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Hydroponic rocket salad growth and production according to different color profiles

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ABSTRACT

The aim of this study was to evaluate the influence of different profile colors based on nutrient flux on microclimate, growth and yield of four rocket cultivars. The experiment was conducted during four months in a protected environment in the NLT system, which consisted of benches composed of eight hydroponic profiles for the plants conduction. The treatments were arranged in a 4x2x2 factorial design, with four cultivars (Cultivada, Folha Larga, Rococo and Runway), two color profiles (black and white) and two growing seasons (autumn and winter). The experiments were conducted in a randomized block design with three replications. The evaluations were realized on every four days, throughout the growth period. Leaves fresh and dry mass, stems and roots, plant height, leaf number and leaf area index were evaluated. The different color profiles resulted in variations on crop growth and production due to the thermal changes within the hydroponic profile. The greatest growth and increased productivity were obtained from plants cultivated in white growing channels during the autumn. The cultivars Cultivada, Folha Larga and Rococo have similar performance, better than ‘Runway’.

Keywords: *Eruca sativa*, NLT, temperature, dry mass, yield.

RESUMO

Crescimento e produção de rúcula em sistema hidropônico com diferentes cores de perfis

O objetivo deste estudo foi avaliar a influência de diferentes cores de perfil de cultivo em NLT sobre o microclima, o crescimento e a produção de quatro cultivares de rúcula, em duas estações do ano. O experimento foi conduzido durante quatro meses em ambiente protegido, no sistema NLT, constituído por bancadas, compostas por oito perfis hidropônicos para a condução das plantas. Os tratamentos foram arranjados em esquema fatorial 4x2x2, sendo quatro cultivares (Cultivada, Folha Larga, Rococó e Runway), duas cores de perfis (preto e branco) e duas estações de cultivo (outono e inverno). Os experimentos foram conduzidos em delineamento experimental em blocos casualizados, com três repetições. As avaliações foram realizadas a cada quatro dias, durante todo o período de crescimento. Avaliou-se a massa fresca e seca de folhas, caules e raízes, altura de planta, número de folhas e índice de área foliar. As diferentes cores de perfis provocaram variações no crescimento e produção da rúcula em razão das modificações térmicas no interior do perfil hidropônico. O maior crescimento e maior produtividade foram obtidos em plantas cultivadas em canais de cultivo de cor branca, durante o outono. As cultivares Cultivada, Folha Larga e Rococó apresentam desempenho produtivo semelhante, sendo superiores a ‘Runway’.

Palavras chave: *Eruca sativa*, NLT, temperatura, massa seca, produtividade.

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The hydroponic cultivation of vegetables stands out for providing higher yield, uniformity and product quality. In addition, the more efficient use of production factors, especially water and nutrients (Castellane & Araújo, 1994), greater control of climatic conditions and less use of pesticides, provides a regular supply of the crops, minimizing the effects of seasonality and can provide growers higher competitiveness and better prices (Paulus *et al*., 2012).

Among the leafy vegetables grown in hydroponic systems, the rocket salad (*Eruca sativa*) is standing out on the world due to its high nutritional content, short cycle, high production per area and wide acceptance by consumers, mainly due to its unusual organoleptic characteristics (Reghin *et al*., 2005; Amorim *et al*, 2007). The rocket is considered a medicinal plant with many properties such as gastrointestinal, diuretic, stimulant laxative, anti-inflammatory and it is also considered source of Vitamin C and iron (Amorim *et al*., 2007).

The rocket production can be done throughout the year, but its growth is favored by mild temperature conditions. Temperatures above 30°C can stimulate the plant to anticipate the reproductive phase, with a prematurely floral tassel emission, making its leaves more rigid and spicier (Filgueira, 2003). According to Furlani *et al*. (1999), for a better crop growth and development, the temperatures should be about 25°C during the day and 17°C at night, with a relative humidity around 65%. Thus, the crop is been produced mainly on the

South and Southeast of Brazil.

According to Mattos *et al.* (2001), another important factor to be considered for obtaining high yields is the radiant energy balance on the bench, which can be different depending on the cover material, conditioning the air temperature inside the solution circulation channel, which is part of the root system development environment. The thermal regime in the roots environment can affect water and nutrients absorption and the plant shoots and roots growth (Yan *et al*., 2012).

The expression of the productive potential of the rocket salad depends on the environment, however the choice of the cultivar is also decisive for the success of the cultivation system adopted (Echer *et al*., 2001). The cultivars currently available on the market differ mainly for the leaf type, which can have flat or jagged edges (Sala *et al*., 2004).

Fontes (2005) affirm that there is a lack of knowledge about the genotype interactions; cultural techniques in hydroponic vegetable production, requiring research to improve this technology. Despite its importance for the Brazilian agriculture, the hydroponic cultivation of rocket salad is still little studied and an increase on the demand for this crop leads to a lack of technical informations, especially related to the crop management.

According to this, the present study aimed to evaluate the influence of different color profiles on microclimate, growth and production of four rocket salad cultivars during two seasons.

MATERIAL AND METHODS

The experiment was conducted during the autumn and winter periods, 2012, at the experimental area of Federal University of Santa Maria in Frederico Westapalen, Rio Grandedo Sul State, Brazil (27^{0}23’S, 53^{0}25’W, 490 m altitude) with a climate classified as Cfa, humid temperate with hot summer, according to Köppen (Alvares *et al*., 2013). The experiment was conducted in a protected environment with metallic structure, with dimensions of 10x20 m and 3.0 m in height with side curtains and covered with transparent low density polyethylene film, 150 μ of thickness, treated to block ultraviolet radiation with 87% of transmittance, nonselective.

The treatments were carried out in a 4x2x2 factorial scheme, with four cultivars: Cultivada, Folha Larga, Rococó and Runway; two colors of hydroponic profiles: black and white; and during two seasons: autumn and winter. The experimental design was in randomized blocks with three repetitions. Thus, the system was formed by hydroponic benches with 10 grown profiles (with a total of 30 profiles), 240 plants per bench and 720 plants for the whole experiment, being 360 for the white profile and 360 for the black profile.

The seedlings production was performed in phenolic foam trays with cells of 2.5x2.5x2.0 cm and seven seeds per cell. Sowing for the autumn season was held in April and for the winter season in June. After sowing, the phenolic foam trays were placed on a flat PVC plate with a slope of approximately 4%, where they remained until the transplantation. After the first leaf emergency, the thinning was carried out, remaining five seedlings per cell.

For the seedlings production, a commercial nutrient solution, recommended for leafy vegetables, was used, with the following nutrients composition (%): 10 (N), 9 (P_2O_5), 28 (K_2O), 3,3 (Mg), 4,3 (S), 0,06 (B), 0,01 (Cu), 0,07 (Mo), 0,05 (Mn) and 0,02 (Zn). For the preparation of 1000 L, 660 g of the compound was used, with 485 g of calcium nitrate and 18 g of Fe EDTA, being diluted to 50% of the concentration and provided in 15 minutes of irrigation turns with 60 minutes of interval during daytime (6 am to 9 pm). During the growing season, the moisture of the phenolic foam trays was evaluated and the interval between irrigations was set according to climatic conditions observed in the period. At night, two irrigations of 15 minutes were held, at 12 am and 3 am.

Seedlings were transplanted to the final production benches when the second leaf was visually identified. The transplant took place 20 days after sowing for the two evaluated seasons. The hydroponic benches were formed by 10 profiles, 6.0 m long, 9 cm wide and 5 cm deep, alternating colors, with four black profiles and four white profiles, painted with plastic white ink. On each side of the bench, a border profile was kept. The spacing used was 25 cm between plants in the profiles and 17 cm between plants of the different profiles. The system was powered by two sets of pumps with $^1/_3$ cv and two fiber glass tanks with 500 L capacity, both painted with white acrylic ink, one for receiving the nutrient solution from the white channels and one for receiving the nutrient solution form the black channels.

A dual system of supply and solution collection from the benches was installed. The nutrient solution was pumped and collected at the end of the hydroponic benches by collecting troughs, featuring a closed system, being supported by iron trestles with approximately one meter in height and arranged to provide a 4% slope in the profiles. The used nutrient solution was the same for the seedlings production, prepared for a 100% of its concentration. Each reservoir accommodated 400 L, corresponding to the nutrient solution volume of 1.11 L/plant.

The control of the pH and electric conductivity of the nutritive solution was performed daily, using a digital pH meter (Model AP-009IA) and conductivity meter (Az-8301 model). The pH of the nutrient solution was maintained around 6.0 (±0.5), and due to higher pH of the water used to formulate the solution, a sulfuric acid (H_2SO_4) solution at 10% of concentration was used to make the adjustment. Whenever the electrical conductivity of the nutritive solution reached 75% of the initial concentration, a replacement of 25% of the nutrients was carried out. Throughout the experiment no waste of the nutrient solution was performed. In addition to the daily monitoring of pH and electric conductivity, the solution level in the reservoir was also monitored through the water replacement in order to keep 400 L of solution.

The growth evaluations started after transplantation and were repeated on every four days intervals, totaling 11 evaluations at the end of each experiment. In each evaluation three samples of five plants of each treatment (a sample for each repetition) were collected randomly. After the collection, the plants were immediately taken to the laboratory and separated into leaf, stem and root system. Therefore, the number of leaves was determined (being considered all identifiable leaves, except cotyledon), root length and plant height (with the aid of a graduated ruler) and total leaf area, using the leaf area meter (Li-3100 Area Meter, LIQUOR, USA). The leaf area index was calculated as the ratio of canopy leaf area and the unit area projected onto the ground (m^2/m^2). The samples were weighed on an analytical scale to determine the fresh weight of each part. After weighing, the material was placed in a circulating air oven at 65°C until constant weight to determine the dry mass.

For the record of the air temperature inside the greenhouse a thermo-hygrometer (S1615 model, PCD) was installed in the center of it, at a height of 1.4 m. For the record of the air temperature inside the cultivation profiles at three times during the day (9 am, 3 pm and 9 pm), two digital thermo-hygrometers were installed (Model HTR-170), one in the white profile and the second in the black profile. The data of global solar radiation were obtained from an automatic station of the National Institute of Meteorology (INMET) located about 300 m from the greenhouse.

The data were submitted to analysis of variance and for the growth evaluations the means of the treatments were submitted to the adjustment of the regression models and to evaluate the production at the end of cultivation, the means were compared by Tukey´s test at 5% of error probability using the statistical package SISVAR (Ferreira, 2010).

RESULTS AND DISCUSSION

The average air temperature and solar radiation during the fall and winter seasons and temperature inside the hydroponic profiles are shown in Figure 1. Meteorological data showed that the average air temperature recorded in the autumn season was 18.1°C and during winter was 18.2°C. For the average minimum temperature values of 11.5°C were recorded for the autumn season and 13.7°C for the winter season. The maximum temperature recorded in the autumn season was 27.7°C and during winter was 24.3°C. The results showed a temperature range of 16.1°C during autumn and 10.6°C for the winter.

For proper growth and production of larger and tender leaves, the crop requires air temperatures between 15 and 18°C (Filgueira, 2003). Furlani *et al*. (1999) emphasize the importance of variation in temperature between day and night for the crop to get the best growth and development, with daytime temperatures around 25°C and night temperatures around 17°C, which means a temperature range of 8°C. In this study the temperature range values were higher than those mentioned above.

The global solar radiation, observed outside the greenhouse in the autumn season oscillated between a minimum value of 7.46 and a maximum value of 19.14 Mj/m^2/day, with an average of 13.64 Mj/m^2/day (Figure 1B). In the winter season, the solar radiation ranged from the minimum value of 7.76 and a maximum of 15.99 Mj/m^2/day, with an average for the period of 13.02 Mj/m^2/day.

Regarding the air temperatures inside the profiles, it is possible to observe in Figures 1A and 1B, that higher temperatures, for both seasons, were observed inside the black profile. Mattos *et al*. (2001) highlight the importance of considering the radiant energy balance on the hydroponic benches, which may vary with the color of the PVC profile, affecting the air temperature in the circulation channel of the solution, which is part of the root growth environment.

The variables in the experiment were affected by cultivars, hydroponic color profile and growing season, however, no significant interaction between these factors was observed. Thus, regression analysis was performed for plant growth parameters for the different evaluation dates. For other factors a mean test was performed with the data of 40 days after transplant, when the plants achieved the harvest point. For the evaluations of leaf and root dry mass and leaf area index (LAI) in both color profiles (Figures 2A, 2B and 2D) it is possible to observe that from 20 days after transplantation the white profile resulted in higher means, and the difference increased until the end of the cycle, when the superior percentage for the white profile for leaf dry mass was 25%, 36% for the root and 16% for the leaf area index.

At the end of the experiment the obtained shoot dry mass values (stem and leaves) was higher for 'Cultivada' and lower for 'Runway'. Santos *et al*. (2011), in a study conducted with two nutrient solutions, in Santa Maria, obtained for the average of the two treatments, lower values for the 'Folha Larga' and 'Rococo' cultivars. The cultivar 'Bella', which has similar characteristics of the aerial parts than 'Runway', presented higher shoot dry mass.

The variable plant height showed higher daily increment when grown in white profile, from the eighth day after transplantation (Figure 2C). These results show that some influence may exist on the growth environment provided by the white profile, being more suitable for culture. The largest reflection of solar radiation in the white profile may have contributed to increasing the amount of scattered radiation, which, according to Costa *et al*. (2011), is more efficient for the plant photosynthetic process.

The leaf dry mass production between the two evaluated seasons (Figure 2E) was higher in the autumn, from 28 days after the transplant, becoming more significant at the end of the cycle. This difference probably occurred because of the more favorable temperature and solar radiation for the carbohydrate production in autumn, as shown in Figures 1A and 1B.

Evaluating the accumulation of root dry mass during rocket growth in the two seasons, we observed that it is possible to observe similar performance

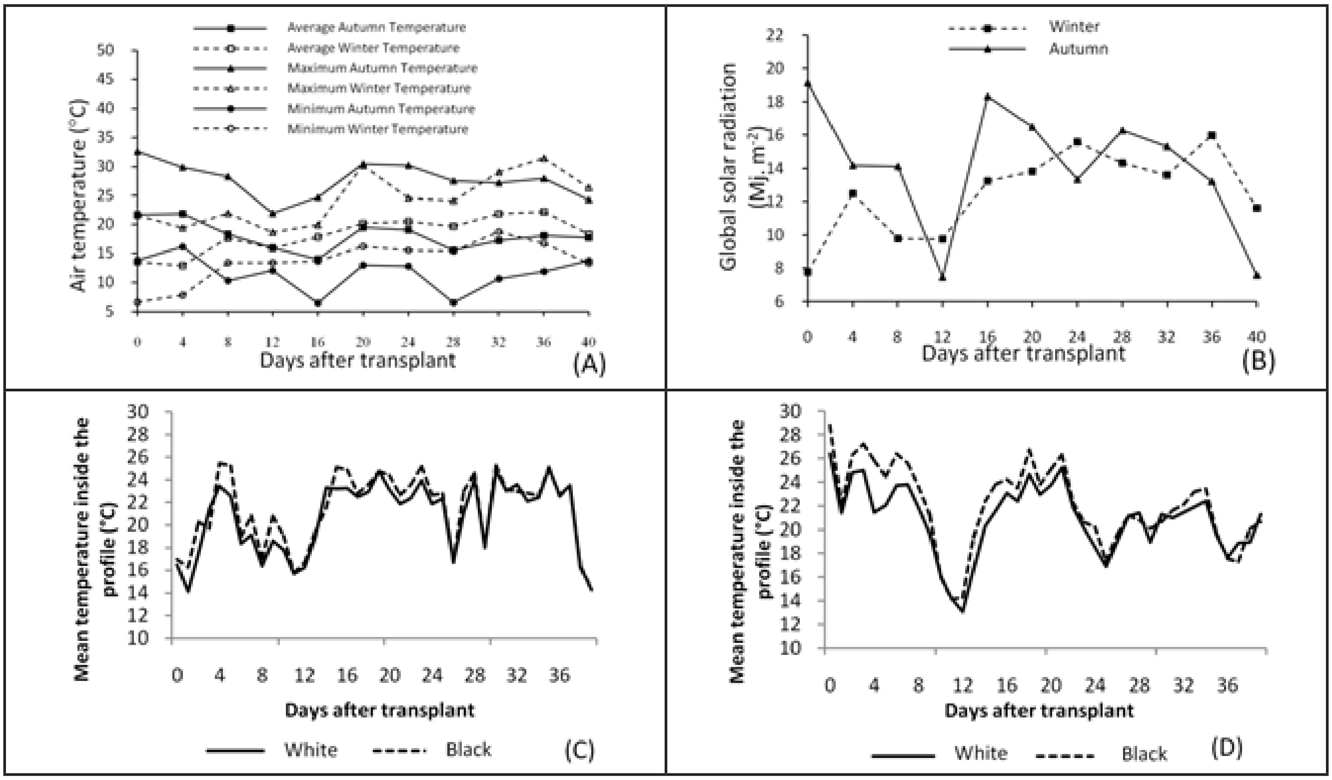

Figure 1. Variation in the air average, maximum and minimum temperature inside the oven (A). Variation of the global solar radiation (B), during the rocket salad cultivation in autumn and winter. Air temperature variation within the growing profile in the fall (C) and winter (D) at different evaluation times during the rocket salad cultivation. Frederico Westapalen, UFSM, 2012.

up to 20 days after transplanting. From this moment, the autumn season showed superiority until the end of the cycle, being 47% higher than the winter season. At the end of the cycle, the root dry mass accumulation was 68.72 g/m² and 46.76 g/m² for the autumn and winter seasons, respectively (Figure 2F). The superiority of the autumn season is possibly related to the temperature of the nutrient solution and the environment inside the growing profile, which was lower during the autumn season. The temperature variation was probably influenced by the variation of the solar radiation, which at the end of the cycle was higher for the winter season. As commented by Yan *et al*. (2012), in optimal temperatures the transpiration rate rises and consequently reduces growth and mass accumulation.

From the plant height analysis in the two evaluated seasons, we observed that until 16 days after transplanting the performance was similar for the two seasons, and after this date, the winter season resulted in superior trend for this variable, becoming more significant from 28 days after transplantation (Figure 2G). In the autumn, the incident solar radiation decreases, while during the winter the opposite occurs. These informations are in accordance to the observed data in Figure 2G, in which it is possible to observe an inversion in these two lines along the rocket salad cycle.

Regarding the leaf area index in the two evaluated seasons (Figure 2H), it is possible to observe the superiority of the winter season, which at the end of the cycle was 3.74, being 3.0% higher than the autumn season, that achieved the mean of 3.63. Suiting the leaf area obtained by Silva *et al*. (2008) in a study of five soil salinity levels and four different substrates to plant density of this study (117.65 plants/m²), the average of the treatments resulted in a leaf area index of 2.68, lower than the one observed in the present study for the average of four cultivars in two growing seasons. In comparison to the rates obtained for each cultivar in both color profiles and in two seasons, the cultivar Runway presented the lowest performance.

Another possible connection is to the temperature of the nutrient solution and the environment within the growing profile. According to Mattos *et al*. (2001), the black color absorbs greater amount of solar energy in form of heat and diffuses part of the heat to the circulating nutrient solution and to the internal profile of the environment, which might interfere negatively on the crop growth.

For the leaf and root dry matter of the four cultivars, there was slow initial growth of all materials close to 16 days after transplantation, for both variables (Figure 3A and 3B). There was a similar performance throughout the cycle of the cultivars Folha Larga and Rococo with a trend of superiority for 'Cultivada' at the end of the cycle. On the density of 23.5 plants/m^2, plants achieved, at the end of the experiment, the following leaf dry mass: 'Cultivada' 293.33 g/m², 'Folha Larga' 257.10 g/m², 'Rococo' 256.45 g/m² and 'Runway' 140.49 g/m². These results showed a final production of 'Runway' 52% lower than 'Cultivada".

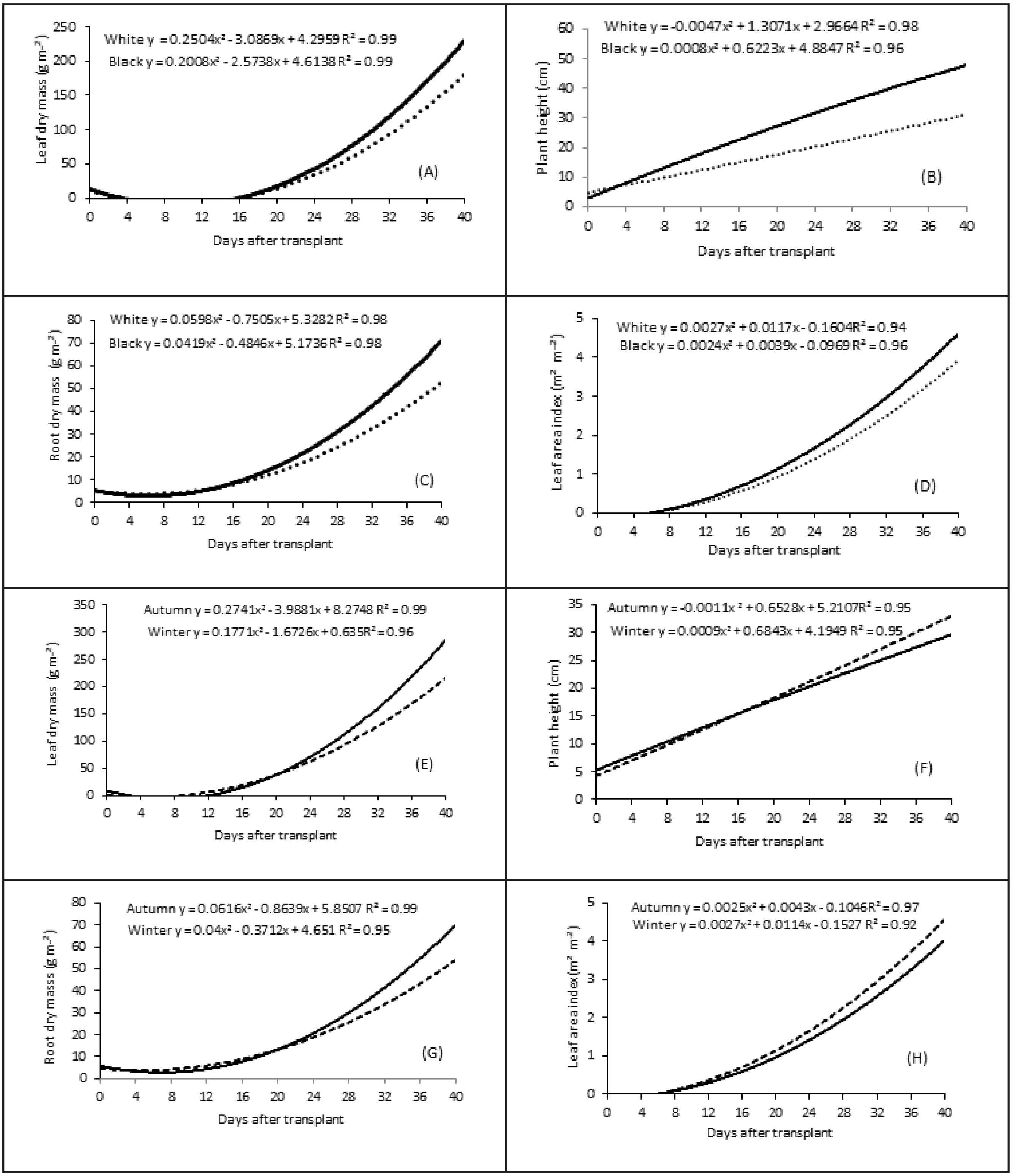

Figure 2. Leaf dry mass (A= profile color, E= season), root dry mass (B= profile color, E= season), plant height (C= profile color, G= season) and leaf area index (D= profile color, H= season) of rocket cultivars during the growth cycle. Frederico Westapalen, UFSM, 2012.

The production of root dry mass remained similar for the four evaluated cultivars, up to 24 days after transplantation, when the Runway cultivar presented lower performance, compared to other cultivars. At the end of the experiment, the cultivar Cultivada presented root dry mass of 73.93 g/m², being 48% higher than 'Runway' (50.08 g/m²). The superiority of 'Cultivada' was also observed in relation to the 'Rococo' and 'Folha Larga', being 38% for both cultivars. The cultivars Folha Larga and Rococo remained similar throughout the entire cycle, with root dry mass content of 53.40 and 53.56 g/m² respectively, at the end of the cycle (data not shown). The 'Runway', even

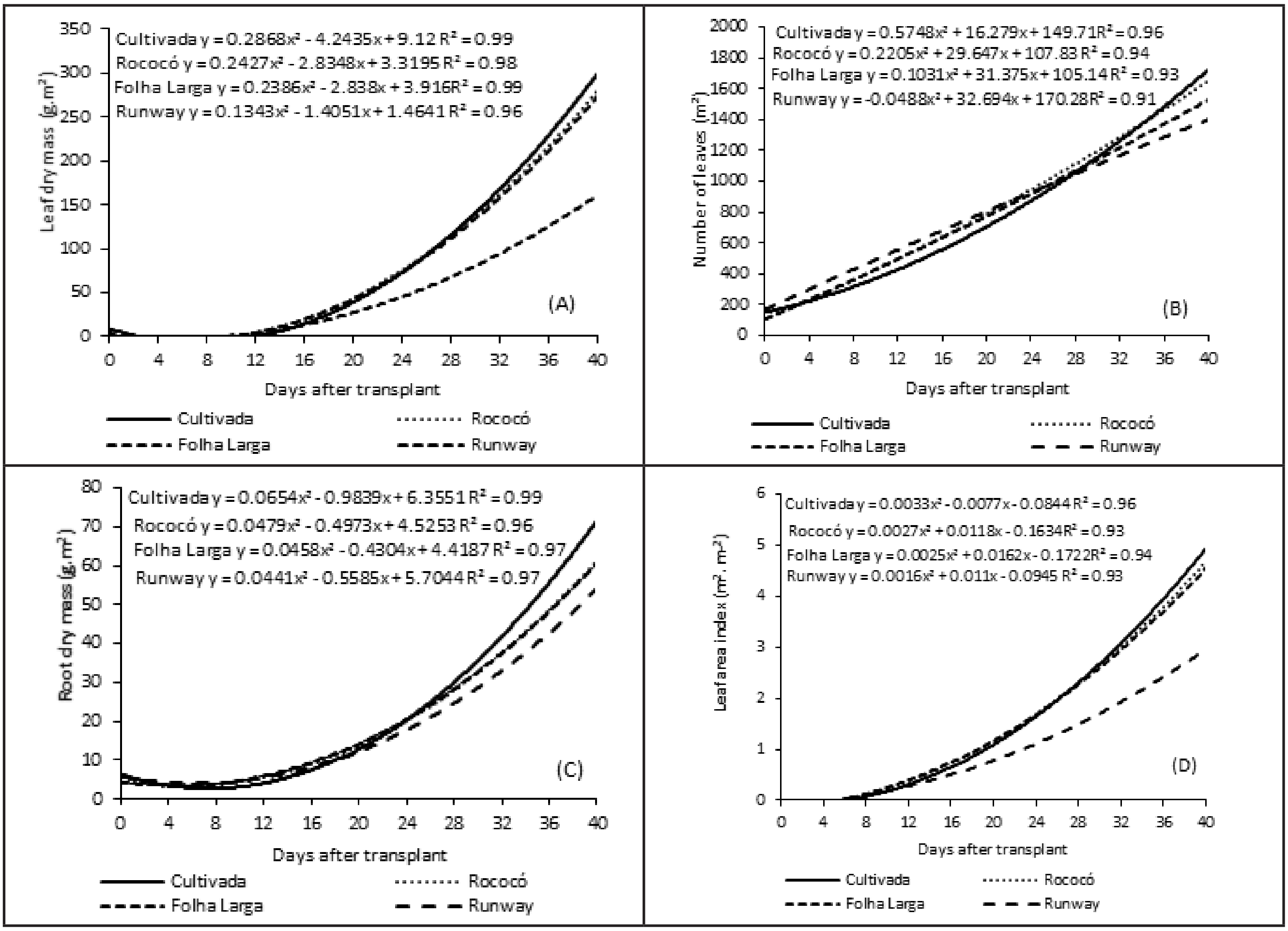

Figure 3. Leaf dry mass (A), root dry mass (B), number of leaves (C) and leaf area index (D) of four rocket cultivars during the growth cycle. Frederico Westapalen, UFSM, 2012.

with lower production of shoot dry mass, showed similar performance to 'Folha Larga' and 'Rococo' in the evaluation of root dry mass. Regarding the number of leaves, similar performance between cultivars Folha Larga, Cultivada and Rococo was observed throughout cycle, with a greater dispersion at the end of the cycle (Figure 3C). Cultivar Runway showed superior performance during the entire cycle, when compared to others.

The trend of stabilization of leaf emergence, when the plant is physiologically ready for commercial harvest, was observed between 28 and 32 days after transplanting in the autumn season, and during winter at 36 days after transplantation, except for 'Rococo' and 'Cultivada' in the autumn, which presented a rise between 36 and 40 days after transplantation. Transforming the results of the experiment in number of leaves per plant, the average of the experiment at the end of the cycle was 12.18 leaves per plant. This result is similar to that obtained by Freitas *et al.* (2009), who obtained 11.69 leaves per plant on average of two growing seasons between June and October 2005, in an experiment conducted in Mossoró, Rio Grande do Norte State, Brazil.

The leaf area index for the cultivars Cultivada, Folha Larga and Rococo presented similar trend until 36 days after transplant, when 'Cultivada' stood out. On 16 days after transplant, the cultivar Runway presented lower performance, that was evident through the cycle (Figure 3D). The cultivars Cultivada, Folha Larga and Rococo tended to be similar until the 36 days after the transplant, when the 'Cultivada' presented different response. The 'Runway' presented lower performance from 16 days after transplanting and this performance became increasingly evident throughout the cycle (Figure 3D).

Table 1 shows the data for leaf fresh mass, number of leaves, plant height and leaf area index at the end of the cycle, when the plants reached the harvest point. For fresh mass production of the cultivars Folha Larga, Cultivada, Rococo and Runway, it is possible to observe that 'Cultivada' promoted the bests results, but with means that were not different from those achieved by 'Folha Larga' and 'Rococo'. The smallest was observed for 'Runway'. The lower performance of 'Runway', for most of the evaluated parameters is possibly due to its jagged leaf morphology, unfavorable to the leaf mass accumulation.

Between the color profiles, the fresh mass production was 19% higher in plants grown in white profiles, compared to those in black profiles. This result may be related to variations in the root system optimum temperature for growth due to high temperatures

Table 1. Leaf fresh mass (LFM), number of leaves (NL), plant height (AP), leaf area index (LAI) 40 days after transplanting of four rocket cultivars grown in hydroponic system and cultivated with two color profiles during autumn and winter seasons. Frederico Westapalen, UFSM, 2012.

Cultivar	LFM (g/m^2)	NL	AP (cm)	LAI
Cultivada	2394.01 a	1558.86^{ns}	30.19^{ns}	4.47 a
Folha Larga	2080.11 a	1445.13	27.91	3.89 a
Rococó	2066.01 a	1403.95	28.24	3.95 a
Runway	1185.35 b	1325.52	27.94	2.40 b
Profile color				
Black	1763.76 b	1416.70^{ns}	28.22^{ns}	3.40 b
White	2098.98 a	1450.03	28.91	3.96 a
Season				
Autumm	2032.45^{ns}	1474.55^{ns}	27.60 b	3.63^{ns}
Winter	1830.29	1392.19	29.53 a	3.73
CV (%)	23.62	15.79	10.20	20.24

*Means followed by the same letters in the column do not differ according to Tukey´s test at 5% of significance.

and high incidence of light, causing a reduction in the growth rate, due to the increased temperature of the circulating nutrient solution in the root zone in black profiles. According to Cometti *et al*. (2013), in hydroponic cultivation systems, the temperature of the nutrient solution is closely related to the amount of oxygen (O_2) dissolved in the solution. According to these authors, increasing the solution temperature results in a release of the O_2, reducing the respiration of the root system.

The plant height at the end of the cycle was not influenced by cultivars or color profiles. Only the growing season affected this variable. The maximum height observed during the autumn season was 27.6 cm and during the winter season was 29.53 cm, which could be related to the lower solar radiation in the period, increasing the competition between plants and resulting in an elongation of support tissues. The values obtained in this study were lower when compared to those reported by Costa *et al*. (2011), which on the average of six treatments obtained 32.65 cm at 44 days after sowing. On the other hand, they were significantly higher than 20.74 cm, observed by Luz *et al*. (2011) and also for the 25.35 cm observed by Freitas *et al*. (2009), on the average of two growing seasons.

The leaf area index varied according to cultivars and profile colors. The results indicated that the ‘Cultivada’ presented higher leaf area index, 13% higher than ‘Rococo’, 15% higher than ‘Folha Larga’ and 86% higher than ‘Runway’. It is possible to observe that the leaf area index do not follow the trend of the number of leaves, being more evident for ‘Runway’ due to its irregular leaf format. This characteristic lead to a difference in the leaf area, even with the same number of leaves, or higher, when compared to other cultivars. Figueiredo *et al*. (2010), studying the relation between leaf area, number of leaves and fresh and dry biomass for the rocket, concluded that there exist little relation between the number of leaves and the increase in the leaf area, being the difference less evident at the beginning and at the end of the crop cycle. According to Sala *et al.* (2004), in Brazil the preference of consumers and wholesalers is for bigger leaves, with a long petiole and with a dark green color.

For the profile colors, the higher leaf area index (LAI) was achieved with the use of the white profile, being 16.5% higher than the ones grown in black profiles. The leaf area is important because it is a growing variable that can indicate yield since the photosynthetic process depends on the sunlight absorption and its conversion in chemical energy, and this is a process that occurs in the leaf. According to Oliveira *et al*. (2013), the leaf area reduction is an important mechanism of adjustment for plants grown under stress, such as in higher temperatures, since under these conditions, the reduction on the respiration rate is important.

The temperature in the root zone is an important factor that can affect the plant growth and water and nutrients absorption (Yan *et al*., 2013). In a study conducted with sweet pepper submitted to different nutritive solutions in hydroponic systems, Dodd *et al.* (2000) observed that the crop growth is accelerated in temperatures of 20°C, when compared to 30°C. Yan *et al*. (2012) related that the specific absorption rates for plant nutrients depends on the root system temperature, and even a little increase in temperature can promote big changes on plant growth and nutrients absorption, affecting the yield.

According to this, one of the main characteristics of the hydroponic cultivation is the possibility to control the nutrient solution or root system temperature. Thus, the correct choice of the hydroponic profile color represents an easy option of management to control the nutritive solution temperature, reducing the need of an environment management to control the root system temperature.

It is possible to conclude that the rocket salad cultivars presented a higher growth when cultivated in white profile during autumn. The use of the black profile resulted in more oscillation of the root system temperatures. The cultivars Cultivada, Folha Larga and Rococo presented a similar productive performance, being greater than ‘Runway’.

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