Growth and yield of *Syagrus schizophylla* (Mart.) Glass. in response to light gradients

Crecimiento y rendimiento de *Syagrus schizophylla* (Mart.) Glass. en respuesta a gradientes de luz

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Abstract

This research studied growth and yield of *Syagrus schizophylla,* an extinction-endangered ornamental palm, grown under five light gradients. The treatments were: G_1 - PAR=1234.10 µmol photons m^{-2} s^{-1}, G_2 - PAR=913.16 µmol photons m^{-2} s^{-1}, G_3 - PAR=666.34 µmol photons m^{-2} s^{-1}, G_4 - PAR=419.56 µmol photons m^{-2} s^{-1} and G_5 - PAR=534.77 µmol photons $m^{-2}s^{-1}$. Before the experiment and at three, five and seven months of treatment, growth (plant height, collar diameter, number of leaves, petiole length, leaf length and width), gas exchange, chlorophyll *a*, and leaf green color intensity were assessed. The highest net photosynthetic rates were observed in plants under G_2, G_3 and G_4. Values of maximum quantum efficiency (F_v/F_m) over 0.75 were observed under G_2. At seven months, estimated SPAD values were 36 in G_2 plants and 32 in G_1 plants. According to the Dickson quality index (DQI), presented the highest growth and development rates We conclude that G_2 suits plants to be transplanted into the field, whereas G_3 would be best for plants grown under shade environments.

Keywords
Arecaceae • gas exchange • palm tree • photosynthesis • shading

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Resumen

Syagrus schizophylla es una especie de palmera ornamental en peligro de extinción. El objetivo de esta investigación fue estudiar los aspectos fisiológicos del crecimiento y la calidad de las plantas producidas bajo gradientes de luz. Los tratamientos de gradientes de luz fueron: G1 - PAR = 1234.10 μmol fotones m^{-2} s^{-1}, G2 - PAR = 913.16 μmol fotones m^{-2} s^{-1}, G3 - PAR = 666.34 μmol fotones m^{-2} s^{-1}), G4 - PAR = 419,56 μmol fotones m^{-2} s^{-1} y G5 - PAR = 534,77 μmol fotones m^{-2} s^{-1}. Antes de aplicar los tratamientos y a los tres, cinco y siete meses de tratamiento, se analizaron la altura de la planta, diámetro del collar, número de hojas, largo del pecíolo, largo y ancho de la hoja), intercambio gaseso, fluorescencia de la clorofila a y color verde de la hoja. Las tasas fotosintéticas netas más altas se observaron en plantas bajo G2, G3 y G4. Em G2 se observaron valores de Fv/Fm superiores a 0,75. En el séptimo mes, los valores estimados del índice SPAD fueron 36 en plantas bajo G2 y 32 en plantas bajo G1. El mejor crecimiento y desarrollo de las plantas se observó en G2 de acuerdo con DQI que muestra que este gradiente debe usarse para plantas destinadas al campo, mientras que G3 sería mejor para plantas destinadas a entornos sombríos.

Palabras clave

Arecaceae • intercambio gasesoso • palmera • fotosíntesis • sombreado

Introduction

Syagrus schizophylla (Mart.) Glass. is an indigenous Arecaceae, naturally found in the Brazilian Sandy Coast (Restinga) and the Atlantic Rain Forest (17). Ordinarily known as *aricuriroba*, *coco-babão* and *licuriroba,* the fruits are considered an unconventional food and an alternative source of carbohydrates, proteins and lipids (23). Unfortunately, the species is considered endangered by the Flora Conservancy National Center (CNCFlora Red List, Brazil), mainly given to both urban and tourist pressures (25).

In forests, palm distribution depends on light and water availability. The Arecaceae family shows a wide diversity of genera and species, still unstudied regarding adaptive traits. Due to spatial distribution and diversity, palms are suitable models for studying biodiversity of tropical and subtropical ecosystems (17, 23, 25).

The photosynthetically active radiation (PAR, μmol fótons $m^{-2}s^{-1}$), ranges between 400 and 700 nm (10). Red light incidence (600-700 nm) on the leaf mesophyll enhances stomatal opening (1). However, exposure for long periods may cause red light syndrome, leading to low quantum yield, low photosynthetic capability and lack of stomatal response (20, 27). Light intensity and quality vary according to daytime, season, location, climate, position within the plant canopy, and even within the cell (21). Such variations can result in morphoanatomical changes affecting leaf biomass allocation, chlorophyll *a*/*b* ratio, leaf thickness, stomatal density and photochemical dissipation (27), organization of the photosynthetic apparatus, etiolation, leaf area and carbohydrate storage, among others (14, 20). Blue, red and infrared light activate specific receptors, triggering independent key physiological events (20). This research hypothesizes that using shade nets with light gradients in the blue and red ranges would result in optimized plant carbon allocation and photosynthesis. We studied the physiological response of *S. schizophilla* to different wavelengths determining the best environmental conditions for sapling yield. The experiments used different shade nets, assuming that specific wavelengths modify the intercepted energy, leading to optimized carbon fixation, growth and yield (5, 10).

Given the need for the preservation and recovery of negatively anthropized areas, this study might contribute to optimizing plant conservation, preservation and sustainable use, while offering income diversification in rural areas.

Material and methods

Plant material, seedling transplant and light gradients

Seeds were obtained and germinated as described by Beltrame *et al.* (2019). Ninety days after emergence, seedlings of *S. schizophylla* were transplanted into pots of approximately 6.3 L, previously filled with a mixture of commercial substrate Plantmax® and coconut fibre (1:1; v:v) with the following physicochemical characteristics: P = 0.01 g kg^{-1}, K = 5.47 g kg^{-1}, S = 4.82 g kg^{-1}, Ca = 7.89 g kg^{-1}, Mg = 4.34 g kg^{-1}; B = 15.07 mg kg^{-1}, Fe = 1.54 mg kg^{-1}, Mn = 4.34 mg kg^{-1}, Zn = 26.46 mg kg^{-1}, Cu = 0.2 µg kg^{-1}, pH = 4.11, CE 0.8 µS cm^{-1}, bulk density = 0.42 g cm^{-3}, true density = 1.58 g cm^{-3} and total porosity of 73% of container volume.

Initially, the plants were kept for 270 days under an average of 534.77 µmol photons m^{-2} s^{-1} (May 2016 to February 2017), in a greenhouse, with mean PAR 534.77 µmol photons m^{-2} s^{-1}. After that period, treatments lasted 210 days (from March to October 2017). The seedlings were randomly organized and grown under tunnels (1.80x1.50x1.80 m) covered with different shade nets resulting in different light gradient treatments: plain sunlight - control (G_1) (PAR=1234.10 µmol photons m^{-2} s^{-1}), red Chromatinet® 50% of shade (G_2) (PAR=913.16 µmol photons m^{-2} s^{-1}), two overlapping layers of red Chromatinet® 50% of shade (G_3) (PAR=666.34 µmol photons m^{-2} s^{-1}), black polyolefin 50% of shade (G_4) (PAR = 419.56 µmol photons m^{-2} s^{-1}) and overlapping layers of milky plastic film and polyolefin 50% of shade (G_5) (PAR = 534.77 µmol photons m^{-2} s^{-1}).

HOBO Pro v2 Data Loggers hourly monitored mean, minimum, and maximum temperatures throughout the experimental period. In addition, light spectral quality was evaluated using the USB2000+RAD Ocean Optics UV/Vis spectrum radiometer, obtaining three consecutive readings in each tunnel, at 9 am and three consecutive readings at noon, on bright sunny days.

Growth analyses

Before light treatments (BT), and at three, five and seven months, we measured collar diameter (DC), shoot height (SH), number of leaves (NL), petiole length (LP), leaf length (LL) and width (LW). The LP, LL and LW were measured with a ruler, on the second pair of fully expanded leaves.

After seven months, shoot (SDW) and root dry weight (RDW), and plant total leaf area (TLA) were determined. All leaves were detached, and leaf blades and petioles were separated with pruning shears for TLA determination using a Li-3100 (Li-Cor, USA) leaf area meter. For dry weight determination, plant shoot and roots were separated, paper bagged and dried in a convection oven at 70 ± 2°C for 96 hours. Root and shoot dry weights were gravimetrically determined (±0.0001 g).

Dickson quality index (DQI) was calculated according to Dickson *et al.* (1960) (eq. 1), using total dry mass (TDM), shoot height (SH), collar diameter (DC), shoot dry weight (SDW) and root dry weight (RDW).

$$\mathbf{DQI = \{TDM/[(SH/DC) + (SDW/RDW)]\}} \qquad (1)$$

Gas exchange, chlorophyll *a* fluorescence and green color intensity

Gas exchange was evaluated between 8 am and 10 am with a portable infrared analyzer (IRGA - model Li-6400 XT - Li-Corporation/USA). Evaluation cycles correspond to cycle 1 = one month after initializing treatments (AT)], cycle 2 = three months after AT and cycle 3 = seven months after AT. Net photosynthesis (A), transpiration (E), stomatal conductance (g_s) and internal vs. external CO_2 (C_i/C_a), were determined on the second pair of completely developed leaves. For that purpose, a 6 cm^2 chamber was conditioned with 1500 µmol photons m^{-2} s^{-1} light intensity, 500 µmol s^{-1} airflow, and 400 ppm standard CO_2 concentration (obtained with a CO_2 mixer) at room temperature, with mean temperatures varying between 25 and 30°C. Light response curves with 24 levels of PPFD from 1500 to 0 µmol m^{-2} s^{-1} allowed for Optimal photosynthetic photon flux density (PPFD) determination. Meanwhile, and on the same leaf used for gas exchange measurements, chlorophyll fluorescence was determined using a Pocket fluorimeter PEA (*Plant Efficiency Analyser*, Hansatech, England).

Leaves were dark-adapted for 30 minutes with leaf clips (Hansatech), avoiding leaf veins, so that all reaction centres were in the oxidized state. Maximum quantum yield of photosystem II (*Fv/Fm*) and the photosynthetic index (*PI*) were determined according to Strasser *et al.* (2004). Leaf green colour intensity (SPAD index), which correlates with chlorophyll content, was measured with a portable chlorophyll meter (model SPAD-502 Minolta, Japan). Mean values were obtained from eight measures per plant.

Gas exchange and chlorophyll fluorescence were measured one, three and seven months later. SPAD measurements were taken before treatments (AT) and three, five and seven months later.

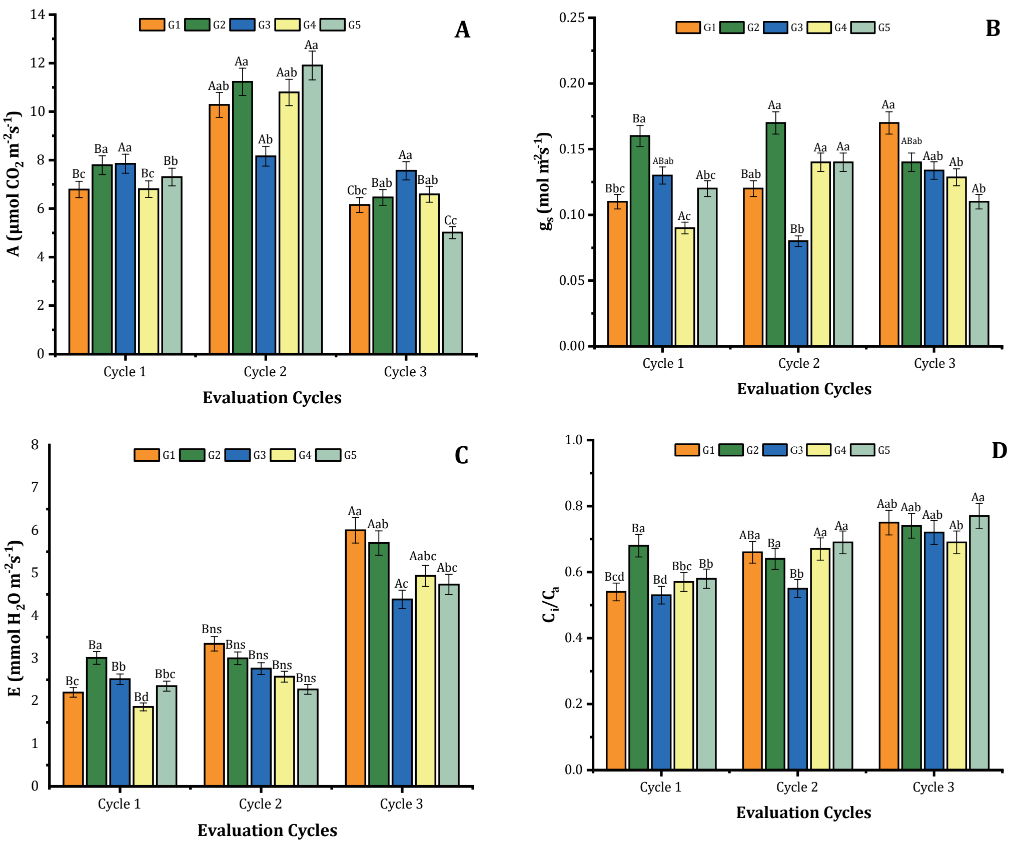
Statistical analysis

The experiment was conducted in a completely randomized design with five light gradient treatments and six replications, totalizing 30 plants. Data were subjected to ANOVA, and means were compared by Tukey test at 5% probability. Statistical analyses were performed with *R* (26).

Results and discussion

Light, gas exchange and photosynthetic capacity

Under all light gradients, air temperature and humidity were very similar, with mean temperatures varying between 25 and 30°C, and air humidity around 80%. Light spectrum varied as follows: 300 - 900 nm in G_1, 300 - 850 nm in G_2, 300 - 800 nm in G_3, 400 - 700 nm in G_4 and 400 - 750 nm in G_5. Net photosynthesis (A) varied independently of light gradient (figure 1A). At cycle 1, the highest A values were observed in G_2 and G_3, reaching approximately 8.0 µmol CO_2 m^{-2} s^{-1} (figure 1A).



Cycle 1 (one month of light treatment), cycle 2 (three months of light treatment) and cycle (seven months of light treatment).

Upper case letters compare evaluation cycles; lower case letters compare light gradients, by Tukey test (p<0.05).

Ciclo 1 (un mes de fototratamiento), ciclo 2 (tres meses de fototratamiento) y ciclo (siete meses de fototratamiento).

Letras mayúsculas comparan ciclos de evaluación; letras minúsculas comparan gradientes de luz, según la prueba de Tukey (p<0,05).

Figure 1. Net photosynthesis (*A*), stomatal conductance (g_s), transpiration (*E*) and internal vs. external concentration of CO_2 (C_i/C_a) of *Syagrus schizophylla* plants under light gradients (G_1, G_2, G_3, G_4 and G_5) and evaluation cycles.

Figura 1. Fotosíntesis neta (A), conductancia estomática (gs), transpiración (E) y concentración interna *vs.* externa de CO_2 (Ci/Ca) de plantas de *Syagrus schizophylla* bajo gradientes de luz (G1, G2, G3, G4 and G5) y ciclos de evaluación.

At cycle 2, that is, after three months of light treatment, mean A values were different among light gradients. G2 and G5 were different from G3, showing the highest rates of net photosynthesis (figure 1A, page 4). At seven months (cycle 3), higher mean values were observed in plants from G2, G3 and G4, varying between 6 and 7.5 µmol CO2 m^{-2} s^{-1} (figure 1A, page 4). Gas exchange measurements, particularly net photosynthesis, allows understanding genotype x environment photosynthetic patterns (15), constituting a reliable indicator of plant physiological status (24).

Stomatal conductance (g_s) showed statistical differences among treatments. At evaluation cycle 1, the highest mean g_s were observed in plants from G_2 and G_3 (figure 1B, page 4). At cycle 2, no significant differences were observed in G_2, G_4 and G_5. The lowest g_s was observed in G_3 (figure 1B, page 4). However, at evaluation cycle 3, mean g_s exceeded 0.11 mol m^{-2} s^{-1} regardless of light gradient (figure 1B, page 4).

While studying *S. schizophylla* palm plants, the highest g_s observed in G2, G3 (cycles 1 and 3) and G2 (cycle 2), suggested that red light somehow influences the stomatal opening. Our results might be related to light incidence and quality, resulting in fast g_s increases and responses to white light components (1). Dumont *et al.* (2013) reported that stomata are especially sensitive to blue light. In this sense, a weak but significant linear correlation between A and g_s (R = 0.45), corroborated our results. On the other hand, Lavinsky *et al.* (2014) reported that A increased 3.5 fold in *Euterpe edulis* saplings acclimated at 25.0 mols photons m^{-2} d^{-1}, in relation to understory saplings, acclimated at 1.3 mol photons m^{-2} d^{-1}, and presenting low respiration rate and rapid gas response.

Transpiration rate (*E*) of *S. schizophylla* plants showed statistical differences among light gradients at evaluation cycles 1 and 3. At evaluation cycle 1, E was highest in G_2 (figure 1C, page 4). No significant differences in E under light gradients were observed in cycle 2. At cycle 3, the highest *E* values were close to 6.0 mmol H_2O m^{-2} s^{-1} in G_1 and G_2 plants (figure 1C, page 4). Assimilation of CO_2 inevitably requires water loss (*E*), as gas diffusion rates increase with stomatal conductance (18).

Mean internal *vs.* external CO_2 ratio (C_i/C_a) of *S. schizophylla* plants showed statistical differences, with the highest C_i/C_a in G_2 plants (figure 1D, page 4). At evaluation cycle 2, mean C_i/C_a ratios in G_1, G_2, G_4 and G_5 showed no differences (figure 1D, page 4). In cycles 2 and 3, at three and seven months, mean C_i/C_a ratio increased significantly under light treatments, probably related to plant growth and development, and light quality, since gas exchange is maximized under blue (400-500 nm) and red (600-700 nm) lights (25). In this study, *S. schizophylla* plants showed different responses under different shading, stating a species-dependent need to use shade nets.

Cycles 1 and 2 showed no statistical differences among F_v/F_m (figure 2A, page 6). In contrast, cycle 3 resulted in F_v/F_m significant differences among G_2 (lower value) and G_5 (higher value) plants, all exceeding 0.75 (figure 2A, page 6). These results suggest that despite the light treatment, *S. schizophylla* did not suffer photoinhibition, in accordance with Bolhàr-Nordenkampf *et al.* (1989) who reported that F_v/F_m varied from 0.75 to 0.85 in plants with intact photosynthetic apparatus. These authors state that photoinhibitory damage on PSII reaction centres causes decreased F_v/F_m. Lavinsky *et al.* (2014) reported that *E. edulis* acclimated to understory conditions showed a steep drop in F_v/F_m, from 0.8 to 0.5, during the first week after being transferred to a more luminous environment. After 21 days of re-acclimation, F_v/F_m increased, and at 110 days it was almost re-established to the initial value (0.7). Another study also observed that stressed plants tend to decrease F_v/F_m values, dissipating the exceeding energy and preventing photoinhibition (12). In accordance with our findings, other authors found decreased F_v/F_m and photosynthetic index (*PI*) in cucumber plants exposed to red light (19, 20, 27). Osório *et al.* (2012) also state low F_v/F_m for photosynthesis, photochemical efficiency and photoinhibition studies.

Regarding photochemical efficiency, the photosynthetic index (*PI*) showed interaction among treatments. The highest *PI* value at cycle 1 exceeding 6, was observed in plants from G_1, while other treatments had *PI* values under 4.5 (figure 2B, page 6). At evaluation cycle 2, the highest values were observed in G_1, G_3 and G_5 (figure 2B, page 6). Cycle 3, showed no significant differences among *PI* in G_1, G_3, G_4 and G_5, varying from 3.5 to 4.5 (figure 2B, page 6). Finally, excepting G_5 plants, *PI* of *S. schizophylla* plants decreased along cycles, probably given by light stress (13).

Upper case letters compare evaluation cycles; lower case letters compare gradients by Tukey test ($p < 0.05$).

*ns = non-significant ($p < 0.05$).

Las letras mayúsculas comparan los ciclos de evaluación; las letras minúsculas comparan gradientes mediante la prueba de Tukey ($p < 0,05$).

* ns = no significativo ($p < 0,05$).

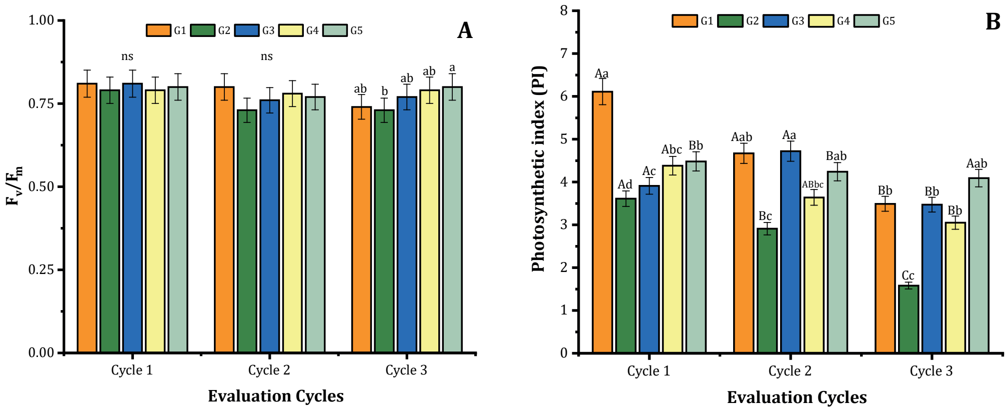


Figure 2. Maximum quantum yield of photosystem II (F_v/F_m) and photosynthetic index (*PI*) of *Syagrus schizophylla* plants under light gradients (G_1, G_2, G_3, G_4 e G_5) at evaluation cycles 1 (one month of light treatment), 2 (three months of light treatment) and 3 (seven months of light treatment).

Figura 2. Rendimiento cuántico máximo del fotosistema II (Fv/Fm) e índice fotosintético (PI) de plantas de *Syagrus schizophylla* bajo gradientes lumínicos (G1, G2, G3, G4 y G5) en los ciclos de evaluación 1 (a un mes de tratamiento con luz), 2 (a los tres meses de tratamiento con luz) y 3 (a los siete meses de tratamiento con luz).

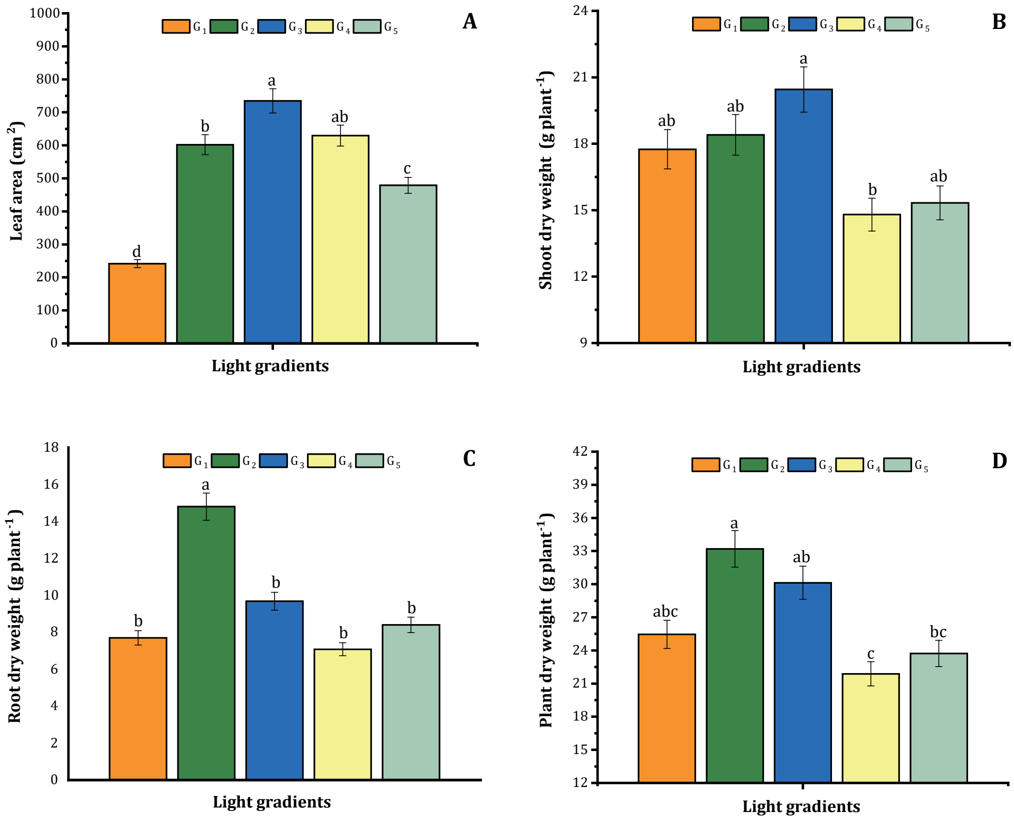
Plant growth and development as a function of light

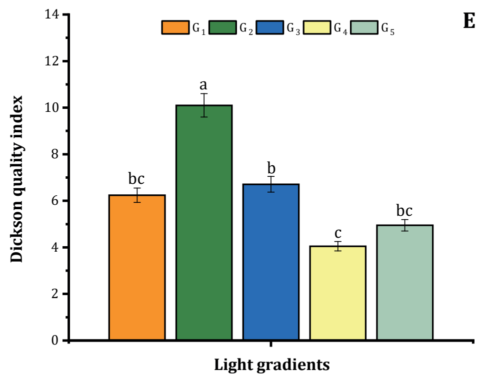
Total leaf area was higher in G_2, G_3 and G_4, followed by G_5 and G_1 plants; the latter presenting the smallest leaf area, 250 cm^2 (figure 3A, page 7). Similarly, Gatti *et al.* (2011) observed decreasing leaf area of *E. edulis* plants as light intensity increased.

Significant differences were only observed among shoot dry weights in G_3 and G_4 (figure 3B, page 7). However, the highest root dry weight, 14.5 g $plant^{-1}$, was observed in G_2 (figure 3C, page 7). Mean plant dry weight under G_2 exceeded 33 g $plant^{-1}$ (the highest mean), while the lowest mean was 22.5 g $plant^{-1}$, in G_4 (figure 3D, page 7).

The highest Dickson quality index (DQI) was observed under G_2 (above 10.0); followed by G_3, G_1, G_5 and G_4 plants, in decreasing order and ranging from 7.0 to 4.0 (figure 3E, page 7). DQI is considered a good parameter for quality assessment in nursery plants, considering the amount and even the distribution of phytomass, pondering different parameters that help estimate plant performance in the field (9). De Oliveira *et al.* (2009) observed DQI ranging from 2.29 to 2.77 for *Copernicia hospita* seedlings after three months of growth, and values from 15.78 to 20.70 after nine months of growing in different-size containers under plain sunlight. For *B. capitata,* Costa *et al.* (2018) recommended red shade nets, inducing stomatal and leaf anatomical changes enhancing light harvesting, photosynthesis and plant growth and development. *B. capitata* plants grown under red shade net (50%) showed higher biomass than plants from other shade treatments (4).

The present research suggests that red shade nets contribute to increased plant growth rates and vigour of *S. schizophylla* by enhancing photosynthetic efficiency. Moreover, gas exchange, growth and development of *S. schizophylla* plants throughout the experiment with light gradients generated valuable information in relation to productivity. Plants exposed to a greater amount of light had greater biomass. Additionally, in G_2, a higher DQI suggested this index may also predict plant survival after field transplanting and/or shade environments. The results not only confirm that this species is tolerant to light variations but also suggest it undergoes acclimation, optimizing resource allocation through structural and physiological adaptations.





Different letters indicate significant differences for Tukey test ($p < 0.05$).

*ns = non-significant ($p < 0.05$).

Diferentes letras indican diferencias significativas según la prueba de Tukey ($p < 0,05$).

* ns = no significativo ($p < 0,05$).

Figure 3. Leaf area (A), shoot dry weight (B), root dry weight (C), plant dry weight (D), Dickson quality index (E) of *Syagrus schizophylla* plants at seven months under different light gradients (G_1, G_2, G_3, G_4 and G_5).

Figura 3. Área foliar (A), peso seco del brote (B), peso seco de la raíz (C), peso seco de la planta (D), índice de calidad de Dickson (E) de plantas de *Syagrus schizophylla* bajo diferentes gradientes de luz (G1, G2, G3, G4 y G5) a los siete meses de tratamiento.

Conclusions

One layer of Red Chromatinet® 50% should be recommended for the first year of growth of *S. schizophylla* plants to be later transplanted to the field. Two Red Chromatinet® 50% layers would be best for plants meant to grow under shade environments.

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