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Translated from the original in spanish **Original article**

Photosynthetic response of Guadua angustifolia Kunth and Bambusa vulgaris Schrad. former J.C. Wendl. at different light intensities

Respuesta fotosintética de Guadua angustifolia Kunth y Bambusa vulgaris Schrad. ex J.C. Wendl. a diferentes intensidades de luz

Resposta fotossintética de Guadua angustifolia Kunth e Bambusa vulgaris Schrad. ex-J.C. Wendl. em diferentes intensidades de luz

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ABSTRACT

Photosynthetic response studies at different light intensities facilitate understanding plant physiology, optimizing management and sustainable use of species. The purpose of the research was to evaluate the photosynthetic response of G. angustifolia and B. vulgaris at different light intensities. Photosynthetic assimilation measurements were performed using a portable iFL - LCpro-SD system. The compensation point (Γ^*) was determined by three A/Ci curves under three different light intensity levels. The evaluation of the photosynthetic response to increasing light intensity was from 25 to 1800 PPFD µmol m-2s-1. G. angustifolia presented a Γ^* of 73.9 µmol CO_2 $m^{-2}s^{-1}$, indicating higher carbon capture efficiency at lower concentrations compared to B. vulgaris, which showed a Γ^* of 88.1 µmol CO_2 $m^{-2}s^{-1}$. Furthermore, G. angustifolia exhibited a lower diurnal respiration rate (Rd) (0.33 µmol CO_2 $m^{-2}s^{-1}$), which optimizes its energy efficiency, while B. vulgaris presented a higher Rd (1.08 µmol CO_2 $m^{-2}s^{-1}$), implying higher energy consumption under low light intensity conditions. G. angustifolia did not show photoinhibition, as its photosynthetic assimilation rate increased continuously with light. In contrast, B. vulgaris experienced photoinhibition starting at 700 µmol $m^{-2}s^{-1}$ of PPFD. These findings show that G. angustifolia is better adapted to capture carbon under conditions of low CO_2 concentrations and high light intensities, while B. vulgaris seems to be better adapted to environments with higher CO_2 concentrations.

Keywords: gas exchange, bamboo, ecophysiology, ecology.

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RESUMEN

Los estudios de respuesta fotosintética a diversas intensidades lumínicas facilitan comprender la fisiología vegetal, optimizar el manejo y aprovechamiento sostenible de las especies. La investigación tuvo como fin evaluar la respuesta fotosintética de *G. angustifolia* y *B. vulgaris* a diferentes intensidades de luz. Las mediciones de asimilación fotosintética se realizaron utilizando un sistema portátil iFL - LCpro-SD. El punto compensación ($\Gamma*$) se determinó mediante tres curvas A/Ci bajo tres niveles diferentes de intensidad lumínica. La evaluación de la respuesta fotosintética al incremento en la intensidad de luz fue de 25 a 1800 PPFD µmol $m^{-2}s^{-1}$. *G. angustifolia* presentó un $\Gamma*$ de 73.9 µmol CO_2 $m^{-2}s^{-1}$, indicando mayor eficiencia en la captura de carbono a concentraciones más bajas en comparación con *B. vulgaris*, que mostró un $\Gamma*$ de 88.1 µmol CO_2 $m^{-2}s^{-1}$. Además, *G. angustifolia* exhibió una menor tasa de respiración diurna (R_d) (0.33 µmol CO_2 $m^{-2}s^{-1}$, lo que optimiza su eficiencia energética, mientras que *B. vulgaris* presentó una R_d más alta (1.08 µmol CO_2 $m^{-2}s^{-1}$, lo que implica mayor consumo de energía en condiciones de baja intensidad lumínica. *G. angustifolia* no mostró fotoinhibición, ya que su tasa de asimilación fotosintética aumentó continuamente con la luz. En contraste, *B. vulgaris* experimentó fotoinhibición a partir de 700 µmol $m^{-2}s^{-1}$ de PPFD. Estos hallazgos evidencian que *G. angustifolia* está mejor adaptada para capturar carbono en condiciones de baja concentraciones de CO_2, y altas intensidades de luz, mientras *B. vulgaris* parece adaptarse mejor a ambientes con mayor concentración CO_2.

Palabras clave: Intercambio de gases, bambú, ecofisiología, ecología

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RESUMO

Estudos da resposta fotossintética a diversas intensidades luminosas facilitam o entendimento da fisiologia vegetal, otimizam o manejo e o uso sustentável das espécies. O objetivo da pesquisa foi avaliar a resposta fotossintética de *G. angustifolia* e *B. vulgaris* a diferentes intensidades luminosas. As medidas de assimilação fotossintética foram realizadas utilizando um sistema portátil iFL - LCpro-SD. O ponto de compensação ($\Gamma*$) foi determinado usando três curvas A/Ci sob três níveis diferentes de intensidade de luz. A avaliação da resposta fotossintética ao aumento da intensidade luminosa foi de 25 a 1800 PPFD µmol $m^{-2}s^{-1}$. *G. angustifolia* apresentou Γ^* de 73,9 µmol CO_2 $m^{-2}s^{-1}$, indicando maior eficiência na captura de carbono em concentrações mais baixas em comparação com *B. vulgaris*, que apresentou Γ^* de 88,1 µmol CO_2 $m^{-2}s^{-1}$. Além disso, *G. angustifolia* exibiu menor taxa de respiração diurna (R_d) (0,33 µmol CO_2 $m^{-2}s^{-1}$, o que otimiza sua eficiência energética, enquanto *B. vulgaris* apresentou maior R_d (1,08 µmol CO_2 $m^{-2}s^{-1}$, o que implica maior consumo de energia em condições de baixa intensidade luminosa. *G. angustifolia* não apresentou fotoinibição, pois sua taxa de assimilação fotossintética aumentou continuamente com a luz. Em contraste, *B. vulgaris* experimentou fotoinibição de 700 µmol $m^{-2}s^{-1}$ PPFD. Essas descobertas mostram que *G. angustifolia* está melhor adaptada para capturar carbono em condições de baixas concentrações de CO_2 e altas intensidades luminosas, enquanto *B. vulgaris* parece se adaptar melhor a ambientes com maiores concentrações de CO_2.

Palavras-chave: trocas gasosas, bambu, ecofisiologia, ecologia.

INTRODUCTION

Photosynthesis is a biological process essential for plant life and plays a crucial role in the evolution and balance of ecosystems (Yang *et al.*, 2018). Through this physiological process, plants, algae and certain groups of bacteria transform light energy into chemical energy, which is stored in the form of carbohydrates, mainly as glucose. (Liu and van Iersel 2021; Xu *et al.*, 2024; Zhang and Ye 2021) This process is not only essential for plant growth and development, but also plays a fundamental role in regulating the global carbon cycle, by contributing significantly to the absorption of atmospheric carbon dioxide (Stojanović *et al.*, 2024; Kulsirilak *et al.*, 2024).

The efficiency of photosynthesis is influenced by various environmental factors, among which light intensity stands out as one of the most determining factors (Su, Jin and Wei 2024; Daryaei , Sohrabi and Puerta-Piñero 2019). Understanding how plants respond to different levels of illumination is essential to optimize agricultural and forest management practices, especially in species of high economic and ecological relevance such as *G. angustifolia* and *B. vulgaris.*

In this context, both bamboo species have aroused great interest in the scientific community, due to their potential to contribute to environmental sustainability, restoration of degraded soils and generation of renewable resources (Díaz, González-Martínez and Pérez 2021; Asante *et al.*, 2024). These plants are known for their rapid growth, carbon storage capacity, and wide range of applications, from sustainable construction to paper and biofuel production (Aguirre-Cadena *et al.*, 2018; Sapuyes *et al.*, 2018; Orozco Gutiérrez and Cesar de Lira Fuentes 2020). In addition, *G. angustifolia* plays an important role in soil conservation and water management in the regions where it is cultivated (Piedrahíta *et al.*, 2019).

Studies of photosynthetic response to different light intensities not only contribute to a better understanding of plant physiology, but also offer valuable information for their management and sustainable use (Daryaei , Sohrabi , and Puerta-Piñero 2019; Su, Jin, and Wei 2024). Cao *et al.* (2024) pointed out that drought stress decreases photosynthesis in *Phyllostachys edulis,* limiting its ability to efficiently exploit intense light. In this sense, this work aims to evaluate the photosynthetic response of *G. angustifolia* and *B. vulgaris* to different light intensities, providing a scientific basis to understand cultivation practices and maximize the ecological and economic benefits of these species.

MATERIALS AND METHODS

Area of study

The research was carried out at the Amazonian Experimental Research and Production Center - CEIPA of the Amazon State University, located in Arosemena de Tola, Napo province, Ecuador (Figure 1). The center has an area of 2,848 hectares, of which at least 2,000 are native forest. The region is characterized by a warm and humid climate, with an average annual temperature ranging between 24°C and 25°C. The average annual rainfall reaches

4,000 mm. The altitude varies between 580 and 990 meters above sea level and the relative humidity is 80 %.

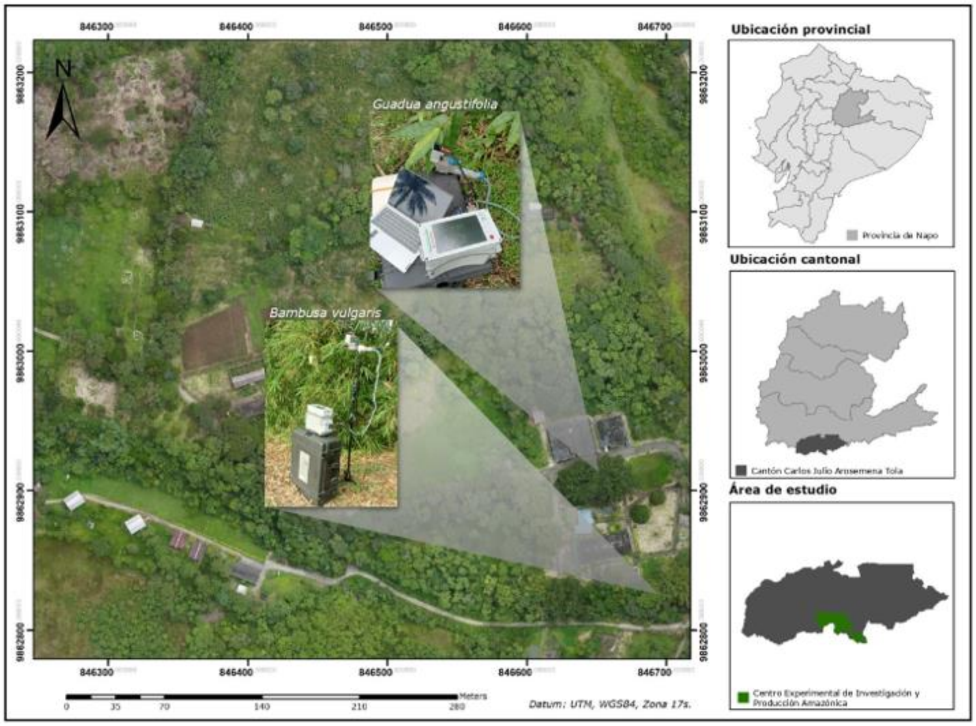

Figure 1. *- Study area*

Photosynthetic parameter measurements

Photosynthetic assimilation measurements of *G. Angustifolia* and *B. vulgaris* were performed using a portable integrated photosynthesis and chlorophyll fluorescence measurement system (iFL - LCpro -SD) with fully programmable microclimate control, developed by Opti-Sciences Inc. and ADC BioScientific Ltd. (UK). This system is equipped with a high-intensity actinic white light source, with a predominantly blue spectrum, facilitating chloroplast migration comparable to natural conditions. The iFL reaches a maximum light output of 2,000 µmol m^{-2} s^{-1}. In addition, it has an integrated system to measure leaf absorption, using an RGB (red, green, blue) sensor to assess leaf reflectance and transmittance. It also includes an infrared (IR) temperature sensor, covering approximately 80 % of the chamber area, recording the following photosynthetic variables (Table 1).

***Table 1. -** Definitions of abbreviations for photosynthetic parameters*

Abbreviation	Definition	Units
PPFD	Photosynthetic photon flux density	μmol m $^{-2}$ s $^{-1}$
TO	Photosynthetic assimilation	μmol CO_2 m $^{-2}$ s $^{-1}$
A_{max}	Maximum photosynthetic assimilation	μmol CO_2 m $^{-2}$ s $^{-1}$
Ci	Intracellular $_{CO2}$ concentration	μmol CO_2 m $^{-2}$ s $^{-1}$
DC	$_{CO2}$ concentration in chloroplasts	μmol CO_2 m $^{-2}$ s $^{-1}$
AND	Transpiration rate	mmol m $^{-2}$ s $^{-1}$
Gs	Stomatal conductance	mol m $^{-2}$ s $^{-1}$
┌ *	$_{CO2}$ compensation point	μmol CO_2 m $^{-2}$ s $^{-1}$
R_d	Daytime breathing	μmol CO_2 m $^{-2}$ s $^{-1}$
ETR	Electron transport rate	μmol m $^{-2}$ s $^{-1}$
ETR_{max}	Maximum electron transport rate	μmol m $^{-2}$ s $^{-1}$

Determining the compensation point (┌ *)

Measurements for the determination of ┌ * were performed following the methodology described by Laisk (1977), with some adjustments introduced by the authors (see Table 2). The experiment consisted of generating three A/Ci curves under three different levels of light intensity. At each level, the CO_2 concentration was progressively increased, maintaining the temperature and humidity at ambient conditions. ┌ * is defined as the minimum light intensity at which the photosynthesis rate of a plant equals the respiration rate. At this point, the amount of oxygen produced by photosynthesis is equivalent to the amount of oxygen consumed by respiration, and similarly, the amount of CO_2 absorbed during photosynthesis is equal to the amount released in respiration (Schmiege *et al.,* 2023).

***Table 2. - Characteristics of the** Laisk protocol*

No.	Time (min)	Light intensity (µmol m $^{-2}$ s $^{-1}$)	$_2$ concentration (µmol m $^{-2}$ s $^{-1}$)	Humidity (%)	Temperature (°C)
1	4	200	115	Environmental	Environmental
2	2	200	160	Environmental	Environmental
3	2	200	205	Environmental	Environmental
4	2	200	250	Environmental	Environmental
5	4	400	115	Environmental	Environmental
6	2	400	160	Environmental	Environmental
7	2	400	205	Environmental	Environmental
8	2	400	250	Ambiental	Ambiental
9	4	600	115	Ambiental	Ambiental
10	2	600	160	Ambiental	Ambiental
11	2	600	205	Ambiental	Ambiental
12	2	600	250	Ambiental	Ambiental

Photosynthetic response to increased light intensity

The data collection of photosynthesis in response to different light intensities followed the methodology proposed by Ávila-Lovera & Tezara, (2018); Cao *et al.* (2024) and Zhang *et al.* (2023) with adjustments to the PPFD proposed by the authors. Healthy leaves of *G. angustifolia* and *B. vulgaris* were measured, without malformations or insect damage. 5 replicates were carried out in the morning hours between 8:00 and 11:00 a.m. for ten completely clear days, the temperature was set at 30 °C, the relative humidity 80 % and the atmospheric concentration of CO_2 at 450 µmol m $^{-2}$ s $^{-1.}$ The increase in light intensity was from 25 to 1800 PPFD µmol m $^{-2}$ s $^{-1.}$ The light increment sequence was programmed in 12 steps (25, 50, 100, 150, 250, 450, 600, 750, 1000, 1250, 1500 and 1800 PPFD µmol m $^{-2}$ s $^{-1)}$ with a duration of four minutes for each data collection with a total experiment duration of 48 minutes for each replicate.

Data processing and analysis

Data from the photosynthetic response curves at different light intensities of *G. angustifolia* and *B. vulgaris* were analyzed using descriptive statistics. Additionally, an adjustment was made using the Rectangular Hyperbola model, implemented in the SigmaPlot 15.0 software (Kieffer *et al.,* 2024). An analysis of variance (ANOVA) was performed to determine significant differences in the photosynthetic parameters A_{max}, E, Gs, Ci, Cc and ETR_{max} between the species under study using the OriginLab 2024 software.

RESULTS

Determining the Compensation Point ($\Gamma*$)

In Figures 2a and 2b, significant differences were evident in the $\Gamma*$ and R_d of *G. angustifolia* and *B. vulgaris.* The first species showed a $\Gamma*$ of 73.9 µmol CO_2 m^{-2} s^{-1}, suggesting a higher efficiency in CO_2 capture at lower concentrations compared to *B. vulgaris,* whose $\Gamma*$ of 88.1 µmol CO_2 m^{-2} s^{-1} indicates that it requires higher concentrations of CO_2 to balance its photosynthesis and respiration rates. Regarding R_d, G. *angustifolia* exhibited a value of 0.33 µmol CO_2 m^{-2} s^{-1}, indicating a lower release of CO_2 in the absence of light and a higher energetic efficiency. In contrast, *B. vulgaris* showed a higher R_d 1.08 µmol CO_2 m^{-2} s^{-1}, implying a higher energy consumption under low light conditions, potentially limiting its efficiency in reduced light environments.

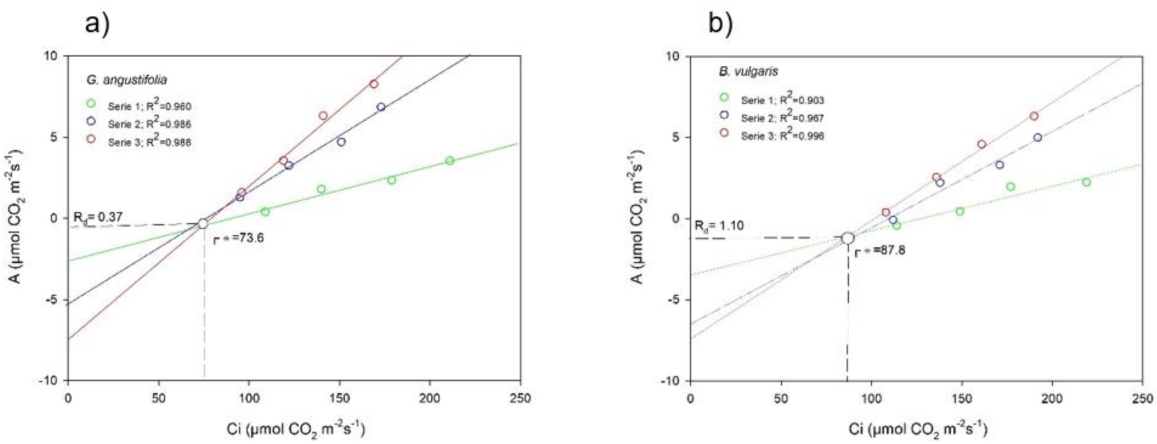

Figure 2. *- Compensation point of the species under study; G. angustifolia (a); B. vulgaris (b).*

Legend: *Photosynthetic assimilation (A); Intracellular* CO_2 *concentration (Ci);* CO_2 *compensation point (* Γ^* *); Diurnal respiration (* R_d *).*

Photosynthetic response to increased light intensity

In Figure 3a and 3b, the curves of photosynthetic assimilation in response to light are presented. Under low light intensity conditions (PPFD: 25, 50, 100, 150 µmol CO_2 m^{-2} s^{-1}), no significant differences were evident ($p>0.05$). However, from 250 µmol m^{-2} s^{-1} of PPFD, significant differences were observed between both species. *G. angustifolia* did not show photoinhibition, since the assimilation rate continued to increase with light. In contrast, *B. vulgaris* experienced photoinhibition starting at 700 µmol m^{-2} s^{-1} of PPFD, with a maximum assimilation rate of 12.84 µmol CO_2 m^{-2} s^{-1}. These results highlight the greater tolerance of *G. angustifolia* to high light intensities, compared to *B. vulgaris*, whose photosynthesis is limited by photoinhibition at high light intensities.

In Figure 3c and 3d, the electron transport rate (ETR) is shown in response to different light intensities, which allowed to evaluate the efficiency of electron transport in chloroplasts, essential for the generation of energy during the light phase of the photosynthetic process, where *G. angustifolia* presented a higher ETR showing significant differences ($P < 0.05$) from 1000 µmol m^{-2} s^{-1} of PPFD with an ETR of 173.9 ± 8.81 µmol m^{-2} s^{-1}, while *B. vulgaris* showed an ETR of 129.13 ± 4.08 µmol m^{-2} s^{-1}.

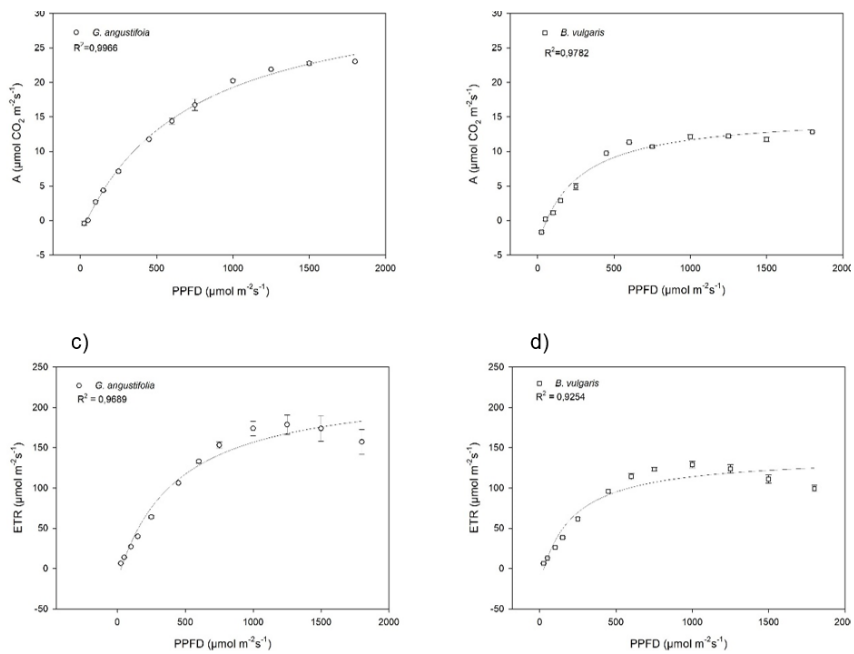

Figure 3. *- Response curves of photosynthetic assimilation and electron transport under different light intensities; G. angustifolia (ayc); B. vulgaris (byd).*

Legend: *Photosynthetic assimilation (A); Electron transport rate (ETR); Photosynthetic photon flux density (PPFD).*

G. angustifolia reached a maximum photosynthetic assimilation (A_{max}) of 23.06 ± 0.11 µmol CO_2 m^{-2} s^{-1}, significantly higher compared to *B vulgaris,* which presented an A_{max} of 12.84 ± 0.06 µmol CO_2 m^{-2} s^{-1} ($p < 0.05$). This suggests a higher photosynthetic efficiency in *G. angustifolia,* possibly due to its better adaptation to more intense light conditions or its greater capacity to take advantage of available solar energy. Regarding stomatal conductance (Gs), which measures the efficiency of stomata in gas exchange, *G. angustifolia* also showed a significantly higher value (Gs = 0.26 mol m^{-2} s^{-1}, $p < 0.05$) compared to *B. vulgaris* (Gs = 0.13 mol m^{-2} s^{-1}). This higher stomatal conductance suggests that *G. angustifolia* is more efficient in regulating stomatal opening, allowing it to optimize both CO_2 entry and the regulation of water loss through transpiration (Table 2).

Regarding the maximum electron transport performance (ETR_{max}), *G. angustifolia* reached its ETR_{max} at an irradiance of 1250 µmol m^{-2} s^{-1} of PPFD, while *B. vulgaris* reached it at 1000 µmol m^{-2} s^{-1} of PPFD. This indicates that *G. angustifolia* can handle high light intensities without experiencing photoinhibition, while *B. vulgaris* seems to reach its limit earlier, which could explain its lower photosynthetic rate under high irradiance conditions. In contrast, other parameters such as transpiration rate (E), intracellular CO_2 concentration (Ci) and CO_2 concentration in chloroplasts (Cc) did not show significant differences between the two species, suggesting that the observed differences in photosynthesis may be more related to light management capacity and CO_2 use efficiency than to the control of transpiration or CO_2 accumulation within photosynthetic tissues (Table 3).

These results demonstrate the ability of *G. angustifolia* to thrive in high irradiance environments, which could be key to its success under high light intensity conditions, where efficient photosynthesis and stomatal regulation play a crucial role in its productivity.

Table 3. - *Photosynthetic parameters of the species under study*

Parameters	***G. angustifolia***	***B. vulgaris***
A_{max} (µmol CO_2 m^{-2} s^{-1})	$23.06^a \pm 0.11$	$12.84^b \pm 0.06$
E (mmol $m^{-2}s^{-1}$)	$2.12^a \pm 0.15$	$2.22^a \pm 0.15$
Gs (mol $m^{-2}s^{-1}$)	$0.26^a \pm 0.02$	$0.13^b \pm 0.01$
Ci (µmol CO_2 $m^{-2}s^{-1}$)	$328^a \pm 11$	$315^a \pm 11$
Cc (µmol CO_2 $m^{-2}s^{-1}$)	238th ± 14	254th ± 16
ETR_{max}	$178.63^a \pm 11.88$	$129.13^b \pm 4.08$

Legend: *Maximum assimilation (A_{max}); Transpiration rate (E); Stomatal conductance (Gs); Intracellular CO2 concentration (Ci); CO2 concentration in chloroplasts (Cc); Electron transport rate (ETR).*

DISCUSSION

Determining the CO_2 compensation point is crucial to understanding plant physiology, as it represents the balance between photosynthesis and respiration (Schmiege *et al.*, 2023). At this point, CO_2 uptake during photosynthesis equals the amount of CO_2 released in respiration, reflecting the efficiency of light and carbon use by the plant (Cao *et al.*, 2024).

Knowing this threshold allows for optimizing growth conditions and predicting plant responses to environmental factors such as light intensity and CO_2 concentrations.

Previous studies have investigated Γ * and R d in various species, highlighting their importance in adaptation to different light levels and CO availability. ₂ (Ye et al. 2013; Shao *et al.,* 2009; Cocozza *et al.,* 2016) Other research have reported that species adapted to shaded environments have lower compensation points and lower respiration rates, which optimizes energy efficiency under these conditions *(*Bögelein *et al.,* 2012; Ghashghaie *et al.,* 2003) Species under adverse light conditions experience limited development due to reduced photosynthetic capacity. Lack of adequate light decreases the rate of CO_2 assimilation, leading to lower energy production and greater reliance on respiration, which can compromise plant growth and survival in environments with low light availability.

Comparison between *G. angustifolia* and *B. vulgaris* in terms of photosynthetic response under different light intensities reveals significant differences in their adaptation to high light conditions. In this study, *G. angustifolia* did not show photoinhibition even at high PPFD levels, maintaining a continuous increase in the photosynthetic assimilation rate. In contrast, *B. vulgaris* experienced photoinhibition starting from 700 µmol m^{-2} s^{-1} of PPFD, which limited its maximum photosynthetic assimilation to 12.84 µmol CO_2 m^{-2} s^{-1}.

These results are consistent with previous studies pointing to photoinhibition as a common phenomenon in plants exposed to high light intensities, where the photosynthetic capacity is overwhelmed by excess light energy, negatively affecting photosynthesis. (Genty, Briantais y Baker 1989; Azcón Bieto *et al.,* 2008) In *B. vulgaris,* photoinhibition could be related to a lower capacity to dissipate excess light in the form of heat or other forms of non-photochemical energy. On the other hand, the resistance of *G. angustifolia* to photoinhibition could be due to more efficient mechanisms of regulating excess light, such as non-photochemical photoprotection (NPQ) or a higher capacity for electron transport (Demmig -Adams and Adams 1992; Cocozza *et al.,* 2016)

Studies on other bamboo species have also documented significant variation in photosynthetic responses to different light intensities, reflecting differential adaptation to growing environments. For example, *Phyllostachys edulis* showed a decrease in photosynthetic rate when exposed to high light levels, suggesting a lower tolerance to photoinhibition compared to species such as *G. angustifolia* (Cao *et al.*, 2024). This ability of *G. angustifolia* to maintain high rates of photosynthesis under high irradiance conditions makes it more suitable for use in open or exposed environments, where light is an abundant resource.

In physiological terms, the higher tolerance of *G. angustifolia* to high irradiance can be explained by a higher efficiency in light use, an efficient stomatal adjustment, and a higher electron transport capacity, which allows it to avoid the photooxidative damage that normally occurs under conditions of excess light (Ralph and Gademann 2005). These characteristics make it more efficient in carbon capture and, therefore, better adapted to high light conditions compared to *B. vulgaris*.

CONCLUSIONS

Determination of the CO_2 compensation point and photosynthetic response of *G. angustifolia* and *B. vulgaris* under different light intensities revealed key physiological differences between these two species. *G.angustifolia* showed a lower CO_2 compensation point (73.9 µmol CO2 $_{m}$ - ^{2} s $^{-1}$) compared to *B. vulgaris* (88.1 µmol CO2 $_{m}$ - ^{2} s $^{-1}$), suggesting that the former is more efficient in carbon assimilation at low CO_2 concentrations. Furthermore, *G. angustifolia* demonstrated higher tolerance to high light, with no signs of photoinhibition, whereas *B. vulgaris* experienced photoinhibition at 700 µmol m^{-2} s^{-1} of PPFD, reducing its photosynthetic efficiency under high irradiance conditions.

The maximum photosynthetic assimilation rate (A_{max}) was also higher in *G. angustifolia* (23.06 µmol CO_2 m^{-2} s^{-1}), indicating its greater capacity to capture carbon, while *B. vulgaris* reached an A_{max} of 12.84 µmol CO_2 m^{-2} s^{-1}. These differences in photosynthesis reflect species-specific adaptations to their environment. Therefore, these findings show that *G. angustifolia* is better adapted to capture carbon under conditions of low CO_2 and high light intensities, while *B. vulgaris,* although requiring more energy to maintain its respiratory functions, might be better adapted to environments with higher CO_2 concentrations.

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Conflicts of interest:

The authors declare not to have any interest conflicts.

***Contribution of the authors*:**

The authors have participated in the writing of the work and analysis of the documents.