GAS EXCHANGE CHARACTERISTICS AND DRY MATTER PRODUCTION IN *AMARANTHUS CRUENTUS* L. UNDER VARYING NITROGEN SUPPLY

CARACTERÍSTICAS DAS TROCAS GASOSAS E PRODUÇÃO DE MATÉRIA SECA EM *AMARANTHUS CRUENTUS* L. SOB DIFERENTES DOSES DE NITROGÊNIO

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ABSTRACT

The objective of this study was to evaluate the responses of *Amaranthus cruentus* L. to variation in the nitrogen supply. Increased nitrogen availability resulted in greater accumulation of shoot dry matter. The specific leaf weight was increased in the plants that received the highest amount of nitrogen. The levels of chlorophyll *a*, *b* and total and carotenoids as well as the photosynthetic capacity were significantly increased in response to the increase in nitrogen supply. Higher nitrogen availability resulted in greater stomatal conductance, but with little effect on transpiration and CO_2 concentration in the substomatal cavity. The results show that *A. cruentus* L. plants are sensitive to changes in nitrogen availability during the vegetative phase.

Keywords: Photosynthesis. Amaranto. Growth. Photosynthetic pigments.

RESUMO

O objetivo deste estudo foi avaliar as respostas de *Amaranthus cruentus* L. à variação no suprimento de nitrogênio. Aumento na disponibilidade de nitrogênio resultou em maior acúmulo de massa seca da parte aérea. O peso foliar específico foi aumentado nas plantas que receberam a maior quantidade de nitrogênio. Os teores de clorofila *a*, *b* e total e de carotenoides assim como a capacidade fotossintética foram significativamente aumentados em resposta ao aumento no suprimento de nitrogênio. Maior disponibilidade de nitrogênio resultou em maior condutância estomática, mas com efeito pouco significativo na transpiração e na concentração de CO_2 na cavidade subestomática. Os resultados mostram que plantas de *A. cruentus* L. são sensíveis às mudanças na disponibilidade de nitrogênio durante a fase vegetativa.

Palavras-chaves: Fotossíntese. Amaranto. Crescimento. Pigmentos fotossintéticos.

The most notable species within the genus *Amaranthus*, which has been the object of this study, in several countries of the world are *A. caudatus, A. cruentus* and *A. hypochondriacus* (1) (2). Historical evidence suggests that amaranth cultivation had its culmination during the Aztec, Inca and Mayan civilizations and was related not only to food but also to religious issues (1). Between the years of 1960 and 1980, after being banished by the Spanish settlers, amaranth is again cultivated, being taken to Europe and later spreading to Africa, China and America ((1)(3). Considered as a C_4 plant, *Amaranthus* adapts to a wide variety of environmental conditions. In Brazil, it was verified that several species are well adapted to the climatic and edaphological conditions of the Central region (2). *Amaranthus* is a genus of great economic importance because both leaves and seeds can be used as food. The nutritional quality of leaves and seeds is related to the large amounts of proteins, vitamins and minerals (3), besides not possessing gluten making it important for celiac people.

Nitrogen is an edaphic factor that influences crop productivity by being an essential constituent of several molecules. In species of *Amaranthus* large differences have been observed in responses to nitrogen supply in terms of biomass production and nutritional quality (4). Due to the scarcity of research regarding the physiological responses of this plant to changes in nitrogen supply, the present study aimed to evaluate the responses of *A. cruentus* to nitrogen availability in terms of biomass production, photosynthetic characteristics and the content of photosynthetic pigments.

Seeds of *Amaranthus cruentus* L. cv. BRS Alegria were sown in 4 L plastic pots filled with vermiculite and kept in a greenhouse under natural photoperiodic conditions and minimum and maximum average temperature of 21 and 33 ^oC, respectively. The plants were divided into three groups corresponding to the different dosages of nitrogen applied as ammonium nitrate. The doses used were: 9.88, 4.94 and 1.97 kg N ha^{-1}, which correspond to 100%, 50% and 20% of full strength Long Ashton nutrient solution (5), respectively. All the other nutrients were supplied as 70% of full strength. The plants received 250 mL of nutrient solution three times a week and tap water when necessary. The gas exchange characteristics were measured after 26 days of sowing and 33 days of sowing just before sampling the plants for dry matter determination. A portable infra-red gas analyser (LCpro, ADC, Hoddesdon, UK) was used for measurements of net CO_2 assimilation (A), stomatal conductance (g_s), transpiration (E) and intercellular CO_2 concentration (C_i) on the youngest fully expanded leaf. A photosynthetic active radiation of 1000 µmol m^{-2} s^{-1} was supplied by a light unit mounted on the top of leaf chamber. The specific leaf weight (SLW) was determined in 4 leaf discs of known area per plant after being oven dried at 60 ^0C for 48 hours. The SLW was determined according to the equation: SLW = DM/A, where A is the area and DM is the dry matter of discs. Pigments were extracted in 80% aqueous acetone and the content was calculated according to Lichtenthaler (6) and the concentration expressed on a leaf area basis (g m^{-2}). Thirty-three days after sowing, the plants were collected and divided into stem and leaves before been oven dried at 60 ^0C for 48 hours. The data were submitted to analysis of variance and Tukey's honestly multiple comparison at 5% significance level by using the Software SPSS/PC 9.0.

Under nitrogen deficiency, there was a decline in the transport of reduced nitrogen to the aerial part, resulting in a decrease in meristematic activity and initiation of new leaves, favoring root growth (7). Although the dry mass of the roots was not evaluated, the amaranth responded positively to the increase in nitrogen supply in terms of dry mass in the aerial parts (Figure 1A), as observed in other studies with nitrogenous fertilization (1). The leaf expansion rate is sensitive to nitrogen concentrations in the zones of cell division and expansion (8), with a higher rate of total nitrogen deposition in the growth zone in plants cultivated under high nitrogen content. This fact may explain the increase in leaf dry mass observed in this study (Figure 1A). The specific leaf weight (SLW) was higher in the plants that received the highest amount of nitrogen during the experiment compared to those that received lower nitrogen concentration (Figure 1B). Comparisons between the published studies correlating nitrogen availability with *Amaranthus* productivity are difficult to make because the vast majority of these studies were performed under field conditions where these are very adverse among the different studies. However, the higher biomass production detected in this study confirms the *Amaranthus* responses to the nitrogen supply observed under field conditions (1)(9). Altering the nitrogen dosage of 1.97 to 4.94 kg N ha^{-1} resulted in an increase in total dry mass of the shoot of 133%, whereas for 9.88 Kg N ha^{-1} the increase was 282% (Figure 1A).

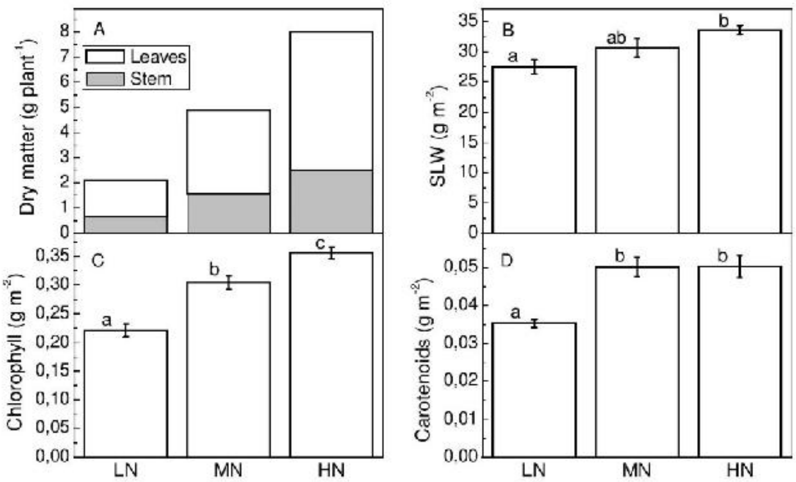

Figure 1. Shoot dry mater (A), specific leaf weight (B), total chlorophyll (C) and carotenoids (D) concentrations of amaranth plants grown under low (LN), medium (MN) or high (HN) nitrogen supply. Values are mean ± error of 15 (A) and 6 (B,C,D) plants. Values sharing the same letters are not significantly different at 5% significance level.

The present study demonstrates that the higher availability of nitrogen increased the area available for light energy capture and the levels of photosynthetic pigments (Figures 1C, D) and, therefore, increased the photosynthetic capacity directly (Figure 2A). The photosynthetic pigments in the thylakoids membranes consist largely of green chlorophylls but also yellow-orange pigments classified as carotenoids which efficiently transfer their excitation energy to the same reactions centers as do chlorophylls. SLW is an indication of leaf thickness, which is a consequence of the increase in mesophyll thickness (10), with a positive correlation between chlorophyll concentration and SLW. In the present study, higher nitrogen availability resulted in an increase in SLW (Figure 1B) and total chlorophyll and carotenoids concentrations (Figure 1C; Figure 1D). Although nitrogen deficiency has no effect on g_s in some species, in others may be increased or reduced. These contradictory results can be explained by the fact that plant responses to nitrogen supply depend on several parameters such as species and growth conditions. In the present study, the increase in nitrogen availability resulted in higher g_s, but with little effect on transpiration (Figures 2B, C). An increase in g_s implies a greater availability of CO_2 in the substomatal cavity (C_i). It is interesting to note that in plants of *A. cruentus* deficient in nitrogen the low photosynthetic rate was accompanied by a lower g_s when compared with high nitrogen availability (Figures 2A, B), but the C_i practically did not differ between the treatments (Figure 2D). These data show that in *A. cruentus* plants stomatal closure is not fully responsible for the reduction in the photosynthetic rate, also suggesting a non-stomatal limitation of photosynthesis. This study shows that high levels of nitrogen were fundamental for a greater accumulation of biomass in the aerial part and greater capacity for CO_2 assimilation in *A. cruentus* cv. BRS Alegria.

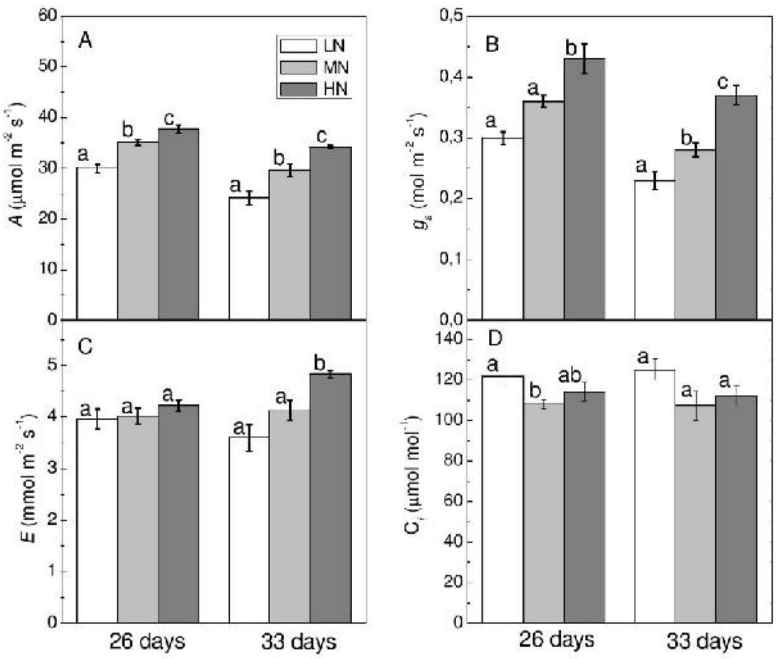

Figure 2. Net CO_2 assimilation (*A*, A), stomatal conductance (g_s, B), transpiration (*E*, C), and intercellular CO_2 concentration (C_i, D) of amaranth plants grown under low (LN), medium (MN) or high (HN) nitrogen supply after 26 and 33 days of sowing. Values are mean ± error of 8-10 plants. Values sharing the same letters are not significantly different at 5% significance level.

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