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Reflector materials on benches act as supplementary sources of light in rucola cultivation

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Abstract

The purpose of this work is to present an alternative to the use of lamp and light diodes to increase production systems that lead to better natural energy use and better plant development. The species *Euruca sativa L.* was used, cultivated under a protected environment, and four treatments were taken (control; glossy white laminate; bright red laminate; aluminized thermoreflective screen). Our findings showed to reduce the efficiency of laminated reflective materials in increasing rucola production. The application of the red laminate with greater efficiency, positive results with the increase of fresh matter and number of leaves, increasing the energy efficiency of the plant. Furthermore, the better use of natural light can reduce production costs, since the application of artificial light generates an increase in fixed production costs.

Keywords: *Euruca sativa*; natural lighting; protect cultivation; reflector

Introduction

Worldwide, there is a tendency to increase production under greenhouse conditions, which results in greater food safety, quality of the products obtained, increase in added value, reduction of the erosive effects of environmental elements on the physical and chemical characteristics of the soil, drop in the number of pesticides applied, reduction and/or isolation of the interaction of weeds with the crop, among other benefits. However, these cultivation systems require highly skilled labor, in addition to the use of high technology, which is accompanied by high economic costs (Chang et al., 2013; Bisbis et al., 2018; Costa et al., 2021).

Among the current technologies applied to cultivation environments, there is wide use of light supplementation with light-emitting diodes (LED), with emphasis on the production of vegetables (Hwang et al., 2020). This supplementation can vary, according to the equipment used, concerning the wavelength of the diodes, quality and light intensity, promoting changes in the photosynthetic process of plants, changing their behavior and providing better production conditions (Tang et al., 2019).

For species of the Brassicaceae family, for example, supplementation with LED exerts significant changes in the photosynthetic process, increasing the production of marketable organs (He et al., 2015, Dou et al., 2020), in addition to chemical compounds beneficial to human health (Tan et al., 2020), however, there are variations for not only the intensity of light used but also for the wavelength emitted depending on the sets of LEDs used.

The combinations between the colors used in LED light supplementation are responsible for changes in the morphophysiological behavior of the plants. In this sense, red spectra, with wavelengths close to 660 μmol m^{-2} s^{-1} are

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intrinsically related to increased synthesis of secondary metabolites and the efficiency of the photosynthetic system, as it directly interferes with the photochemical phase. On the other hand, supplementation with white lights, which consist of a combination of different spectra, including the participation of green, provides less photosynthetic capacity, and, consequently, decreases the accumulation of carbon (C), the development and productivity of plants, in comparison with the red spectrum (He et al., 2015; Dou et al., 2020), since light supplementation with a higher wavelength of red along with a lower wavelength of blue provides greater photosynthetic capacity in the plant.

Despite being very widespread, the materials used for light supplementation are expensive, significantly burdening their installation in protected cultivation environments and making their application limited (Morrow, 2008; Nelson & Bugbee, 2014) and are dependent on stable electricity further increasing costs.

In this sense, and bearing in mind the hypothesis that other materials could have a similar effect to the detriment of commercial technologies, that is, increasing the photosynthetic photon flux (PPFD), different reflective coverings were used on benches, within an environment protected, to expand the offer of photosynthetically active radiation to the abaxial parts of the leaves and to verify if these materials could be used as luminous supplementation, interfering in the physiological and productive characteristics of rucola.

Material and Methods

Experimental conditions

To evaluate the effect of different bench surfaces on plant growth, physiological parameters and production of rucola (*Euruca sativa* L.) a pot experiment was carried out in a protected environment. The experiment was carried out from March to April 2019 in the experimental area of the State University of Mato Grosso do Sul, University Unit of Cassilândia, Brazil. A total of 48 plastic pots (1.0 dm^3) were used, arranged in a completely randomized design with four repetitions of each treatment [4 surfaces composed of different materials on the bench].

The “Folha Larga” rucola seeds were purchased commercially, in their packaging to maintain their vigor. Five seeds were sown in each plastic pot filled with 1.0 dm^3, containing commercial substrate (Carolina Soil®) and after the emergence of the seedlings, thinning was done to keep two plants per container. For the formation of treatments with different coatings of bench surfaces (metal benches 1.40 m wide x 3.50 m long x 0.80 m high) the following reflective materials were used: 1 – Control, no material on the bench surface; 2 – glossy white laminate; 3 – bright red laminate; 4 – aluminized thermoreflective mesh.

Gas exchange and water use efficiency

Twenty-five days after sowing, four plants were randomly selected and evaluated for characteristics of net photosynthesis (A), stomatal conductance (gS), intracellular CO_2 concentration (Ci) and transpiration (E) during the morning, when the plants are in full gas exchange activity, between 8 and 10 am. For the evaluations, healthy leaves without signs of senescence or mechanical damage were selected, using a portable photosynthesis meter (LCi, ADC Bioscientific, Hertfordshire, United Kingdom) and the water use efficiency (WUE) was calculated using if the ratio between net photosynthesis and transpiration (A/E).

Chlorophyll and growth attributes

After performing the physiological analyses, the relative content of chlorophylls was evaluated using a digital chlorophyllometer (CCM-200, Opti-Sciences, Hudson, USA), and the plants were harvested to obtain the leaf area by evaluation in the EasyLeafArea program (Easlon and Bloom, 2014), the fresh mass and dry mass of the aerial part was measured by weighing on an analytical balance after harvest and after drying in a forced ventilation oven at 65ºC until mass stabilization was verified.

Statistical analysis

Data were submitted to preliminary normality and homoscedasticity tests. Then, the means were submitted to analysis of variance (ANOVA) and the LSD test, at the level of 5% probability. Analyzes were performed using SISVAR statistical software (Ferreira et al., 2014).

Results and Discussion

It was found that, although the photosynthetically active radiations external and internal to the environment remained constant, the radiation reflected by the benches varied depending on their color (**Figure 1**).

Regarding the availability of photosynthetically active radiation within the protected environment, which effectively reached the benches, there was a reflectance of this in the order of 7.38%, 17.55%, 11.42% and 11.70% in the treatment control and on countertops covered with a bright red laminate sheet, glossy white laminate sheet and reflective mesh, respectively.

It was found that the color of the benches

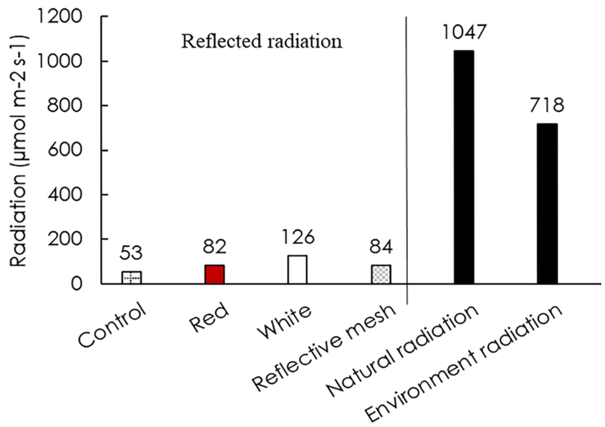

Figure 1. Average values of external and internal radiation to the protected environment and radiation reflected by the different bench covers.

significantly altered the intracellular CO concentrations of the rucola plants, in which all the covered benches outperformed the control treatment (**Figure 2**A).

This superiority was also observed for stomatal conductance, but with an emphasis on the reflective mesh (silver), with no significant difference for the red cover (Figure 2B).

With the use of reflective materials on the cultivation benches, there was greater supplementation of photosynthetically active reflective radiation mentioned above (Figure 1), which penetrates the abaxial part of the leaves and reaches the leaf mesophyll, being used in the photochemical phase in chloroplasts, resulting in a higher rate photosynthetic, thus requiring greater accumulation of intracellular CO_2 (Figure 2 A) in the mesophile to ensure this greater carboxylation (Figure 2 D), directly interfering (positively) with stomatal conductance and leaf transpiration (Figure 2 B and C).

For transpiration and the rate of net assimilation variables, there was a significant superiority of the coverings composed of the red laminate and the reflective mesh, followed by the white laminate, resulting in the case of the reflective bench with red material, provided greater supplementation of photosynthetically active radiation with a wavelength of red, which directly interferes with the net assimilation rate, keeping the stomata open for a longer time to ensure greater photosynthetic activity, thus increasing leaf transpiration (Figure 2C and 2D). In addition, the control treatment outperformed the other

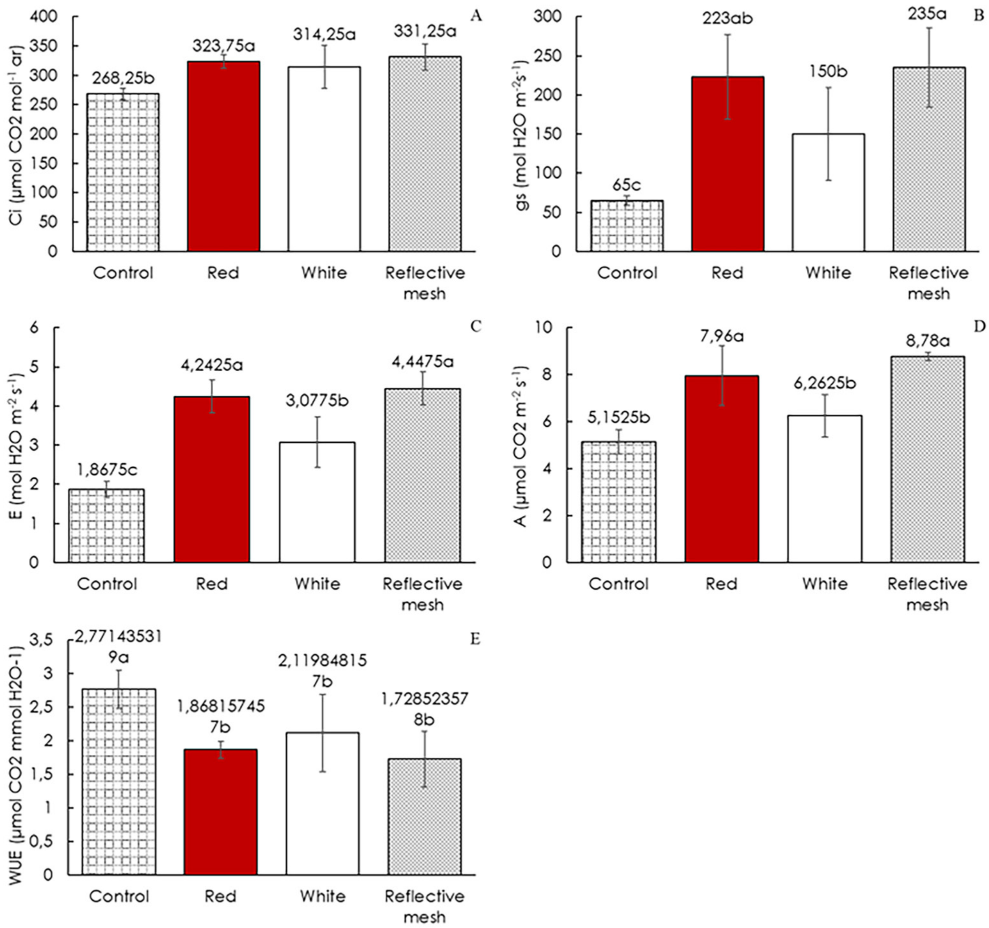

Figure 2. (A) CO_2 intracellular concentration, (B) stomatal conductance, (C) transpiration (D) Net photosynthesis and (E) water use efficiency in rucola plants growth on different bench reflective materials (Bar represented mean ± SE.; n = 4).

treatments in terms of water use efficiency (Figure 2E), as the treatments with coverage provided better conditions for the metabolic activities of the rucola, requiring greater amounts of water.

It was found that for the variables number of leaves and fresh mass of leaves there was a superiority of the treatment composed by the red laminate over the control treatment. However, the red laminate did not differ significantly from the white laminate and reflective mesh (**Figures 3**A and 3D).

There wasn't a difference between these three treatments for the leaf area variable, despite the superiority of the treatment consisting of the reflective mesh over the control (Figure 3B).

For the relative content of chlorophyll, the control treatment stood out, with no difference for the treatment consisting of the white laminate (Figure 3C). On the other hand, for the variable of the dry mass of leaves, the control treatment was significantly inferior to all other treatments (Figure 3E).

It was found that for the variables number of leaves and fresh mass of leaves there was the superiority of the treatment composed by the red laminate over the control treatment. However, the red laminate did not differ significantly from the white laminate and reflective mesh (Figures 3A and 3D). There was also no difference between these three treatments for the variable leaf area, despite the superiority of the treatment consisting of the reflective mesh over the control (Figure 3B).

Plants are autotrophic organisms, dependent on light to carry out the conversion of light energy into chemical energy for the production of phytomass, thus responding to environmental micrometeorological variations when under varying lighting conditions. In this sense, the present study contains the first report of the physiological and morphological changes that occurred through the use of reflective materials on cultivation benches, which increased the offer of photosynthetically active radiation to the abaxial parts of the rucola leaf and promoted better plant growth.

The positive effect of inserting reflective materials in the cultivation environment is evident when an increase in physiological activity is verified (Figure 2), which results in increased growth and changes in the

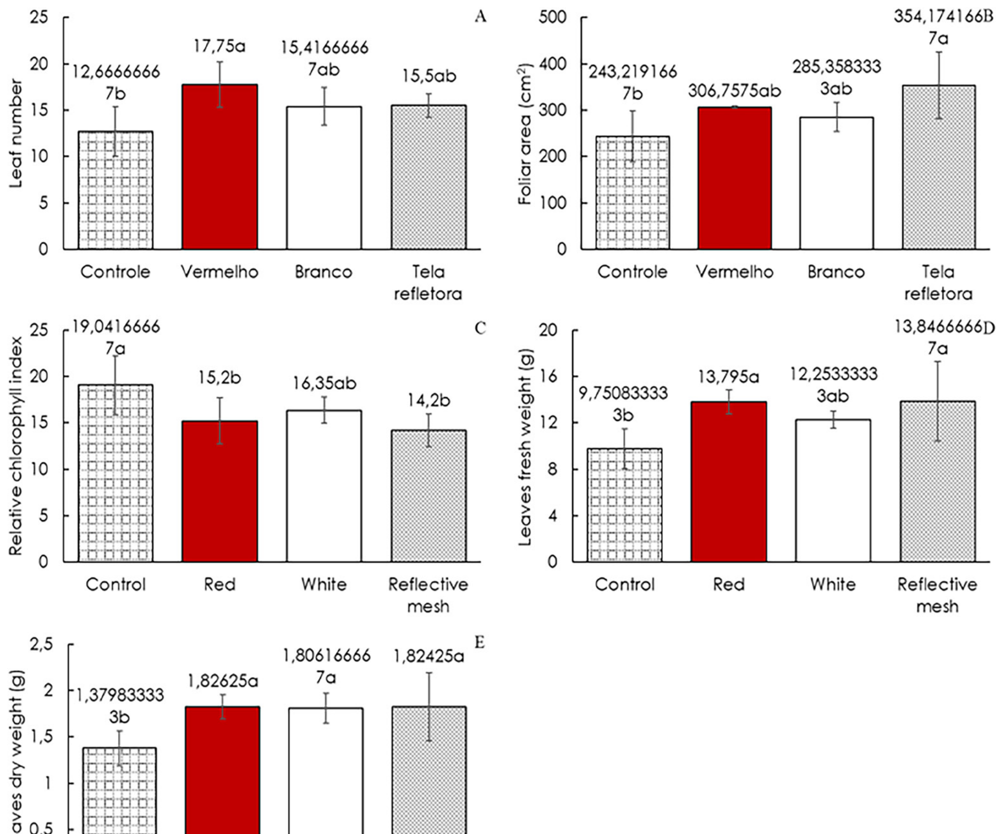

Figure 3. (A) Leaf number, (B) foliar area, (C) relative chlorophyll index (D) leaves fresh weight and (E) leaves dry weight of rucola plants growth on different bench reflective materials (Bar represented mean ± SE.; n = 4).

morphological characteristics of the plants (Figure 3). This effect is related to the luminosity reflected by the materials (Figure 1), which is close to the PPFD intensities used for supplementation with LED lighting for several horticultural crops, such as Brassica rapa subsp. chinensis var. parachinensis (Tan et al., 2020), Brasica olearacea var. capitata L. (Mizuno et al., 2011) and Lactuca sativa L. (Li & Kubota 2009; Stutte et al. 2009).

The increments obtained with the introduction of reflective materials in terms of Ci (Figure 2) are related to the increase in gas exchange, which can be observed in the higher rates of E and gS. This increases the capacity of the plant regarding the entry of atmospheric gases and, consequently, the assimilation of CO_2, represented by A, which is also influenced by the better penetration of light into the aerial part of the plants (Burgess et al., 2017). This set of responses decreases the WUE, due to the loss of water through gas exchange processes with the environment, without negative effects on the photosynthetic capacity.

The set of positive physiological changes with the introduction of reflective materials also implies greater growth and changes in morphological characteristics (Figure 3). The higher rate of atmospheric CO_2 assimilation influences the production of new vegetative organs and their expansion, also increasing the accumulation of phytomass in these organs (Figure 3 E). It is also noteworthy that the lower relative content of chlorophylls is another characteristic that evidenced the greater photosynthetic efficiency of cultivated plants on reflective materials. This result may be related to the higher efficiency of PSII and the rate of electron transport through photosystem II (PSII) in plants with lower chlorophyll content (GU et al., 2017), characterizing an adaptive change to the environment, in environments with greater irradiance.

The visible electromagnetic spectrum is composed of frequencies visible to the human eye, for plants, certain visible bands are necessary for proper plant development. Under constant study, the intensification of the supply of certain colors in the visible spectral range can provide production increases (Dutta & Agarwal, 2017). It is also known that the widespread application of the recommended color ranges is not efficient for all crops. (Khoramtabrizi et al., 2020).

There are several factors involved in this process, which respond to the chemical part (mobilization of the metabolic necessary for the production of ATP to occur), structural (which will be defined by the leaf architecture of the species), and, in a way, the transmission (which it will depend on the quality of the emitted light – ideal light) and the reflection of the plant. In nature, plants that grow in a forest condition, or low light, need to adapt to make the best use of light under the foliage of large trees (Mwendwa et al., 2019). This condition dictates the ideal light range for the development of certain species, with this, the application of artificial light can be diverse within the spectrum range, requiring greater or lesser incidence of a specific range.

Through the use of benches with reflective materials, it is possible to partially supply the demand for light retained by the protected environment; providing the supplement photosynthetically active radiation (PAR), which is directly involved in plant growth and development, is a fraction of global radiation (visible spectrum band), directly linked to the plant's photochemical process, also alters the spectral balance of the plant's environment cultivation, as they emit specific wavelengths, captured by the plant's photoreceptors, resulting in changes in the morphophysiological behavior of the plant. The morphophysiological behavior of the plant is directly influenced by the genotype (genetic characteristics), which can be influenced by the environment, mainly solar radiation. Changes in the growth and development pattern of the plant, concerning the distribution of dry mass in the different organs of the plant, ensuring better biometric growth rates, but the technology needs to be improved for each species and cultivar used.

In the visible spectrum, the longer the wavelength of red light with the lowest energy level. However, with frequencies close to the chlorophyll absorption peak (Brown et al., 1995), it contributes better to the photosynthetic process, contributing to the formation of vegetative organs such as the stem and leaves (Hung et al., 2016). This study corroborates the data found in the present work, also showing the increase in plant growth due to the increase in the dry mass of the leaves (Figure 3 E). Studies suggest that despite the low energy production at the center of the photosynthetic reaction, red light complementation is advantageous in environments enriched in distant light (Mascoli et al., 2020). This complementation with red light leads to improvements, mainly, in Photosystem II of photosynthesis, with a more efficient reoxidation, therefore, faster release of reaction centers and better use of photons (Zhen & Iersel, 2017).

In addition to the red-colored material, the introduction of the white laminated material supplemented the total fresh mass growth, with improvements in several other parameters compared to the control. Other studies suggest a better use of white light with increments of red light, with different intensities according to the need of each crop (Brown et al., 1995; Lazzarini et al., 2017; Zhen & Iersel, 2017). White lights, which consist of a combination of different spectra, including the participation of green in small amounts, improve plant growth due to better light penetration in the system (Lazzarini et al., 2017).

Our findings make it possible to confirm that the insertion of reflective materials may appear as an alternative source of photosynthetically active radiation supplementation, due to the changes observed in the physiological and morphological characteristics of the plants. This new information applies to other growing environments in addition to greenhouses. For example, the use of mulching in the production of horticultural species or even perennial plants such as coffee can change its development differently, depending on the color used, since these materials can increase the light supply in the lower leaves or even in the inside the canopy of the vegetable.

In addition, based on the results obtained, we evidenced the efficiency of laminated reflective materials in the physiological and productive gain of arugula, mainly with white and red colors, through luminous supplementation by the reflection of natural light. Based on the results obtained, it can be inferred that the use of natural light promotes a reduction in production costs as a result since the application of artificial light generates an increase in fixed production costs. Thus, the use of reflective materials, in addition to demonstrating positive effects for the development of vegetables, is a solution for reducing energy consumption in the system, promoting more sustainable crops when compared to crops under artificial light.

Conclusion

The use of benches with reflective material in red color provided greater growth of rucola (dry phytomass and number of leaves) compared to production in a traditional bench, due to the higher photosynthesis rate (A) under increased supplementation of reflected photosynthetically active radiation. Thus, the use of reflective materials on benches can be used as a light supplement.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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