]	internode length [cm]	leaf area [cm^2]	leaf dry mass [mg]
15/180	1.74 a ^{x**}	- **	16.50 ab*	0.12 c*
15/80	2.87 ab	1.52 a	15.30 ab	0.10 bc
15/40	2.98 ab	1.06 a	12.67 a	0.08 ab
20/180	10.16 cd	2.58 b	16.14 ab	0.11 bc
20/80	12.62 cd	3.06 b	17.02 b	0.09 abc
20/40	8.86 bc	2.79 b	16.52 ab	0.06 a
25/180	10.93 cd	2.90 b	14.94 ab	0.10 bc
25/80	16.33 d	3.36 b	15.25 ab	0.08 ab
25/40	14.82 cd	3.14 b	14.93 ab	0.07 ab

^{x} Mean separation within columns and treatments by *Tukey test or **Kruskal Wallis and Nemenyi test; $p < 0.05$; $n = 81$.

Tab. 3: Influence of temperature and photon flux density on the growth of *Ficus benjamina* after six month acclimatization phase and six month in interior environment (20 °C/18 µmol $m^{-2}s^{-1}$ PFD)

acclimatization temperature and PFD treatment [°C/µmol $m^{-2}s^{-1}$]	growth length [cm]	leaves/shoot	internode length [cm]	leaf area [cm^2]	leaf dry mass [mg]
15/180	11.08 a[X**]	5.11 a **	1.72 a **	14.58 a **	0.06 a *
15/80	12.83 ab	5.89 a	2.16 ab	15.63 a	0.07 a
15/40	12.64 ab	6.11 a	2.29 ab	15.49 a	0.07 a
20/180	18.93 b	6.00 a	2.28 ab	16.58 a	0.08 a
20/80	14.32 ab	5.44 a	1.99 ab	15.87 a	0.08 a
20/40	13.44 ab	5.44 a	2.34 ab	16.87 a	0.07 a
25/180	17.19 ab	6.11 a	2.41 b	14.96 a	0.08 a
25/80	16.09 ab	5.44 a	2.17 ab	13.64 a	0.08 a
25/40	14.38 ab	5.67 a	2.06 ab	15.83 a	0.07 a

[X] Mean separation within columns within treatments by *Tukey test or **Kruskal Wallis and Nemenyi test; $p < 0.05$; $n = 81$.

Tab. 4: Influence of temperature and photon flux density on chlorophyll content, chlorophyll a : b ratio, and carotenoid content of *Ficus benjamina* leaves

acclimatization temperature and PFD treatments [°C/µmol $m^{-2}s^{-1}$]	chlorophyll a and b [mg/cm^2]		chlorophyll a : b		carotenoid [mg/cm^2]	
	acclimatization[Y]	indoors[Z]	acclimatization	indoors	acclimatization	indoors
15/180	1.71 a [X*]	2.28 a *	2.06 bcde*	1.75 a **	0.50 a *	0.59 ab *
15/80	2.67 bc	2.30 a	2.02 abc	1.75 a	0.73 d	0.61 ab
15/40	2.49 bc	2.25 a	2.02 abcd	1.73 a	0.63 abcd	0.59 ab
20/180	2.32 bc	2.27 a	2.14 e	1.78 a	0.62 abcd	0.59 ab
20/80	2.78 c	2.29 a	1.95 ab	1.76 a	0.70 cd	0.61 ab
20/40	2.58 bc	2.28 a	1.93 a	1.73 a	0.65 bcd	0.61 ab
25/180	2.44 bc	2.06 a	2.16 e	1.75 a	0.64 abcd	0.49 a
25/80	2.18 ab	2.33 a	2.13 de	1.76 a	0.55 ab	0.63 b
25/40	2.26 abc	2.28 a	2.08 cde	1.72 a	0.58 abc	0.59 ab

[X] Mean separation within columns between treatments by *Tukey or **Kruskal Wallis and Nemenyi test; $p < 0.05$; $n = 81$.
[Y] Determined at end of six month acclimatization phase.
[Z] Determined at end of six month growth in interior environment (20 °C during light exposure/18 °C in darkness, 18 µmol $m^{-2}s^{-1}$ PFD).

3.3 Anatomical characteristics

Anatomical characteristics of *F. benjamina* were influenced by combinations of temperature and irradiance during acclimatization but not after exposure to indoor environments (Tab. 5). At 25 °C/180 µmol $m^{-2}s^{-1}$ leaves were significantly thicker than at 20 °C/40 µmol $m^{-2}s^{-1}$ and 25 °C/40 µmol $m^{-2}s^{-1}$, due to the thickness of palisade parenchyma layers. During the acclimatization phase at 15 °C/180 µmol $m^{-2}s^{-1}$ growing leaves developed thicker spongy parenchyma than at 20 °C/40 µmol $m^{-2}s^{-1}$. In addition, between leaf thickness and dry mass per leaf we found a positive correlation as expected ($p < 0.05$, $r = 0.639$).

4. Discussion

The growth of *F. benjamina* during acclimatization was strongly influenced by temperature and PFD levels. Chlorophyll content does not explain growth results because the dry mass per leaf area did not correlate with chlorophyll content per leaf area. Plants grown in shade have a lower chlorophyll a:b ratio than plants produced in full sun (HANSEN et al., 2002; KITAJIMA et al., 2003). In *F. benjamina* a high chlorophyll a:b ratio occurred only at 20 °C and high PFD. In *Fagus sylvatica* and *Quercus petraea* a positive relation was reported between carotenoid content and shading tolerance (DEMMING-ADAMS and ADAMS, 1992; HANSEN et al., 2002). Our investigations with *F. benjamina* could not confirm these results. Growth at low PFD depends on the concentration of different carotenoids since carotenoids affect the efficacy of light absorption during photosynthesis. Carotin and neoxanthin did not affect shading tolerance, but high contents of lutein often occur in shade-grown plants (JOHNSON et al., 1993). We conclude that low PFD did not influence total carotenoid content, but did affect the non analysed composition of carotenoids.

After six month indoors, growth characteristics were nearly identical, regardless of treatment during the previous six month acclimatization phase. However, temperature and PFD acclimatization treatments can lead to high plant quality for indoor environments. We did not observe any plant growth suppression. CONOVER and POOLE (1977) reported that shading during acclimatization reduced abscission of

Tab. 5: Influence of temperature and photon flux density on anatomical characteristics of *Ficus benjamina* leaves

acclimatization temperature and PFD treatments [°C/µmol $m^{-2}s^{-1}$]	leaf thickness [µm]		palisade parenchyma [µm]		spongy parenchyma [µm]	
	acclimatization[Y]	indoors[Z]	acclimatization	indoors	acclimatization	indoors
15/180	213.28 bc[X*]	158.57 a**	33.61 ab**	24.47 a **	109.36 b**	85.10 a*
15/80	194.06 abc	165.14 a	36.60 ab	25.36 a	97.16 ab	80.98 a
15/40	196.41 abc	173.77 a	34.10 ab	25.52 a	97.06 ab	86.60 a
20/180	206.90 abc	164.76 a	32.90 ab	25.76 a	106.00 ab	80.19 a
20/80	183.23 abc	171.99 a	34.40 ab	25.65 a	92.13 ab	84.08 a
20/40	174.48 a	170.83 a	26.10 a	29.62 a	85.14 a	83.76 a
25/180	215.44 c	171.91 a	43.53 b	26.64 a	102.34 ab	85.90 a
25/80	196.93 abc	174.64 a	33.24 ab	28.77 a	94.38 ab	86.33 a
25/40	181.82 ab	170.91 a	25.80 a	30.13 a	94.78 ab	80.28 a

[X] Mean separation within columns within treatments by *Tukey or **Kruskal Wallis and Nemenyi test; $p < 0.05$; $n = 81$.
[Y] Determined at end of six month acclimatization phase.
[Z] Determined at end of six month growth in interior environment (20 °C during light exposure/18 °C in darkness, 18 µmol $m^{-2}s^{-1}$ PFD).

F. benjamina by reducing the light compensation point when plants were placed indoors.

When *F. benjamina* was grown in full sun light they showed an up to three times higher light compensation point than when grown in 80 % shade. This fact is probably the reason for a considerable reduction in leaf drop by plants produced in shade. The acclimatization of *F. benjamina* is only practicable inside the genetic potential (BJÖRKMAN and HOLMGREN, 1966).

Low PFD in interior environment reduced leaf thickness. Leaves exposed to low PFD developed only thin palisade parenchyma with short palisade cells and reduced spongy parenchyma (SAWWAN and GHUNEM, 1999). Thicker leaves increased the dry mass in *F. benjamina*. RODERICK et al. (1999) and NINEMETS (2001) proved this correlation in different trees and shrubs. More light energy for photosynthesis is available caused by longer palisade cells and thicker spongy parenchyma.

Plants acclimatized at 15 °C and 180 µmol $m^{-2}s^{-1}$ are not marketable because growth is reduced and leaves lack their characteristic gloss. In contrast, there is profuse growth at 20 °C and 180 µmol $m^{-2}s^{-1}$ which necessitates pruning, leading to reduced profitability. But this acclimatization condition can support plant growth for fast green areas in indoors.

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