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Short communication

Photosynthetic photon flux density levels affect morphology and bromatology in *Cichorium endivia* L. var. *latifolia* grown in a hydroponic system

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ABSTRACT

Photosynthetic photon flux density (PPFD) in suboptimal or super-optimal levels can modify the biomass accumulation, bromatological composition and appearance of crops. This study was conducted in a hydroponic system to determine whether PPFD could change physiological and bromatological aspects of escarole (*Cichorium endivia* L. var. *latifolia*). Three PPFD levels (100%, 70% and 50% of PPFD) were investigated to determine crop's responses to this factor. Plants of escarole grown under 50% of incident PPFD had converted 0.88 g of dry matter per mol of incident photosynthetically active radiation (42% more efficient compared to unshaded environment), had 26% more lipid content, higher levels of chlorophyll a, b and total (12%, 14% and 13%, respectively), 42% less acid detergent fiber, 34% less cellulose, 47% less lignin, lesser leaf thickness and better visual features. The attenuation of PPFD in sites or seasons where there is high light intensity is an effective method to improve morphological, bromatological and visual characteristics of escarole.

1. Introduction

Over the last decades, consumption of vegetables has been increased due to their action against several chronic diseases (Díaz-Garcés et al., 2016). This interesting propriety seems to be related to their polyphenolic contents, such as phenolic acids (Clifford, 1999). Previous studies revealed that escarole (*Cichorium endivia* var. *latifolia*) has strong antiradical proprieties (Papetti et al., 2008), being an important vegetable in the quest for a healthier life.

Due escarole be worldwide cultivated, in a wide latitude, this crop is subjected to several environmental conditions, mainly regarding photosynthetic photon flux density (PPFD). Changes in the PPFD of an environment can affect the photosynthetic apparatus of plants. Lower PPFD reduces the photosynthetic rate and hence plant growth. PPFD levels above the light saturation point inhibit enzymes of the Calvin-Benson cycle which follow ATP and NADPH production originated from light reactions, in addition to causing photoinhibition due to an excess of energy in the reaction center of photosystem II (Pospíšil and Yamamoto, 2017). Due it, studies have been identifying a reduction of quantum efficiency, photosynthetic rate, and possible damage to the photosynthetic apparatus (Murchie et al., 2009; Pastenes et al., 2003; Zhang et al., 2008) beyond changes on the yield, bromatological and nutritional aspects, when plants are exposed both to suboptimal or super optimal PPFD levels (Dario et al., 2015).

In ecological studies, nonlinear models have been widely used to describe the biological behavior of different plant and animal species such as the height growth curve estimation and the accumulation of dry biomass of forest species (Elli et al., 2017; Olagoke et al., 2015), animal growth and performance (Ghavi Hossein-Zadeh, 2015) and annual plant species (Ren et al., 2016). In vegetables, specifically in escarole,

Abbreviations: ADF, acid detergent fiber; AGR, absolute growth rate; AIC, Akaike information criterion; ATP, adenosine triphosphate; BIC, Bayesian information criterion; CEL, cellulose; DM, dry mass; HC, hemicellulose; LAI, leaf area index; LAR, leaf area ratio; LIP, lipids; LN, lignin; LRW, leaf weight ratio; NADPH, nicotinamide adenine dinucleotide phosphate; NAR, net assimilation rate; NDF, neutral detergent fiber; PAR, photosynthetically active radiation; RGR, relative growth rate; SCND, soluble carbohydrates in neutral detergent; SLA, specific leaf area; PPFD, photosynthetic photon flux density

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the use of growth models is still limited.

Studies revealing the impact of PPFD levels on the physiological and bromatological aspects as well as on the dry matter modeling of escarole has not been found in the literature. In this context, we originated the following hypotheses: (i) plants grown under high PPFD levels, have a reduction in efficiency when converting solar energy into biomass, but have greater accumulated dry matter due to a higher photosynthetic rate; (ii) reduced PPFD levels provides plants with superior bromatological quality. These hypotheses justify the following aim: to determine the influence of different PPFD levels on morphology, bromatology and growth estimators of escarole.

2. Material and methods

2.1. Site description

A hydroponic experiment was carried out in an experimental greenhouse in the city of Frederico Westphalen, Rio Grande do Sul, Brazil, between the months of November 2015 to January 2016. In the location of the experiment, this period is characterized by having higher levels of incident PPFD, compared to other months of the year. The geographical location of the experiment was S 27° 23', W 53°25', 490 m above sea level. The climate is Cfa according to Köppen's classification, where the three coldest months of the year have temperatures of −3 to 18 °C, with an air average temperature in the warmest month greater than or equal to 22 °C, and precipitation is uniformly distributed during the year.

2.2. Management of hydroponic system

Pelleted escarole seeds were inserted into phenolic foam board on November 05, 2015. After emergence, the plants were placed in a system called "maternity". On November 13, 2015, the plants reached three true leaves and were transplanted into a system called "seedling tray". After the seedling tray stage, a final transplant to the growth tray was performed on December 02, 2015. Each final growth tray was formed by 11 hydroponic channels (6-m long, 0.10-m wide and 0.05-m deep), subjected to a 4% declivity. The spacing was 0.20 m between plants in the channels and 0.20 m between channels. Each hydroponic bench composed a PPFD level. The bench presented 33 channels and a total of 242 plants. Thus, the three PPFD levels totaled 726 plants.

Nutrient solution was pumped inside the hydroponic channels and was collected at the end of each channel by a system of closed system gutters. The used nutrient solution was prepared with 400 mg L^{-1} of the commercial formula HidrogoodFert® (N = 10.00, P_2O_5 = 9.00; K_2O = 28.00; Mg = 3.38, S = 4.00 B = 0.06, Cu = 0.01, Mn = 0.05, Mo = 0.073 and Zn = 0.02%) and 18 mg L^{-1} of the commercial formula Hidrogood Fe EDDHA® (Fe EDTA = 6.00%); we considered these values to be a full dose. Irrigation was performed off-and-on in periods of 15 min throughout the day (6 a.m. – 7 p.m.); and 15 min each two hours during the night (7 p.m. – 6 a.m.). Nutrients were replaced when the electrical conductivity of the nutritive solution reached 50% of its initial concentration.

2.3. Sources of variation and experimental design

To test the hypotheses highlighted, we simulated PPFD levels with black polyethylene meshes, fixed 1.0 m above the hydroponic benches. The experimental design was a randomized complete block, arranged in a factorial layout (PPFD levels x evaluation periods) with four replicates. The following treatments were made: 100% of PPFD (without meshes over the plants), 70% of PPFD (30% transmissivity meshes), and 50% of PPFD (50% transmissivity meshes). Each simulated PPFD level treatment was carried out on a different hydroponic bench.

Escarole plants were collected for analysis from the central hydroponic channels of each treatment, beginning on the first day that they were transferred to the final growth tray. From this moment, weekly destructive evaluations were carried out until the average fresh mass of experimental plants hit 250 g (market mass). The destructive evaluation consisted of the removal of two whole plants in each replication and a separation of its components (root, stem and leaves) for dry mass determination.

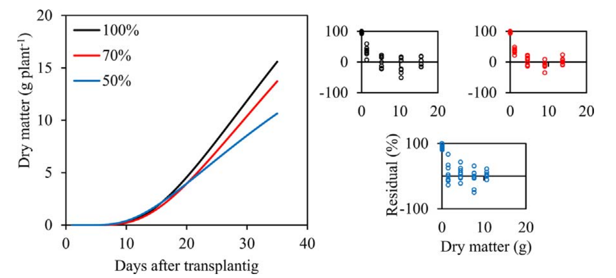

Fig. 1. Dry matter accumulation and residual distribution obtained from the Schumacher's model in escarole plants growing under different PPFD levels depending on the plant's age.

Table 1
Fit statistics and coefficients obtained by the Schumacher's model to explain the accumulated dry matter in escarole grown under different PPFD levels.

PPFD Level (%)	Coefficients		CV (%)[a]	AIC[b]	BIC[c]	R^2_{aj}[d]
	β_0	β_1				
100	80.2695	−57.324	25.74	218.121	221.864	0.969
70	72.2745	−58.126	20.09	186.352	190.094	0.981
50	36.338	−42.012	16.28	154.622	158.365	0.985

[a] Coefficient of variation.
[b] Akaike information criterion.
[c] Bayesian information criterion.
[d] Adjusted coefficient of determination.

2.4. Growth rates and plant traits

In each evaluation period, the following variables were estimated by average values (from four replicates and two plants per replicate) of dry mass (DM): absolute growth rate (AGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area index (LAI), specific leaf area (SLA), leaf area ratio (LAR), leaf weight ratio (LWR) (Thornley, 1976; Gardner et al., 1985). For the determination of growth rates, a total of 40 plants per treatment were collected.

In the last evaluation period, we have determined the chlorophyll index a, b, total and a/b ratio, with a chlorophyll meter (CFL 1030, Falker, Brazil), selecting fully expanded leaves from the upper third of 10 plants in each replication (total of 40 plants per treatment). Collected dry mass samples were properly prepared and subjected to bromatological analysis; the following traits were determined: ash (ASH, % of DM), lipids (LIP, % of DM), neutral detergent fiber (NDF, % of DM), acid detergent fiber (ADF, % of DM), lignin (LN, % of DM), hemicellulose (HC, % of DM), cellulose (CEL, % of DM) and soluble carbohydrates in neutral detergent (SCND, % of DM).

Ash content was determined at 550 °C, according to method AOAC 923.03 (AOACI, 2016). Lipid content was quantified according to the method proposed by Bligh and Dyer (1959). Neutral detergent fiber, ADF, LN and then the calculations for estimating HC, CEL and SCND were performed as proposed by (Senger et al., 2008). We used the Tukey test ($p < 0.05$) to compare the growth rates and plant traits among PPFD levels.

2.5. Photosynthetically active radiation use efficiency

According to the model proposed by Monteith and Moss (1977),