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RESEARCH ARTICLE

GROWTH ANALYSIS AND COMMERCIAL YIELD OF ROCKET PLANTS UNDER DIFFERENT SHADING SCREEN

[1]Tiago Pedó, [1]Felipe Koch, [1]Emanuela Garbin Martinazzo, [1]Simone Morgan Dellagostin, [1]Geison Rodrigo Aisenberg, [1]Vinicius Jardel Szareski, [*,1]Ivan Ricardo Carvalho, [1]Maicon Nardino, [3]Velci Queiróz de Souza, [2]Daniela Meira, [1]Francisco Amaral Villelax and [1]Tiago Zanatta Aumonde

[1]Federal University of Pelotas, Brazil
[2]Federal University of Santa Maria, Brazil
[3]Federal University of Pampa, Brazil

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ABSTRACT

This study aimed to evaluate the growth and yield of rocket plants under different screens shading. It was used rocket seeds of Folha Larga cultivar, which plants were cultivated in a greenhouse in black polyethylene pots without shading, with black and red shading screen, both with 35% light reduction, adopting completely randomized design with 11 collection times. The no shading rocket plants showed higher values for total dry matter, relative growth rate and net assimilation, compared to the screens of red and black shading, respectively. However, the leaf area ratio was higher in plants under the effect of black screen and, leaf matter ratio was higher in plants under red screen. The higher leaves yield was obtained without shading, then red and black screen. The growth and commercial yield of rocket leaves was favored in shading condition with red screen.

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INTRODUCTION

The rocket (*Eruca sativa* Mill.) is plant belonging to the Brassicaceae family, this leafy vegetable is very consumed in the form of salad (Costa *et al*., 2011; Pinheiro *et al*., 2012). Its leaves are characterized by having mild pungency, depending on the genotype and cultivation environment (Filgueira, 2007). In Brazil, the largest consumers are the south and southeast regions, however, consumption is increasing in other regions of the country (Sediyama *et al*., 2007). Cultivation in greenhouse has advantages in the development of plants, especially the increase of productivity and quality in natura of leaves and fruits, better use of factors of production and supply of products throughout the year (Filgueira, 2007), as well to promote the cultivation in warm climates (Costa *et al*., 2011). The production of assimilates and their availability for plant growth and fruit production can be increased by increasing irradiance. However, when the solar radiation is too high, there is an increase in the transpiration rate of plant, causing stomatal closure and reduction of photosynthesis (Andriolo, 2000). The shading screens with different pigments have been used with the intention to change the spectral quality of solar radiation, the search for benefits in crop production (Pinheiro *et al*., 2012). This is because light makes an important role in the regulation of primary production, contributing effectively to the growth of plants (Dousseau *et al*., 2007). The intensity and spectral quality of light radiation make an important role in the morphological development of the plants, aiming better efficiency of the photosynthetic apparatus as the capture and use of radiant energy (Martins *et al*., 2009). In this sense, research on utilization shading screens in several species have been developed, such as *Melissa officinalis* L. (Meira *et al*., 2012), *Solanum lycopersicum* L. (Silva *et al*., 2013) e *Raphanus sativus* L. (Cabanez *et al*., 2015). The vegetables production under the effect of shading screens, in places with high temperature and luminosity, provides best conditions environment, reducing the intensity of radiant energy and allowing better fit its distribution (Pinheiro *et al*., 2012), with complex effect on growth, development and crop yield. The effect of solar radiation may be evaluated by analysis of plant

Corresponding author: *Ivan Ricardo Carvalho,
Federal University of Pelotas, Brazil.

growth characteristics, when the plants are subjected to different luminosity conditions. However, the shading effect on growth and yield is dependent on the intensity and duration of the incident solar radiation (Lacerda *et al*., 2010). The study of the vegetables under different spectral light qualities is essential to enable the understanding of the responses of each species, allowing adopt more efficient management practices. In this sense, it is important to evaluate the effect of light quality on growth and yield of rocket plants. This study aimed to evaluate the growth and commercial yield of rocket plants under different shading screens.

MATERIALS AND METHODS

The experiment was carried out in a chapel model greenhouse, automated with temperature and humidity control, coated polycarbonate, presented 39% reduction in relation to the external environment. Its arrange is in north-south direction, the Federal University of Pelotas, located at latitude 31o52 'S, longitude 52o21' W and 13 m of altitude. The climate of this region is temperate with well distributed rainfall and hot summer, Cfa by Köppen. We used rocket seeds Folha Larga® cultivar, and the seedlings were produced in polystyrene trays of 200 cells, containing commercial substrate (H. Decker®). Seedlings were transplanted when they presented at the stage of final third open leaf to black polyethylene pots, with a capacity of 0.036 m^3, containing soil substrate horizon A1 from Planosol Haplic Eutrophic Solodic. The basic fertilization was performed with triple superphosphate, potassium chloride and urea, according to soil analysis and based on Fertilization and Liming Manual for the states of RS and SC (CQFS RS/SC, 2004). It was adopted spacing of 0.15 x 0.09 m, adapted from Filgueira (2007) and irrigation was located, by microaspersion, according to the water requirements of plants. The pots were arranged on wooden benches constructed to 1.0 m from the floor, provided with rectangular structures from wood 1.5m high, with support function for shading screens (Sombrite®), which were arranged to isolate the top and four sides of each level of shade structures, with the same screens with individual covers and round-robin distribution of vessels performed weekly. Treatments consisted of three levels of shading: without shading, with red and black shading screens. The shading screens presented of 35% shading, according to manufacturer's specifications. From the transplant, successive samplings were made, at regular intervals of seven days until the end of the plant development cycle (77 days after transplantation - DAT), data of primary growth. At each samplings, the plants were separated into organs (shoots, roots and inflorescences, when present) and taken to forced ventilation oven at 70 °C until constant weight. The leaf area (La) was determined with the area meter mark Licor - modelo LI-3100, the leaf area index (L) calculated by the formula L = La/Ss, being Ss the soil surface susceptible to leaf coverage. The primary data of accumulated total dry matter (W_t) were adjusted by simple logistic equation, $W_t = W_m/(1+A\ e^{-B\ t})$, being **$W_m$** an asymptotic estimate of the maximum growth, “**A**” and “**B**” constants adjustment “**e**” natural base logarithm and "**t**", the time in days after transplantation (Richards, 1969). The primary data leaf area (La) were adjusted by orthogonal polynomials (Richards, 1969). The instantaneous values of dry matter yield rate (Ct) were obtained by fitting equation derived from the total dry matter (Wt) and leaf area (La) versus time (Radford, 1967). For determining the instantaneous value of relative growth rate (Rw) was applied to the equation $R_w=1/W_t.d_W/d_t$, where d_W corresponds to the derivative of dry matter and d_t is equal to the derivative with respect to time. The instantaneous values of net assimilation rate (Ea), leaf area ratio (F_a), leaf matter (F_w) and specific leaf area (S_a) were estimated by the equation: $E_a=1/A_f.dW/dt$; $F_a=A_f/W_t$; $F_w=W_f/W_t$ and $S_a=A_f/W_f$, by Radford (1967). The harvest index (Hi) was determined by the equation $H_i=W_f/W_t$, is the W_f leaves dry matter that make up the trade of this species, and W_t the total dry matter of the plant. The evaluation of the commercial leaf yield was conducted at 42 DAT, being evaluated fresh matter of leaves, expressed in g $plant^{-1}$. In addition to these, at the time of the last collection in 77 DAT, was evaluated the number of siliques, obtained by direct counting and expressed in units per plant. The data of maximum and minimum temperatures and solar radiation were obtained by mercury thermometer and pyranometer, respectively, at 1.5 m from the floor and located inside the greenhouse (Figures 1a; 1b). The experimental design was completely randomized in a factorial scheme (three types of shading x 11 times). Evaluations of growth were carried out with three replications and to yield were evaluated 30 repetitions for each treatment. The primary growth data were submitted to analysis of variance at 5% probability and comparatively analyzed and interpreted based on curves trends (Radford, 1967; Dias AND Barros, 2009). The data on harvest index and commercial yield were submitted to analysis of variance, and when F values were significant, the Tukey test was applied, to 5% probability.

RESULTS AND DISCUSSION

Analysis of variance for primary growth data is represented in Table 1. From the analysis of the mean squares for data of leaf area and dry matter of organs, it is observed that there was significant (5%) between the types of screens shading and sampling times. The production of dry matter of leaves, roots and inflorescence presented mean square values with significance level of $p \leq 0,05$.

Tabela 1. Resumo da análise de variância com os quadrados médios da área foliar (A_f), matéria seca de folhas (W_{pa}), de raízes (W_r) e inflorescência (W_{in}) (Summary of the analysis of variance with the mean squares of the leaf area (L_a), dry matter of leaves (W_{pa}), roots (W_r) and inflorescence (W_{in})). Capão do Leão, Universidade Federal de Pelotas, 2014

		Mean Squares			
Fv	GL	L_a	W_{pa}	W_r	W_{in}
Conditions	2	319874.3*	79.02*	1.14*	0.27*
Times	10	474104.9*	129.45*	0.99*	0.34*
CON x TIM	20	95403.8*	12.05*	0.18*	0.12*
Residue	64	1825.2	0.30	0.02	0.006
Total	98				
Mean		318.12	2.91	0.27	0.09
CV(%)		13.43	18.98	53.48	82.58

Meaningfulness Level (p * = 5%).

Total dry matter (W_t) of rocket plants, regardless of the treatment, set the logistics trend, with a high determination coefficient ($R^2 \geq 0,97$). The initial growth was slow until 42 days after transplanting (DAT), with a maximum allocation of dry matter to 77 DAT (Figure 1c). The W_t was lower when in rocket plants under the effect of black shading screen, probably due to lower solar radiation values (Figure 1b). It is possible that the reduction of amount and quality of available light for the plant canopy has affected photosynthesis, and reflected in lower production biomass (Wahid *et al*., 2007; Lambers *et al*., 2008). This may have caused imbalance in the carbon balance of plants and reflected in the growth in biomass terms (Silva *et al*., 2013). Costa *et al*. (2011) evaluated the performance of rocket cultivars under black shading screen and in the open field, reported an increase in dry matter of plants under such light quality.

limiting factor for growth and crop yield (Wahid *et al*., 2007). It is probable that the greatest quantity and quality spectral of light, be reflected in higher C_t when plants were kept without shading compared to those evaluated other environmental conditions submitted. Relative growth rate (R_w) showed maximum values in the initial stages of plant development (7 DAT), with a further decrease until the end of the crop cycle (Figure 1e). The maximum values of R_w occurred in plants without shading, red and black screens, respectively. From the 35 DAT, there were decreased of R_w of the plants without shading, while under red or black shading screen, the reduction

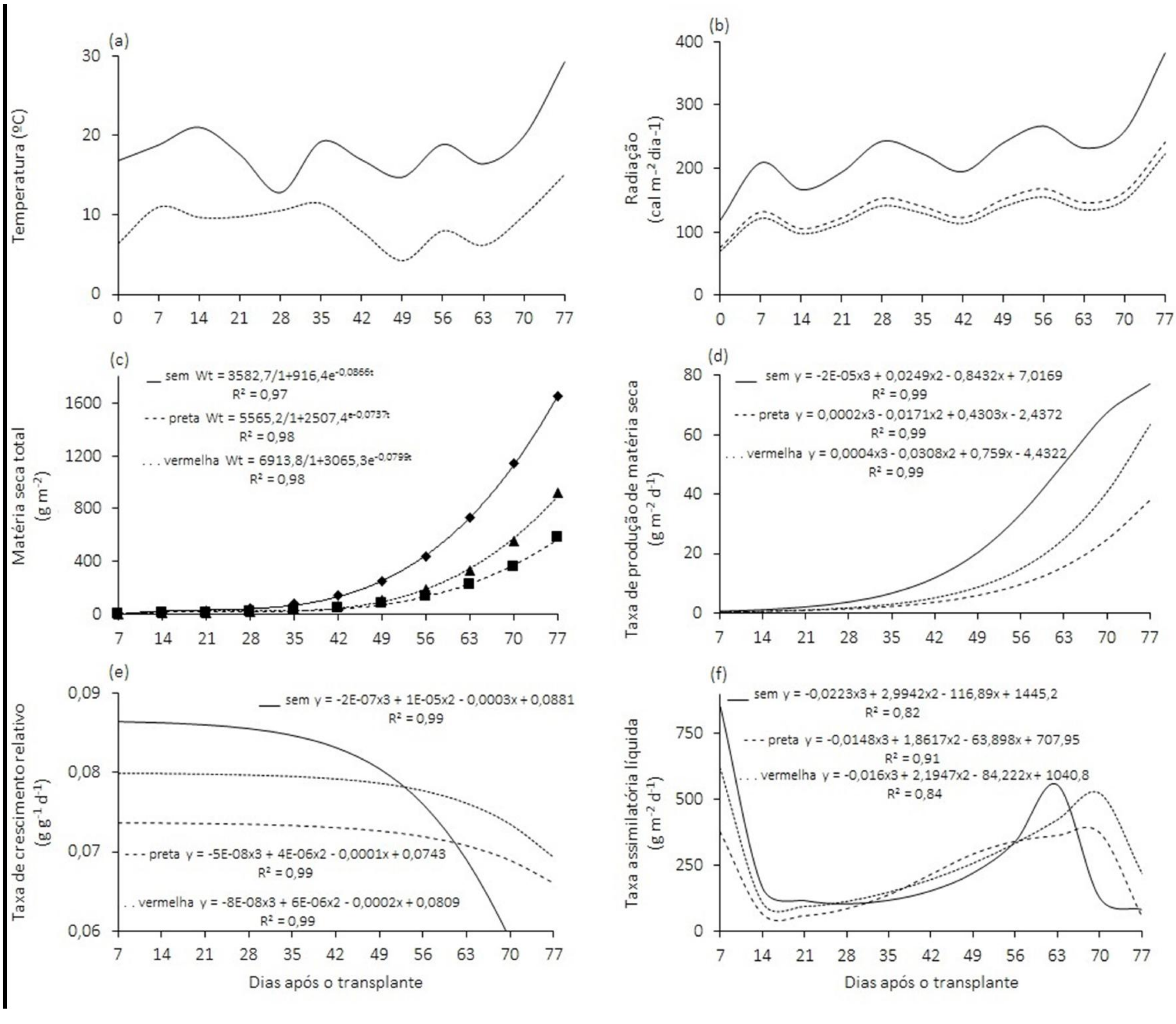

Figura 1. Temperaturas máxima e mínima (a), radiação solar (b), matéria seca total (c), taxa de produção de matéria seca (d), de crescimento relativo (e) e taxa assimilatória líquida (f) de plantas de rúcula sob efeito de telas de sombreamento (Maximum and minimum temperatures (a), solar radiation (b), total dry matter (c), dry matter production rate (d), relative growth (e) and net assimilation rate (f) of rocket plants under the effect shading screens). Sendo: sem sombreamento (———), tela preta (– – –) e vermelha (----) (where: whitout shade (———), black (– – –) and red screens (----)). Capão do Leão, Universidade Federal de Pelotas, 2014

The maximum dry matter production rates (C_t) occurred at 77 DAT, in plants grown under different shading screens (Figure 1d). Plants without shading showed higher dry matter production at 77 DAT, compared to those under the effect of black or red screens. It is observed quantitative change in C_t, is important to note that, the excess or reducing radiation is a

of R_w started at 56 DAT. It is evident that the different types of shading effected the capacity increase of dry matter in relation to that pre-existing, occurring temporal-quantitative change with fostering to plants without shading. The higher initial R_w can be attributed to the high photosynthetic capacity of young leaves (Aumonde *et al*., 2011) or the largest solar radiation available to the photosynthetic process (Pedó *et al*., 2011).

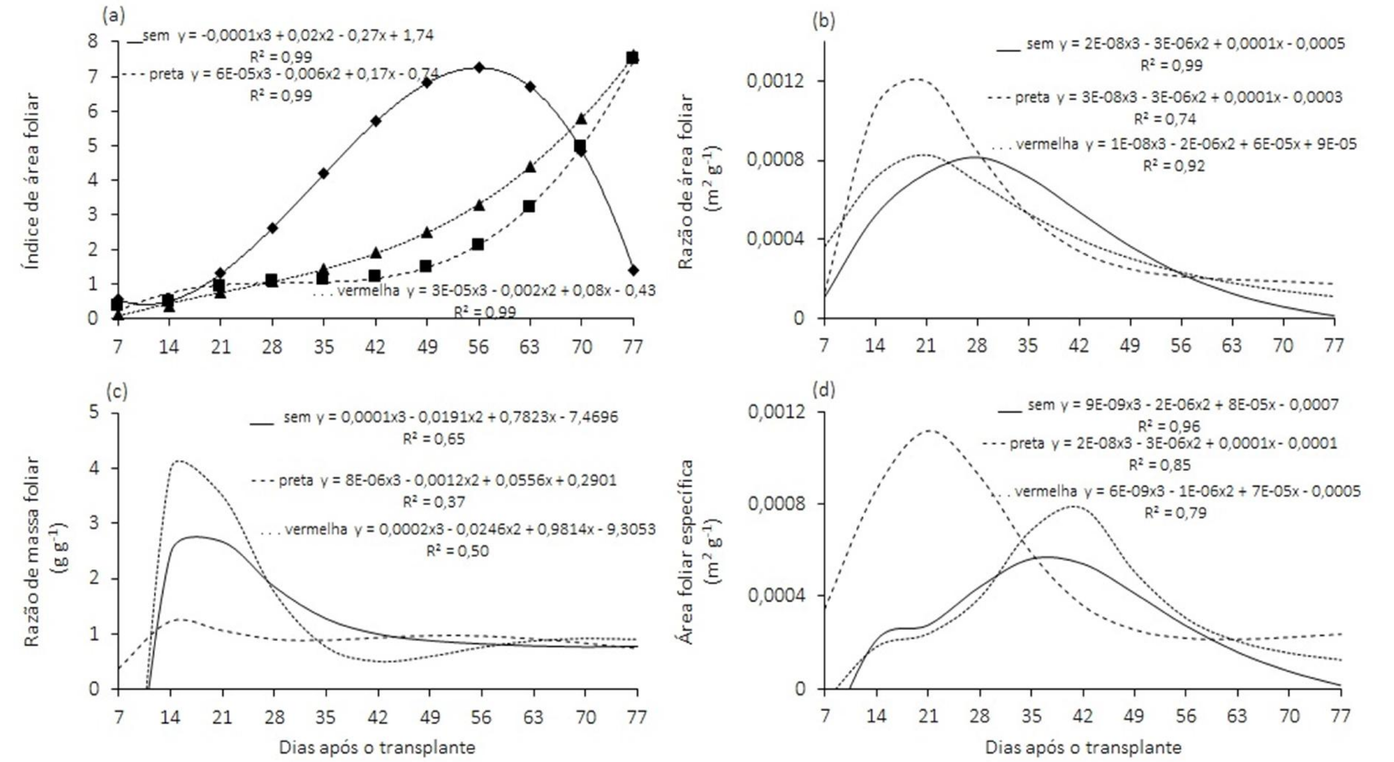

Figura 2. Índice de área foliar (a), razão de área (b) e de massa foliar (c) e área foliar especifica (d) de plantas de rúcula submetidas a telas de sombreamento (Leaf area index (a) area ratio (b) and leaf matter (c) and specific leaf area (d) of rocket plants submitted shading screens). Sendo: sem sombreamento (———), tela preta (– – –) e vermelha (- - - -) (where: whitout shade (———), black (– – –) and red screen (- - - -). Capão do Leão, Universidade Federal de Pelotas, 2014

According Barreiro *et al*. (2006), the increased R_w in initial plants development can be explained by the increased activity of the respiratory organs growth or expansion. The net assimilation ratio (E_a) observed in plants without shading was higher compared to under the effect of shading screens (Figure 1g), corroborating the C_t and W_t values (Figure 1c, d, e). The maximum values of E_a, were obtained at the initial vegetative growth (7 DAT), with a second peak at 63 and 70 DAT for the plants without shading, and under red or black shading screens, respectively. The higher E_a values were obtained in plants without shading, and lower Ea values in plants under the effect of red and black screens. It is common the net assimilation rate is higher at the initial development cycle, when the leaves are young and reach the maximum size in terms of area (Aumonde *et al*., 2011). The E_a also tends to be greater in low self-shaging condition and in situations that the proportion of dry matter allocated in leaves is greater than the size of the leaf area (Gondim *et al.,* 2008; Lopes & Lima, 2015). The E_a decrease can be explained by self-shading increased and the gradual increase of tissues with lower fototssintética activity endowed with lower carbon assimilation capacity, while the second peak Ea is due to the onset of the reproductive phase when these structures become and preferred final metabolic drains enjoy high demand synthesized assimilated via the photosynthetic process (Lopes *et al*., 1986). Most Ea obtained in no shading plants may be due to greater availability of light (Gondim *et al*., 2007). The decrease E_a can be explained by the increase of the self-shading and the gradual increase of tissues, which present lower photosynthetic activity and consequently lower carbon assimilation capacity. While, the second peak of E_a is due to beginning the reproductive phase, when these structures become preferred and definitive metabolic drains enjoy high demand synthesized assimilated via the photosynthetic process (Lopes *et al*., 1986). The most E_a obtained in plants without shading may be due to greater availability of light (Gondim *et al*., 2007). The leaf area index (L), regardless of treatment, showed a high coefficient of determination (R^2 = 0.99). The maximum L occurred at 56 DAT in plants without shading, with subsequent decrease (Figure 2a). Plants submitted to the effect of black or red shading screens tended to increase and the highest leaf area index at 77 DAT compared to those without shading (Figure 2a). Thus, there is indicative of the extension of the growing season in plants under the effect of black and red shading screens, the change negatively, temporarily and quantitatively changed, more drastic in plants under the black shading screens.

The increase in leaf area index results in greater interception of solar radiation and may reflect in the net photosynthesis (Heiffig *et al*., 2006). On the other hand, the decrease of the growth attribute is normal to the course of the cycle, and partly due to increased leaf senescence (Aumonde *et al*., 2011). Maximum leaf area ratio (F_a) values were achieved at 21 DAT in plants under the effect of the black and red shading screens (Figure 2b). However, plants without shading reached the maximum F_a at 28 DAT, with a further decrease by the end development cycle plants (77 DAT). Plants under black shading screen showed higher F_a compared to the others. It is noticed that there was a reduction of the useful leaf area to the photosynthetic process in plants under shading effect with red screen and without shading, compared to those under black shading screen effect. The high initial F_a in plants under the effect of black and red shading screens, may be due to increased efficiency of the photosynthetic apparatus, regardless of leaf area (Campos *et al*., 2008). While that, reduction of F_a may be related to increased self-shading (Peixoto & Peixoto, 2009). However, it is important to note that these environmental conditions may be increased photosynthetic rate, when in a condition of greater stomatal conductance and lower vapor pressure deficit. However, water must be available to maintain the transpiration rate and photosynthetic machinery must be fully active, without impediment to fixing maximum efficiency (Buchanan *et al*., 2000). Leaf matter ratio (F_w) was higher in plants under red shading screen effect and at 14 DAT (Figure 2c). Plants under black shading screen effect had lower F_w compared to the others. Thus, a lower allocation of dry matter of leaves in plants without shading and under black shading screen, respectively, compared to plants under red shading screen environment. The F_w according Aumonde *et al*. (2011), provides an estimate of assimilated fraction retained in the leaves and not exported to other plant organs. The lowest values obtained for the black screen, compared to other spectral light levels, that may be related to the difference in both the synthesis and distribution of assimilates to the leaves formation (Martins *et al*., 2009). Similar results were obtained by Gondim *et al*. (2007) to study the effect of different light intensities on taro plants. It should be noted that most F_w can be related to higher amount of dry matter allocated leaves, maintaining connection with the increase in the deposition of organic compounds on the cell walls, especially in full sun conditions (Aumonde *et al*., 2011). The major dry matter allocated in leaf when combined with the lower expansion results in plants with thicker leaves (Lopes & Lime, 2015), as evidenced by specific leaf area of plants in conditions of absence of shading that showed superior S_a (Figure 2d).

Tabela 2. Harvest index (H_i), number of siliques (N_s) and commercial yield of leaves (R_f) of rocket plants under different shading screens. Capão do Leão, Universidade Federal de Pelotas, 2014

Spectral quality of light	H_i	N_s	R_f (g)
W.S	0.89b[1]	107.3a	17.92a
R.S.S.	0.92a	17.7b	11.19b
B.S.S.	0.91a	7.7c	7.33c
CV (%)	1.43	6.29	8.06

[1]Means followed by the same letter in the column did not differ meaningfully from each other, Tukey, $p < 0.05$). Where: W.S = without shade; S.T.V = red shading screen; S.T.P = black shading screen.

The maximum values of specific leaf area (S_a) were achieved at 21 and 42 DAT in plants under effect black and red shading screen or without shading, respectively (Figure 2d). The plants under effect black shading screen showed higher S_a compared to those in red screen and without shading, respectively. There was, in plants under effect black shading screen, larger leaf expansion and occurrence of thinner leaves (Pedó *et al*., 2013), with a view to attracting greater light energy, which is reduced quali-quantitatively in that environment. The decrease of S_a is result of the increase in dry matter and halt the expansion of leaf area, and the largest S_a in plants of different plant species is due to the canopy shading (Gobbi *et al*., 2009). Harvest index in evaluated in plants under effect of red and black shading screens had to be superior compared to that of without shading plants (Table 2). This result, demonstrates higher carbon allocation in the trade body compared other plant structures. Thus, shading screens provide better environmental conditions for vegetative growth, providing higher allocation of dry matter (Silva *et al*., 2013).

The number of siliques was higher in plants grown without shading compared to those under effect red and black shading screens, respectively (Table 2). The commercial yield of fresh leaves was higher in plants without shading, compared to other plants under shading (Table 2). In plants grown under shade, the largest commercial yield of leaves was observed in rocket plants submitted to red shading screen. The use of shading screens favors the yield of various species (Ilic *et al*., 2012), due to increased diffused radiation and improved spectral quality of the light (Shahak *et al*., 2008). Rocket plants without shading allocated, at the end of the cycle, greater amount of total dry matter. Furthermore, they showed higher net assimilation rate at 7 DAT, compared to plants under the effect of shading screens. The matter ratios and leaf area reached the maximum at 14 and 21 DAT in plants under black and red shading screens, and plants under red shading screen showed higher leaf matter rate. Plants without shading showed an increase in the siliques number, better growth performance and higher yield of fresh leaves, compared to those grown under shading screens. Therefore, plants without shading had better growth performance and commercial yield of rocket plants.

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