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Photosynthetic pigments and gas exchange in castor bean under conditions of above the optimal temperature and high CO_2

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ABSTRACT. The castor bean plant, a Euphorbiaceae oil seed C_3-metabolism rustic and drought-resistant plant, is cultivated in a wide range of environments due to its good adaptive capacity. However, given the current environmental changes, many biochemical and physiological impacts may affect the productivity of important crops, such as castor bean. This work aimed to evaluate the impacts of the castor bean gas exchange in response to high temperature and increased CO_2 concentration. Our experiment was conducted in a phytotron located at Embrapa Algodão in 2010. We adopted a completely randomized design, with four treatments in a factorial combination of two temperatures (30/20 and 37/30°C) and two CO_2 levels (400 and 800 μmol L^{-1}); four replications were performed, obtained in five surveys over the growth cycle, for a total of 80 sample units. An infrared gas analyzer (IRGA - Infra Red Gas Analyzer) was used for the quantification of the photosynthetic rate, stomatal conductance and transpiration. An increase in the atmospheric CO_2 concentration and temperature negatively affected the physiology of the castor bean plants, decreasing the net rate of photosynthesis, transpiration and stomatal conductance.

Keywords: castor bean, climate change, gas exchange, photosynthesis, chlorophyll.

Trocas gasosas e teor de pigmentos fotossintetizantes de *Ricinus communis* L. sob temperatura supra-ótima e elevado nível de CO_2

RESUMO. A mamoneira, uma Euphorbiaceae oleaginosa de metabolismo $C_{3,}$ rústica, resistente à seca, é cultivada numa ampla latitude por apresentar boa capacidade adaptativa. Entretanto, diante das mudanças ambientais em curso, muitos impactos bioquímicos e fisiológicos podem interferir na produtividade de culturas importantes, como a mamona.Assim, objetivou-se avaliar impactos a nível de trocas gasosas na mamoneira em resposta à alta temperatura e incremento da concentração de CO_2. O experimento foi conduzido em câmara controlada (Fitotron) localizado na Embrapa Algodão, no ano de 2010. Adotou-se o delineamento inteiramente casualizado, com quatro tratamentos, em combinação fatorial de duas temperaturas (30/20 e 37/30ºC) e dois níveis de CO_2 (400 e 800 μmol L^{-1}), com quatro repetições, obtidas em cinco coletas ao longo do ciclo, totalizando 80 unidades amostrais. Procedeu-se à quantificação da taxa fotossintética, transpiratória e condutância estomática utilizando um analisador Infravermelho de Gás (IRGA-*Infra Red Gas Analyzer*). O aumento da concentração de CO_2 atmosférico e a elevação da temperatura afetou negativamente a fisiologia da mamoneira, a qual apresentou redução da taxa de fotossíntese líquida, transpiração e condutância estomática.

Palavras-chave: mamoneira, mudanças climáticas, trocas gasosas, fotossíntese, clorofila.

Introduction

Castor bean (*Ricinus communis* L.), a tropical oil plant of high importance, is a member of Euphorbiaceae, with an origin credited to Africa, specifically Ethiopia (BELTRÃO et al., 2006; PACHECO, 2008). Its ease of propagation and adaptation make its commercial culture favorable in a wide range of regions of the world, between latitudes 40°N and 52ºS (BELTRÃO et al., 2007; DRUMOND et al., 2008; PACHECO, 2008). From the point of view of agriculture and industry, all of the parts of castor bean plants can be used, particularly its main products and oil meal (BELTRÃO et al., 2003; PACHECO, 2008).

The castor bean plant to be an essentially tropical, drought tolerant and demanding in the heat and light, is dependent on their production and income, more than any other culture, environmental conditions (PACHECO, 2008). However, the interaction between the temperature and light intensity may affect the seed size and composition (BELTRÃO; SILVA, 1999; PACHECO, 2008). Indeed, temperatures below 16°C significantly reduce the metabolism of the culture and can stop the growth of the plants (PACHECO, 2008).

According to Hendry and Price (1993), the determination of the content of photosynthetic pigments can be an important tool in the diagnosis of stress, and heat stress in plants is closely related to water stress and light (LARCHER, 2000). Therefore, excessive irradiation is capable of overloading the photosynthetic apparatus, causing photoinhibition and the formation of compounds detrimental to metabolic processes (ROS). In addition to causing cellular damage via ROS, excessive irradiation can also degrade the photosynthetic pigments and compromise the integrity of cellular membrane (NETTO, 2009; SCANDALIOS, 1993; TAIZ; ZEIGER, 2009).

The importance of interactions between the climate and agricultural production is well known and, due to the current climate change, has generated worldwide attention. Despite the recent technological advances, agricultural production still suffers from the negative impacts of climate change on productivity, and the relationship is quite complex (ORTOLANI; TARIFA, 1978). Within this context, the objective of this study was to assess the impacts of high temperature and increases in CO_2 levels on the gas exchange (photosynthesis, transpiration and stomatal conductance) and photosynthetic pigment content of castor bean plants.

Material and methods

The experiment was conducted in 2010 under controlled conditions in growth chambers (phytotrons) installed at the Laboratory of Plant Physiology at the National Center for Research on Cotton (Embrapa Algodão), located in Campina Grande, Paraiba State. Each phytotron has dimensions of 3.10 m length x 1.90 m width x 2.50 m height, and the interior is white for a better utilization of light. The light source consisted of fluorescent (40 W) and incandescent (100 W) lamps at a 4:1 ratio, providing a total of 400.68 W m^2. The air inside the chamber was supplemented with 400 and 800 μmol mol L^{-1} CO_2, combined with two different temperature levels: 30/20 and 37/30°C. The temperature was monitored automatically using a 10,000 BTU air conditioner and thermohygrograph installed inside the chamber. The sources used were CO_2 pressure cylinders with 99.8% CO_2, F 58.3 kg cm^2.

The experimental unit consisted of one plant per polyethylene pot (capacity of 20 liters), containing a substrate of peat and sand at 1:1. All of the plants were fertilized with mineral nitrogen at 20% in the substrate and 80% coverage at 15 days after emergence. The seeds of *Ricinus communis* L., cultivar BRS-Energia, were acquired from the Active Germplasm Bank of the CNPA; five seeds were sown per pot, leaving one plant per pot after thinning. Irrigation was performed every three days during the vegetative stage and every two days during the reproductive phase, keeping the water potential close to the field capacity. After trimming, the plants were placed in plastic-bag experimental units to prevent the loss of water from the substrate.

The photosynthetic capacity, transpiration rate and stomatal conductance were measured under light-saturated conditions using an Infrared Gas Analyzer (IRGA-Infra Red Gas Analyzer) (LI-6400, LICOR®, Inc., Lincoln, NE, USA) according to the methodology described by Walker (1987) and Prado and Moraes (1997). The content of chlorophylls a and b and the total chlorophyll were determined using DMSO, following the indications of Arnon (1949) and adapted by Hiscox and Israelstam (1979). The readings were obtained using a spectrophotometer (BIOMATE 3, Thermo Scientific®) at the following wavelengths: 663, 645 and 480 nm. The determination and quantification were reported using the equations of Wellburn (1994).

The experimental design was completely randomized, consisting of a factorial combination of two temperatures (30/20 and 37/30°C) and two CO_2 levels (400 and 800 μmol mol L^{-1}). There were four replications obtained in five surveys over the growth cycle, divided into twenty pots each under the conditions described above, for a total of 80 sample units. The data were subjected to an analysis of variance; the simple effects and interactions were tested by comparing the means using the Tukey test ($p \leq 0.05$), with regression analyses for the collection period.

Results and discussion

With regard to the gas exchange, the net rate of photosynthesis for the castor bean plants was not favorable with an increasing temperature (Figure 1A): the plants showed a better photosynthetic rate at 37/30°C than at 30/20°C. At 40 DAP, there were significant differences in the measurements for both the photosynthetic temperatures, with a decrease of 51.63% noted with increasing temperature. Netto (2009) highlights the fact that an increase in temperature affects the thylakoid membranes, which are particularly sensitive to heat. Demmig-Adams et al. (1996) state that disturbances in photosynthesis are the first signals that indicate a state of stress due to heat; other processes are also highly sensitive, for example, cell elongation, the main component of growth. Souza et al. (2004) confirm that the formation of reactive radicals can damage the components of PSII.

Thus, a reduction in the photosynthetic rate is attributed to both stomatal closure, which leads to a reduction of CO_2 assimilation, and also to the photochemical damage caused by high temperatures (ABROL; INGRAN, 1996). However, damage to the dark reactions cannot be disregarded, as they are enzymatic and occur in the chloroplast stroma, involving the Calvin cycle for C_3 plant metabolism, as in castor bean, during which carbon dioxide is reduced to carbohydrate.

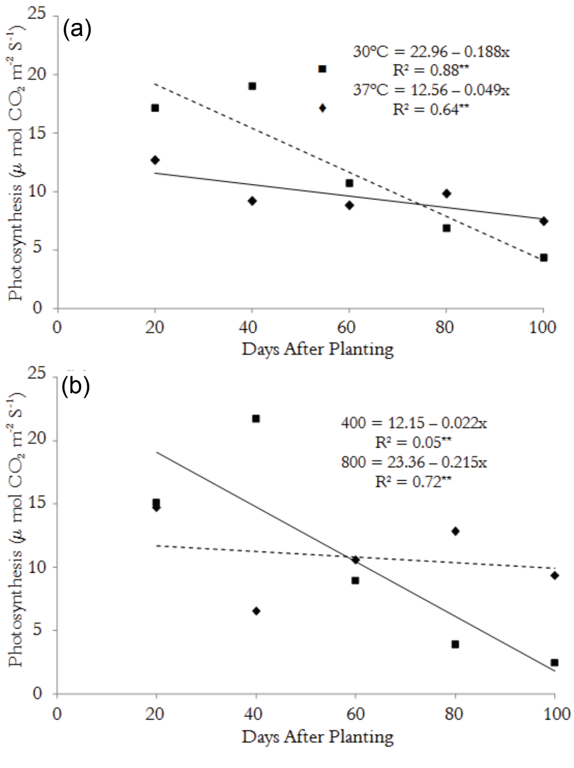

Figure 1. Net photosynthesis in the leaves of castor bean (*R. communis* L.) cv. BRS Energia as a function of the temperature (A) and depending on the concentration of CO_2 (B).

In this work, when the CO_2 concentration was doubled, the photosynthetic rate showed a positive response of 30.27% up to 40 DAP (Figure 1B), with a further decrease of 59.9% to 60 DAP, followed by a linear decline until the end of the cycle. In relation to the normal concentration of CO_2, increases favored an increase in the photosynthetic rate at forty days of 69.81% (Figure. 1B). Several researchers argue that a higher proportion of CO_2 in the atmosphere has the potential to increase the photosynthetic activity (AIDAR et al., 2002; LARCHER, 2000; REDDY et al., 1995, 2005; TAIZ; ZEIGER, 2009;), though most these studies consider only the initial stages of growth and development of the species studied.

When observing the behavior of the plant throughout its growth cycle, this trend of increase in photosynthesis with increases in CO_2 may vary according to the species and cultivar (ABROL; INGRAN, 1996). The species may have a saturation point of CO_2 at which the stomatal conductance is greatly reduced by restricting the PSII efficiency, which can be regarded as a regulatory adjustment of the photosynthetic process (LARCHER, 2000; SAGE, 2002; AIDAR et al., 2002, FARIA et al., 1998) and not having a more significant effect, particularly when the cycle reaches the reproductive stage. With the stomatal closure, an excess of light energy, even under a low irradiance (MAURY et al., 1996), may result in photoinhibition (LIMA et al., 2002).

Moreover, it is known that the optimum temperature for photosynthesis has a large range, possibly because important crop species are adapted to a relatively large range of thermal environments (ABROL; INGRAM, 1996). Al-Khatib and Paulsen (1999) found a significant variation in the photosynthetic rate of wheat cultivars in response to increasing temperature. Abrol and Ingran (1996) state that the optimum temperature for net photosynthesis tends to increase with elevated levels of atmospheric carbon dioxide. Several studies have concluded that inducing an increase in the crop yield by increasing the concentration of CO_2 is much more likely in hot environments than in cold environments (IDSO et al., 1987; RAWSON, 1992).

Regarding the rate of transpiration, there were no significant changes in the plants after increasing the temperature (37°C) (Figure 2A). The increase of CO_2 significantly reduced transpiration by 54.21% at 80 DAP (Figure 2B). According to Wilkinson (2004), stomatal operate in the leaf thermal control in terms of transpiration and in relation to the air temperature, reducing the leaf temperature up to 8.0ºC. Therefore, a reduction in transpiration can result from stomatal closure, leading to a consequent increase in the temperature of the leaves and a vapor pressure deficit between the leaf and the air (NOBEL, 1991, cited by NETTO, 2009).

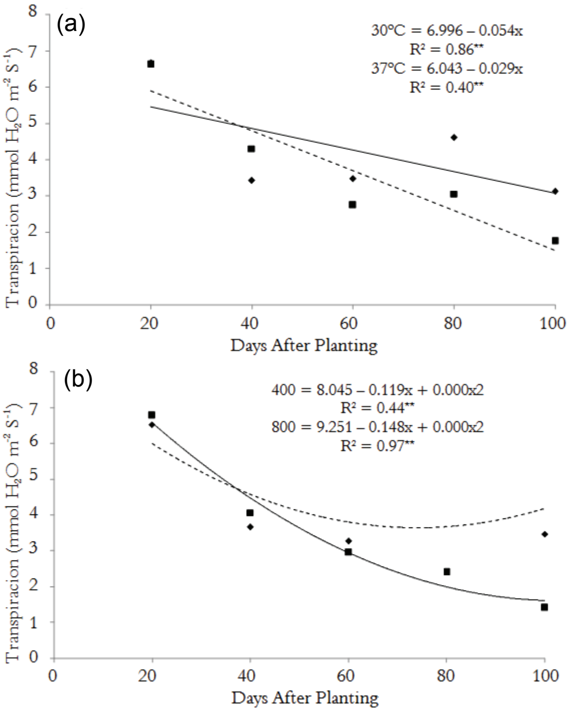

Figure 2. Transpiration rates in the leaves of castor bean (*R. communis* L.) cv. BRS Energia as a function of the temperature (A) and depending on the concentration of CO_2 (B).

Under the two stress factors studied, the castor bean plants reduced their stomatal conductance significantly, 35.15%, at 40 DAP with increasing temperature (Figure 3A) and 72.48% at 80 DAP with increasing CO_2 (Figure 3B). It is known that, under conditions of stress, stomatal movement constitutes an important means of plant defense against the excessive loss of water and eventual death by desiccation (TAIZ; ZEIGER, 2009) and that the guard cells are sensitive to levels of CO_2 (SAGE, 2002).

Thus, under conditions of high temperature and increased concentrations of CO_2, stomatal closure is a major defense strategy to minimize the effects of the ambient conditions (PASSIOURA, 1982). Stomatal closure can be controlled by the soil water availability, the complex effects of abscisic acid (ABA), the conductivity of the xylem and leaf water status (MEDRANO et al., 2002), and the provision of atmospheric CO_2 (LARCHER, 2000).

Many authors report that an increase in the CO_2 concentration favors an increase in the photosynthetic rate (AIDAR et al., 2002, LARCHER, 2000; REDDY et al., 1995; 2005; TAIZ; ZEIGER, 2009); after entering the stomatal, carbon is fixed and stored as sucrose in the cell cytoplasm or starch in chloroplasts (BUCKERIDGE et al., 2007). However, an increase in the temperature will damage the thylakoid membrane, affecting the components of Photosystem II (PSII) (SOUZA et al., 2004), causing a further loss of the carbon metabolism balance. When there is an accumulation of starch in the chloroplast, the activity of the organelle decreases, causing resistance and retro inhibition of the mesophyll photosynthesis (LARCHER, 2000; MAUNEY et al., 1979; SAGE, 2002).

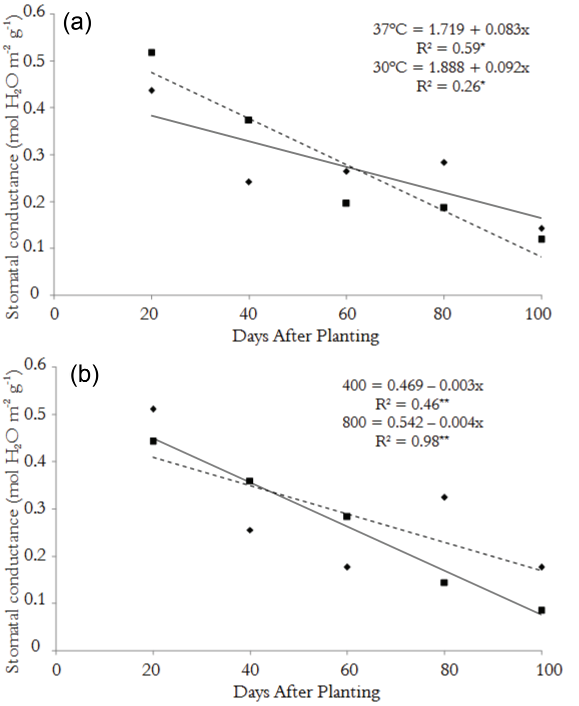

Figure 3. Response of stomatal conductance in the leaves of castor bean (*R. communis* L.) cv. BRS Energia as a function of the temperature (A) and depending on the concentration of CO_2 (B).

Larcher (2000) and Sage (2002) argue that this change in the balance of water and carbon in plants has secondary effects on growth. Buckeridge et al. (2007) explain that the increased availability of CO_2 should increase the photosynthetic rate and allow a greater accumulation of carbon, thus plants should increase in size. However, these authors also state that the additive effects of the temperature and CO_2 would result in a greater accumulation of starch and not in the size of the plants (BUCKERIDGE et al. 2007.)

It was found that, by increasing CO_2 level had significant effects on the concentration of photosynthetic pigments (Table 1). The rise in temperature caused a decrease of 37.8% in the chlorophyll content at 60 DAP (Figure 4A), whereas a high concentration of CO_2 promoted significant decreases of 28.02 and 47.62% after 60 and 80 DAP, respectively (Figure 4B). Therefore, castor bean cv. BRS Energia showed the greatest decrease of chlorophyll a in response to increased CO_2 at 80 DAP.

Table 1. Averages for the variable contents of chlorophyll a, b and total chlorophyll in castor bean leaves exposed to high temperature and high CO_2. Campina Grande, Paraíba State, 2010.

Temp	Chl a (μmol m^{-2})		Chl b (μmol m^{-2})		Total Chl (μmol m^{-2})	
	CO_2		CO_2		CO_2	
	400 μmol L^{-1}	800 μmol L^{-1}	400 μmol L^{-1}	800 μmol L^{-1}	400 μmol L^{-1}	800 μmol L^{-1}
37/30ºC	215,42 aA	136,35 bB	50,65 aA	40,91 bB	266,07 aA	177,27 bB
30/20ºC	183,52 aB	224,58 aA	49,65 aA	53,61 aA	233,17 bB	267,53 aA

Lowercase letters to uppercase for rows and columns. The means followed by the same letter do not differ statistically by Tukey's test at a 5% probability ($0,01 \leq 0,05$). The data are transformed to log (x).

Increasing the temperature and increasing the CO_2 concentration increased the concentration of chlorophyll b at DAP 40, which was followed by a decrease in the concentration until the final stage (Figure 4 C and D). The reduction in chlorophyll b in response to increasing temperature was approximately 29.48% at 60 DAP and 55.5% at 80 DAP. In contrast, the pigment concentration tended to be constant throughout the cycle at a normal temperature (Figure 4C). With the increase of the CO_2, the initial increase in the concentration of chlorophyll b was 27.31% at 40 DAP, followed by a significant drop at 80 DAP (44.5%) and 100 DAP (44.07%) (Figure 4D).

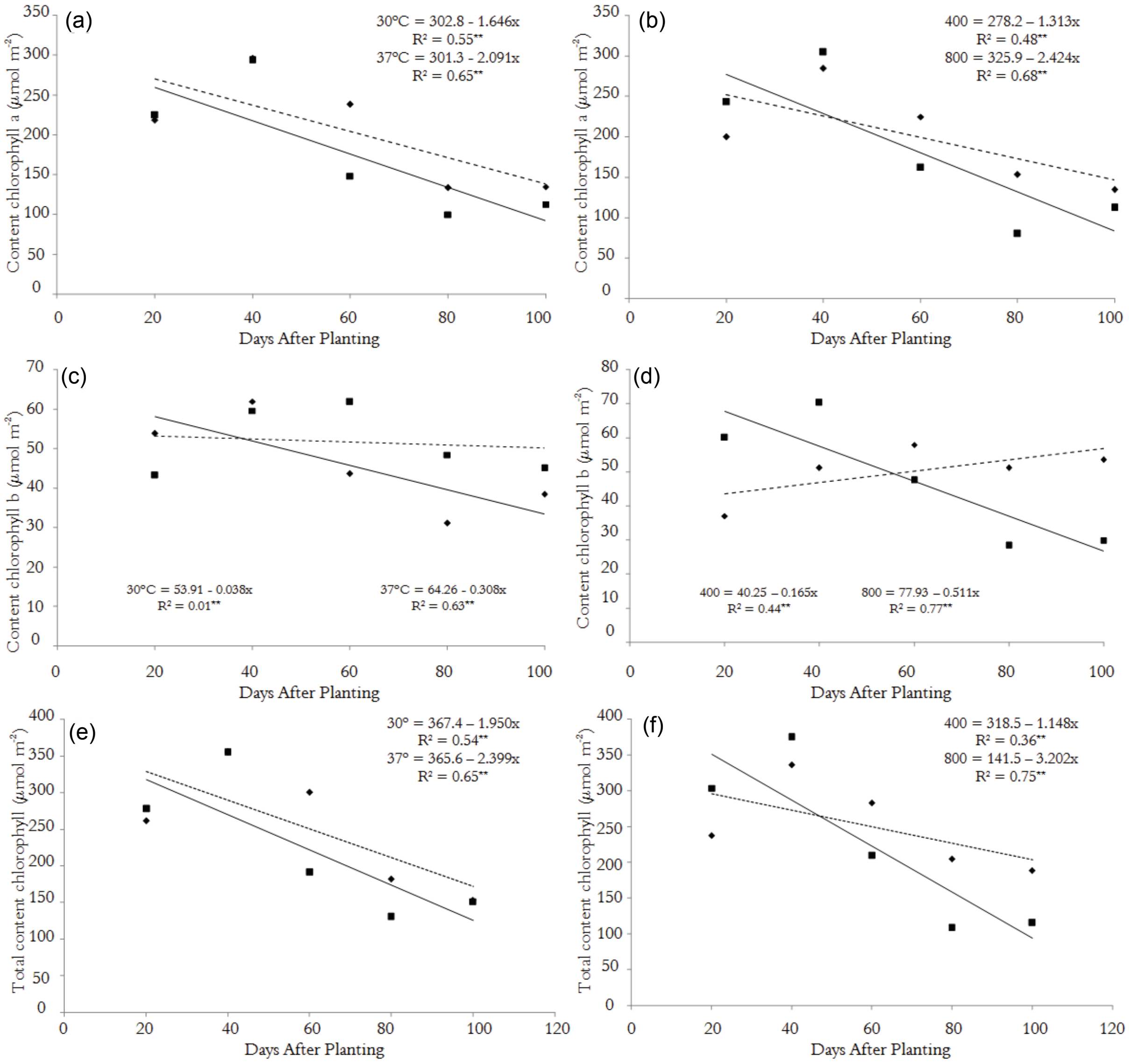

Figure 4. Chlorophyll content in the leaves of castor bean (*Ricinus communis*). A-content chlorophyll *a* in response to increasing temperature; B- content chlorophyll *a* in response to the increase of CO_2; C-content chlorophyll *b* in response to increasing temperature; D- content chlorophyll *b* in response to increase of CO_2; E-content chlorophyll total in response at high temperature; F-content chlorophyll total in response to increase of CO_2.

There was a sudden drop in the concentration of total chlorophyll (Figure 4D) of 36.09% at 60 DAP and 28.02% at 80 DAP with increasing temperature. At the end of the growth cycle, it is observed that the chlorophyll was equivalent at both temperatures. With the increase of CO_2 (Figure 4F), there was no significant difference at the beginning of the cycle, with an increase of 21.74% in the total chlorophyll content in response to increasing CO_2. The chlorophyll content increase at 40 DAP under the two CO_2 conditions did not differ statistically, yet the concentrations decreased in response to increased CO_2 by 25.32, 46.84 and 38.32% at 60 DAP 80 and 100, respectively.

Netto (2005) and Chaves et al. (2003) also claim that the decreases in photosynthetic pigment concentrations can be interpreted as a strategy to reduce the capture of light energy rather than as indicative of damage. Although reducing the photosynthetic efficiency and accumulation of biomass, this strategy prevents the plant from injury.

Conclusion

Considering the entire cycle of castor bean BRS Energia grown under controlled conditions (phytotrons), a temperature increase optimal above (37/30ºC) and a high CO_2 concentration (800 μmol mol L^{-1}) reduced the photosynthesis, transpiration, stomatal conductance and content of photosynthetic pigments in relation to a temperature of 30/20°C and CO_2 level of 400 μmol mol L^{-1}, thus interfering with the growth and development of the castor bean plants.

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