

# Solar radiation levels modify the growth traits and bromatological composition of *Cichorium intybus*

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**Abstract:** Shading greenhouse may be an effective method to achieve a suitable environment for crop growth and to enhance crop yield and quality in places or seasons where there is high light intensity. Therefore, solar radiation levels may modify the biomass accumulation and bromatological composition. Different solar radiation levels (100%, 70% and 50% of available solar radiation) were simulated in order to determine crop responses to these factors in chicory (*Cichorium intybus* L. var. *foliosum*). A hydroponic experiment was conducted in an experimental greenhouse in the city of Frederico Westphalen, Rio Grande do Sul, Brazil. Plants grown in lower solar radiation levels are more efficient in converting solar radiation into dry matter, had a higher lipid content, increased chlorophyll indices *a*, *b* and total, as well as reduced leaf thickness, acid detergent fiber, cellulose, and lignin content, presenting more attractive bromatological features for commercial production. In this study it was demonstrated that the use of shading screens is an effective method to attenuate the solar radiation, this is especially relevant in places or seasons where there is high light intensity, which contribute to achieve better characteristics of the chicory produced.

## 1. Introduction

Growth rate, dry matter production and radiation use efficiency are considered important variables when analyzing yield-limiting factors and their interactions in different production environments. Dry matter accumulation under non-limiting conditions is directly related to the amount

of intercepted photosynthetically active radiation (Caron *et al.*, 2012). Therefore, variation in total biomass due to limiting biotic and abiotic factors may be attributed to changes in the solar radiation levels.

Changes in the solar radiation level of a given environment may affect the photosynthetic apparatus of plants. Lower solar radiation level reduces the photosynthetic rate and hence plant growth. When radiation levels is above the light saturation point, the reaction center of the PSII is inactivated and frequently damaged, constituting a phenomenon called photoinhibition (Taiz *et al.*, 2017). Due it, studies have identified a reduction of quantum efficiency, photosynthetic rate, and possible damage to the photosynthetic apparatus (Zhang *et al.*, 2008; Murchie *et al.*, 2009) beyond changes on the yield, bromatological and nutritional aspects, when plants are exposed both to suboptimal or super optimal radiation levels (Dario *et al.*, 2015; Bianculli *et al.*, 2016).

Achieving an appropriate environment in greenhouses in subtropical regions has become one of the main challenges for chicory producers, due to a large amount of solar radiation transmitted into the greenhouse and then converted into sensible and latent heat. Thus, greenhouse cooling methods and their impact present a considerable problem that requires a solution (Abdel-Ghany and Al-Helal, 2010). A strategy used in greenhouses in order to provide an appropriate environment for plant growth and to increase crop yield is the shading screens (Sethi and Sharma, 2007; Ganguly and Ghosh, 2011). Shading is one of the most inexpensive ways to reduce heat accumulation and to modify the greenhouse environment (Sethi and Sharma, 2007; Holcman and Sentelhas, 2012), besides promoting higher rates of diffuse radiation.

Solar radiation use efficiency ( $\epsilon b$ ) of crops is determined by the slope of the linear regression between produced dry matter and photosynthetic active radiation (PAR) intercepted by the leaves (Monteith, 1965, 1972, 1977; Van Heerden *et al.*, 2010). Reduced solar radiation availability within the greenhouse environment may influence various traits of chicory, especially the leaf area index, the thickness of leaves and chlorophyll content, because cultivation in shaded environments often results in thinner leaves (Wherley *et al.*, 2005; Liu *et al.*, 2016). These leaves contain a greater total chlorophyll content per unit of fresh weight when compared to leaves grown under full sunlight. Chlorophyll content of each leaf, per unit area, may be smaller in environ-

ments with reduced incident solar radiation (Wild and Wolf, 1980; Taiz *et al.*, 2017).

Research showing the change of yield, and bromatological and nutritional traits as a function of incident solar radiation level, both as suboptimal and optimal levels were shown by Bianculli *et al.* (2016), Dario *et al.* (2015), and Kataria and Guruprasad (2015). To the authors' knowledge, this study is the first to investigate the impact of different solar radiation levels on plant growth, radiation use efficiency and biomass partitioning in chicory.

Information that reveals the impact of solar radiation levels on chicory as well as the bromatological composition are relevant in order to improve some management in a greenhouse environment. In addressing this lack of information, the following hypotheses were investigated: (i) solar radiation use efficiency is reduced in the plants grown under high solar radiation level; and (ii) shading screens provide an appropriate environment for plant growth, resulting in plants with better bromatological composition. These hypotheses justify the following aims: (i) to determine the influence of different solar radiation level on plant traits; and (ii) to evaluate the bromatological composition of chicory plants under different solar radiation levels.

## 2. Materials and Methods

### *Study area*

The study was conducted in an experimental greenhouse in the city of Frederico Westphalen, Rio Grande do Sul, Brazil. A hydroponic experiment was performed between the months of March 2016 to June 2016. The geographical location of the experiment was 27°23' S, 53°25' W, 490 m asl. According to the Köppen climate classification, the climate is Cfa, i.e., humid subtropical with mean annual temperatures of 19.1°C, and varying maximum and minimum temperatures of 38 and 0°C, respectively (Alvares *et al.*, 2013).

### *Management of hydroponic system*

Chicory (*Chicory intybus* L. var. *foliosum*) seeds were inserted into phenolic foam board on 25 March 2016. Seedlings were transplanted into a system called "seedling tray" on 3 April 2016, when they reached two to three true leaves; seedling tray had 40 mm-hydroponic channels (3-cm deep, spaced by 7 cm between channels and 10 cm between plants in the channels), with 3% declivity. Seedlings remained

in this system until they reach a developmental level of five true leaves. After the seedling tray stage, the final transplant to the growth tray was performed on 11 April 2016. 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. Thus, three hydroponic benches had 33 channels, with 242 plants per bench, 726 plants throughout the experiment composed the system.

A 1-HP pump coupled to a fiberglass tank with a capacity of 1000 liters powered the hydroponic system. The nutrient solution used was prepared with 400 mg l<sup>-1</sup> of a commercial Hidrogood® Fert (Hidrogood Modern Horticulture, Brazil); these values were considered to be a full dose. 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 nutrient solution used was prepared with 400 mg l<sup>-1</sup> of a commercial Hidrogood® Fert (Hidrogood Modern Horticulture, Brazil); these values were considered to be a full dose. Irrigation was performed in an on-and-off system in periods of 15 minutes throughout the day (6 AM - 7 PM.); and 15 minutes each two hours during the night (7 PM - 6 AM). Potential of hydrogen (pH) and electric conductivity of the nutritive solution were assessed daily with a digital pH meter (pH-0091A model), and with a conductivity meter (Az-8301 model), respectively. The pH of the nutrient solution was kept at 6.0 (±0.5) using sulfuric acid (10% concentration of H<sub>2</sub>SO<sub>4</sub>) or very low sodium hydroxide (2% of NaOH). Nutrients were replaced when the electrical conductivity of the nutritive solution reached 50% of its initial concentration.

#### *Solar radiation level and experimental design*

The experimental design was a randomized complete block, arranged in a factorial arrangement (solar radiation level x evaluation periods) with four replications. Different solar radiation level (SRL) were simulated using black polyethylene meshes, fixed 1.0 m above the hydroponic benches. The following treatments were applied: 100% of available SRL (without mesh over the plants), 70% of available SRL (30% transmissivity mesh), and 50% of the available SRL (50% transmissivity mesh). Each simulated radiation level treatment composed a different hydroponic bench and the meteorological conditions in all treatment were the same, differing only the solar radiation levels in each hydroponic bench.

For the growth traits analysis, the chicory plants

were collected from the central hydroponic channels of each treatment, beginning seven days after the transfer to the final growth tray. The evaluations were performed weekly until the average fresh mass of experimental plants hit 250 g (harvest point). Destructive evaluation consisted of two whole plants in each replication, totaling eight plants per treatment in each period. In laboratory the sectioning plants was performed, including the preparation of leaf discs in order to determine the leaf area and dry matter partitioning. The total dry matter (TDM) of the plants was determined from the sum components (root, stem and leaves). Each component was gathered and placed into pre-identified individual paper sacks. The sacks were then kept in a forced circulation oven at 60°C until a consistent mass was obtained. The samples were later weighed on a precision balance in order to obtain the dry mass of each component, which together resulted in the TDM.

#### *Growth rates and bromatological analysis*

In each evaluation period, the following variables were determined using the average values of dry matter (DM) and leaf area index (LAI): specific leaf area (SLA), leaf area ratio (LAR), leaf weight ratio (LWR), absolute growth rate (AGR), relative growth rate (RGR) and net assimilation rate (NAR). For more details about the used metrics of evaluation and the determination of these variables, see Thornley (1976) and Gardner *et al.* (1985).

The chlorophyll index *a*, *b*, total and *a/b* ratio were determined with a CFL 1030 chlorophyll meter. We selected, in the last evaluation period, fully expanded leaves from the upper third of 10 plants in each replication. All collected dry matter samples were properly prepared and subjected to bromatological analysis; the following traits were determined: ash (ASH, % of DM), lipids (LIP, % of DM), crude protein (CP, % 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).

For the ash content determination, the method AOAC 923.03 (1995) was used, which consider a temperature of 550°C. Lipid content was quantified according to the method proposed by Bligh and Dyer (1959). The values of NDF, ADF and LN were determined, followed by the calculations for estimating HC, CEL and CSND as proposed by Senger *et al.* (2008), and the crude protein (N x 6.25) was determined by micro-Kjeldahl method (Method 960.52) of AOAC (1995).

### Radiation use efficiency

Production of dry matter was based on the model proposed by Monteith (1977), where dry matter production was calculated from intercepted photosynthetically active radiation (*iPAR*) multiplied by the use efficiency ( $\epsilon b$ ). The  $\epsilon b$  was calculated by the ratio between the average production of accumulated TDM and the *iPAR* involved in the production of biomass according to the following expression:

$$DM = \epsilon b * iPAR$$

Where *DM* = dry matter, in g;  $\epsilon b$  = conversion efficiency of in biomass produced, in g MJ<sup>-1</sup> and *iPAR* = intercepted photosynthetically active radiation, in MJ m<sup>-2</sup>.

Estimation of accumulated photosynthetically active radiation was determined according to the expression proposed by Varlet-Grancher *et al.* (1989):

$$*iPAR = 0.95 * (inPAR) * (1 - e^{-k * LAI})$$

Where *iPAR* = intercepted photosynthetically active radiation, in MJ m<sup>-2</sup>; *inPAR* = incident photosynthetically active radiation, in MJ m<sup>-2</sup>; *k* = light extinction coefficient. The *k* value calculated in the current study for the chicory plants was 0.13. LAI = leaf area index.

The light extinction coefficient (*k*) was calculated using the following equation:

$$k = \frac{-\ln(Rn/Rt)}{LAI}$$

Where *k* = light extinction coefficient, *Rn* = solar radiation measured under the plant canopy (MJ m<sup>-2</sup>); *Rt* = radiation above the plant canopy (MJ m<sup>-2</sup>); LAI = leaf area index.

Leaf area index was calculated by the following expression:

$$LAI = LA/UA$$

Where LAI = leaf area index; LA = leaf area, in cm<sup>2</sup>; UA = useful area per plant, in cm<sup>2</sup>.

The fraction of photosynthetically active radiation was considered 47% of the incident solar global radiation found in Rio Grande do Sul (Assis and Mendez, 1989). The estimation of accumulated photosynthetically active radiation was based on Monteith (1977) and Varlet-Grancher *et al.* (1989).

The *PAR* transmissivity of greenhouse cover was calculated based on an assessment using a quantum sensor, 50 cm height from the ground level, measuring 40 random points inside and outside of the greenhouse weekly during the trial period. To calculate transmissivity, the following equation was used:

$$T = (100 * PAR_i) / PAR_o$$

Where *T* = transmissivity, in %; *PAR<sub>i</sub>* = photosynthetically active radiation inside of the greenhouse; *PAR<sub>o</sub>* = photosynthetically active radiation outside of the greenhouse.

With the transmissivity data of greenhouse and

polyethylene meshes, *PAR<sub>i</sub>* was estimated for each treatment, according to the following expressions:

$$\begin{aligned} PAR_{100\%} &= PAR_i \\ PAR_{70\%} &= PAR_i * 0.7 \\ PAR_{50\%} &= PAR_i * 0.5 \end{aligned}$$

Where photosynthetically active radiation inside of the greenhouse; environment with 70% of photosynthetically active radiation available and environment with 50% of photosynthetically active radiation available.

The values of incident global solar radiation during the study were obtained with the Automatic Climatological Station of the National Institute of Meteorology, located at 300 m from the study site (27°39' S and 53°43' W).

Chicory growth and nutritional composition variables were statistically analyzed with the software SAS 9.0 (SAS Institute 2002). Data were initially examined for homogeneity of variance and then subjected to analysis of variance. Tukey test (*p*>0.05) was used to compare the difference between the treatments.

### 3. Results

#### Radiation use efficiency in Chicory

The radiation use efficiency and photosynthetically active radiation accumulated values in the different solar radiation level during the conduct of the study are shown in figure 1. It was observed that the

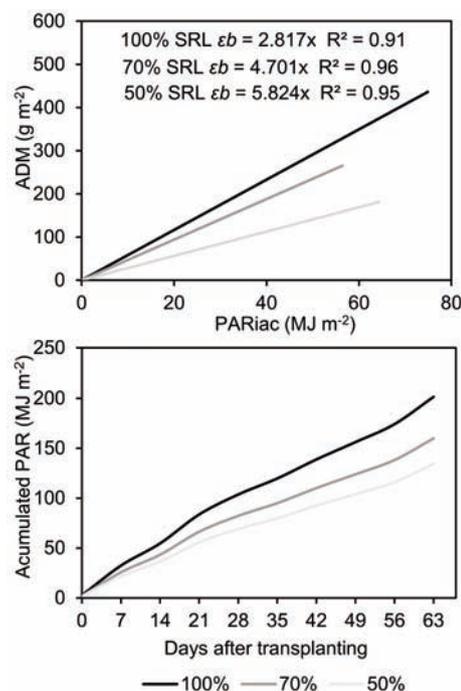


Fig. 1 - Radiation use efficiency ( $\epsilon b$ ) in g MJ<sup>-1</sup> and photosynthetically active radiation levels (PAR) accumulated over *Chicorium intybus* cycle. ADM = accumulated dry matter, PARiac = photosynthetically active radiation intercepted accumulated.

plants growing under reduced radiation availability (50% and 70%) presented respectively 51.6% and 40.1% higher radiation use efficiency than those growing under 100% of solar radiation level. Plants grown in low levels of photosynthetic active radiation were more efficient in converting the radiant energy into accumulated dry matter.

#### Growth rates and leaf traits

The absolute growth rate values were greater in the higher level of solar radiation from 42 DAT up to the crop harvest (Fig. 2A). The relative growth rate showed changes depending on the age of the plants, but for the solar radiation levels was observed difference only at 14 and 21 DAT (Fig. 2B). In relation to the net assimilation rate was not observed changes in the values in function of the solar radiation level, however, the largest net assimilation rate values were observed at 21 DAT (Fig. 2C).

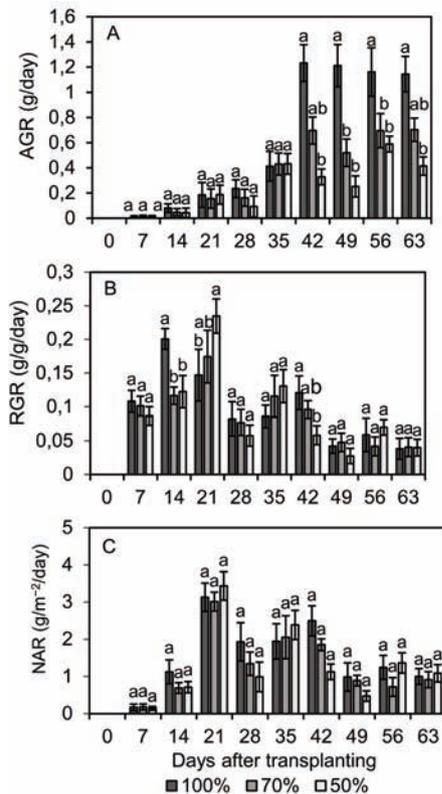


Fig. 2 - Absolute growth rate (AGR), relative growth rate (RGR) and net assimilation rate (NAR) in *Cichorium intybus* grown under different solar radiation levels. Lowercase letters denote differences within each day after transplanting by Tukey test ( $p < 0.05$ ). Bars represent average values  $\pm$  SE ( $n=8$ ).

The attenuation of 50% and 70% of solar radiation reduced the leaf area index of the plants by 51.8% and 19.8% on average when compared with the plants growing under 100% of solar radiation level from 42 DAT up to the crop harvest (Fig. 3A). For the specific leaf area, significant differences can be

observed from transplanting up to 21 DAT, where the plants under lower radiation levels showed the higher specific leaf area (Fig. 3B). In relation to the leaf area ratio, it was identified higher value only at 7 DAT for the plants under 100% of solar radiation level (Fig. 3C). Additionally, for the leaf weight ratio was not verified difference in the different shading levels (Fig. 3D).

Plants grown in lower radiation levels showed higher chlorophyll index *a*, *b*, and total, which were 19.4, 36.4 and 25.3% higher than those observed for the 100% of solar radiation level, respectively.

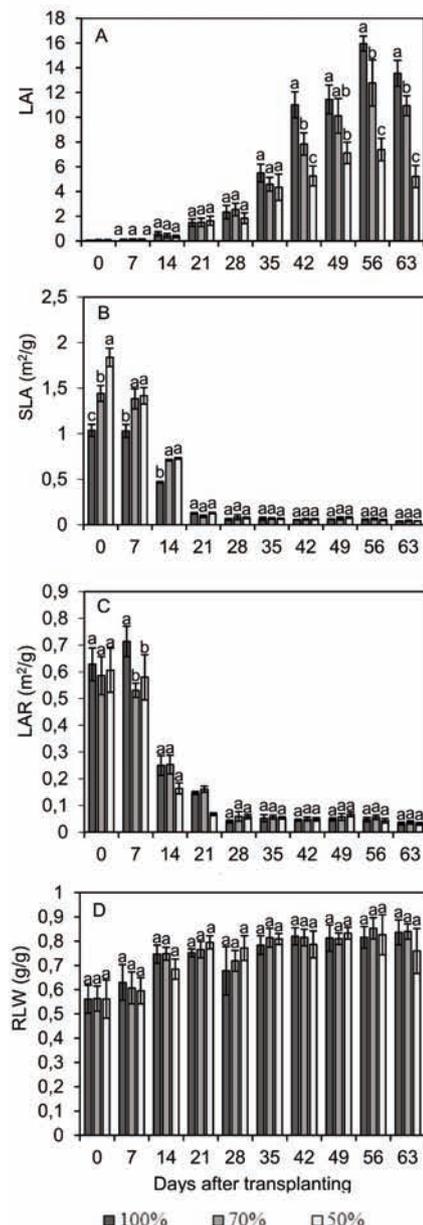


Fig. 3 - Leaf area index (LAI), specific leaf area (SLA), leaf area ratio (LAR) and leaf weight ratio (RLW) in *Cichorium intybus* grown under different global solar radiation levels. Lowercase letters denote differences within each day after transplanting by Tukey test ( $p < 0.05$ ). Bars represent average values  $\pm$  SE ( $n=8$ ).

However, plants without light restriction showed higher chlorophyll-*a/b* ratio (Fig. 4).

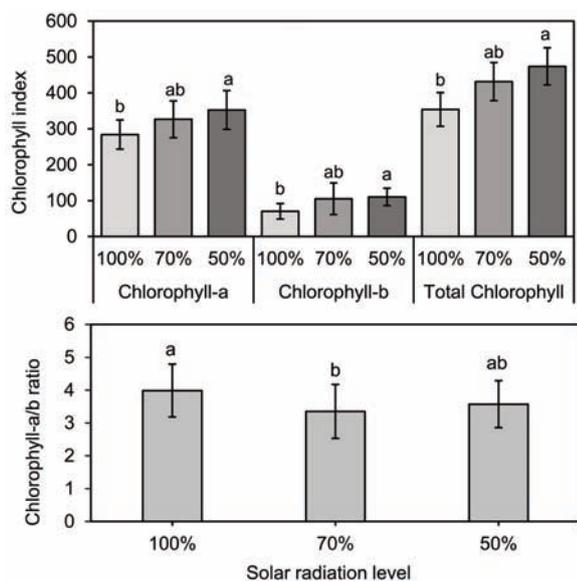


Fig. 4 - Chlorophyll-a, chlorophyll-b, and total chlorophyll index and chlorophyll-a/b ratio in *Chicorium intybus* grown under different solar radiation levels. Lowercase letters denote differences between solar global radiation levels by Tukey test ( $p < 0.05$ ). Bars represent average values  $\pm$  SE (n=8).

#### Biomass partitioning and bromatological composition

The pattern of dry matter accumulation in the leaves, roots and stem of the chicory plants was similar for all solar radiation levels; however, there was observed an increase in the proportion of leaves during the crop cycle, with a decrease in the percentage of roots and stem of the plants. This pattern of partitioning was observed for all solar radiation levels (Fig. 5).

Reduced levels of solar radiation increased the lipids and ASH contents and decreased the neutral detergent fiber, acid detergent fiber, lignin, hemicellulose and cellulose values that characterized less

rigid leaves. The crude protein content and soluble carbohydrates in neutral detergent were not affected by shading levels (Fig. 6). In overall, the bromatological traits of chicory plants were affected by the solar radiation levels.

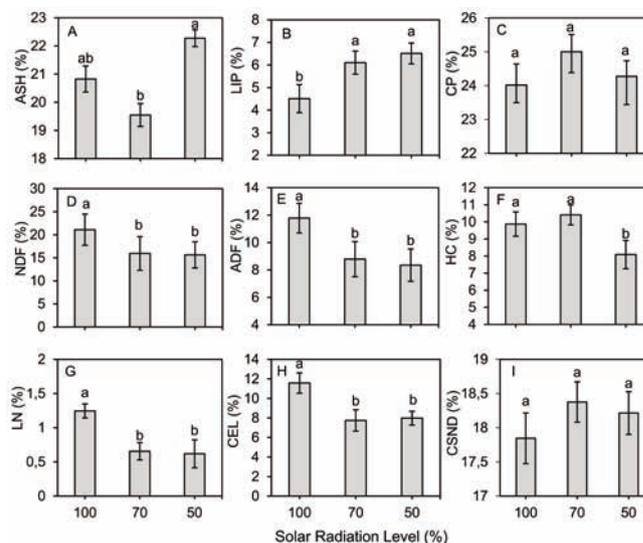


Fig. 6 - Ash percentage (ASH), Lipids (LIP), Crude protein (CP), Neutral detergent fiber (NDF), Acid detergent fiber (ADF), Lignin (LN), Hemicellulose (HM), Cellulose (CEL), Soluble carbohydrates in neutral detergent (CSND) in *Chicorium intybus* leaves growing in different solar radiation levels. Lowercase letters denote differences between solar global radiation levels by Tukey test ( $p < 0.05$ ). Bars represent average values  $\pm$  SE (n=8).

#### 4. Discussion and Conclusions

##### Solar radiation levels modify the radiation use efficiency and growth rates

The results showed that growing conditions have a striking effect on the radiation use efficiency in relation to its capacity to convert solar radiation into dry biomass. The efficiency of plants to convert solar energy into biomass was higher in low solar radiation

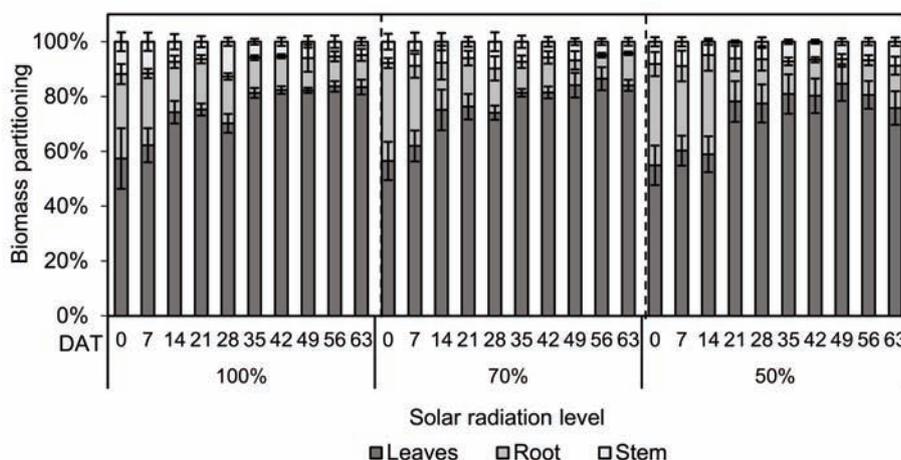


Fig. 5 - Biomass partitioning (%) in each days after transplanting (DAT) among leaves, roots and stem in *Chicorium intybus* grown under different solar radiation levels. Bars represent average values  $\pm$  SE (n=8).

level. The higher efficiency of chicory plants was not enough to compensate the limitations of solar radiation. This is justified by the higher leaf area index observed under high levels of radiation.

The highest leaf area index observed for plants growing under 100% of solar radiation may be related to the higher rate of photosynthesis, since there were no limitations on the availability of solar radiation. According to Taiz *et al.* (2017), sun leaves increase CO<sub>2</sub> assimilation having more availability of rubisco, and can dissipate excess of light energy due to a large pool of components in the xanthophyll cycle. In this sense, it is important to emphasize that plants with higher conversion efficiency are not always the ones that result in higher yield. This affirmation was confirmed in this study, where the chicory plants grown under reduced solar radiation levels were more efficient into convert solar radiation into biomass, however, showed lower leaf area index. This response can be explained due the morphological changes occurred in function of the shading conditions.

The shading effect provided by the solar radiation level of 50% significantly increased the specific leaf area of the plants mainly up to 14 days after transplantation. The decrease in leaf thickness of plants grown at higher levels of shading maybe linked to the fact that plant prefers to spend photoassimilated for the expansion of the leaf area (Cooper and Qualls, 1967; Carvalho *et al.*, 2006; Gondim *et al.*, 2008; Lenhard *et al.*, 2013), thus ensuring itself a greater possibility of intercepting solar radiation.

In chicory, the attenuation of solar radiation above the plants with the use of shading screens resulted in an alteration in leaf thickness which was responsible for changes in the chlorophyll content and bromatological composition (Sims and Percy, 1992; Terashima *et al.*, 2001; Oguchi *et al.*, 2003). This plant response is correlated, where a reduction in the leaf thickness can imply in changes in the chlorophyll content and bromatological composition depending on the intensity of leaf thickness alteration in function of the level of shading. The morphological changes were considered positive, as the leaves of these plants were more tender. This characteristic may be considered in the market commercialization due to a better acceptability of the consumer's for products with greater bromatological features.

#### *Reduced solar radiation levels improve morphological and bromatological traits of chicory*

The current study confirmed the difference in the

bromatological quality of chicory plants grown in different solar radiation level. In overall, a higher lipids content and lesser fiber, lignin, hemicellulose and cellulose components were observed under reduced solar radiation levels. This result reveals an important bromatological change, which confers more quality to the chicory produced.

The reduction of lipid content in chicory plants under high solar radiation levels may be associated with the occurrence of light saturation and photoinhibition. According to Taiz *et al.* (2017), the light saturation in the leaves of most species occurs between 500 and 1000  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , whereas the full solar radiation can provide around 2000  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . Excessive light causes damage to chloroplasts, one of the locations of fatty acids synthesis (Halliwell, 1987; Mittler, 2002; Gill and Tuteja, 2010).

The higher content of lipids in chicory plants produced under reduced solar radiation level is an important finding that can help people health, once lipids deliver energy and essential fatty acids, being essential for fat-soluble vitamin absorption, and may contain natural antioxidants (Lindley, 1998). Considering the consumer's point of view, the higher content of lipids and reduction of fiber, lighin, hemicellulose and cellulose components are favorable, since the leaves will present better characteristics for consumption.

Such effects produced by the attenuation of solar radiation can be explained due to the fact that shading reduces the availability of assimilates used for the development of secondary cell walls (Kephart and Buxton, 1993). Additionally, this fact is relevant because the lignin and cellulose components are important substances against abiotic stress, including UV-B radiation (Rozema *et al.*, 1997). In *Phalaenopsis orchids*, e.g., an increase in the lignin content in the leaves and roots of the plants where observed when the light intensity was increased, being this result associated with the induction of PAL, CAD and POD activities (Copur and Tozluoglu, 2008).

Regarding the morphological and physiological changes, the highest content of chlorophyll-*a*, *b* and total observed for the plants grown under 50% of solar radiation level is related to the need to increase the utilization of the available radiation for the plants. The current study confirmed the ability of plants to compensate the low level of radiation by increasing the number of photosynthetic pigments, which resulted in a higher radiation use efficiency by plants (Fig. 1).

Higher chlorophyll content in plants grown under

low solar radiation level is consistent with the findings of Minotta and Pinzauti (1996), Cardillo and Bernal (2006), and Hazrati *et al.* (2016). A lower chlorophyll *a/b* ratio in the lowest light intensity treatment is due to chlorophyll-*b* being degraded more slowly in shaded environments (Lee *et al.*, 2000).

Information generated in the current study is relevant, as it provides valuable information to vegetable's producers, assisting in the strategy to minimize the effect of the high solar radiation inside of the greenhouses. We proved the attenuation of solar radiation is an effective method to improve morphological and bromatological aspects of chicory. By using this simple method, both researchers and farmers might have a competitive advantage in planning their cropping systems, mainly in sites or seasons where the high light intensity is a limiting factor for chicory cropping.

Chicory plants grown in lower solar radiation levels are more efficient in converting solar radiation into dry matter, have a higher lipid content, chlorophyll index *a*, *b* and total, reduced leaf thickness, acid detergent fiber, cellulose, and lignin content, which confirm the hypothesis tested. In this study it was demonstrated that the use of shading screens is an effective method to attenuate the solar radiation; this is especially relevant in places or seasons where there is high light intensity, which contributes to achieve better characteristics of the chicory produced.

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