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Microclimate under different shading screens in greenhouses cultivated with bromeliads

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ABSTRACT

This study had as its objective the evaluation of the influence of shading screens of different colors on the different microclimate variables in a greenhouse covered with transparent low-density polyethylene (LDPE). The experiment was conducted with five treatments: thermo-reflective screen (T1); a control - without screen (T2); red screen (T3); blue screen (T4); and black screen (T5), all of them with 70% of shading. An automatic micrometeorological station was installed in each treatment, measuring air temperature (T), relative humidity (RH), incoming solar radiation (Rg), photosynthetically active radiation (PAR) and net radiation (Rn) continuously. The control (T2) and red screen (T3) treatments promoted the highest solar radiation transmissivity, respectively 56.3 and 27%. The black screen (T5) had the lowest solar radiation transmissivity (10.4%). For PAR and Rn the same tendency was observed. The highest temperature was observed under blue screen (T4) treatment, which was 1.3 °C higher than external condition. Blue screen (T4) treatment also presented the highest relative humidity difference between inside and outside conditions.

Key words: solar radiation, air temperature, protected crops

Microclima sob diferentes malhas de sombreamento em ambiente protegido cultivado com bromélias

RESUMO

O objetivo deste trabalho foi avaliar a influência de malhas de sombreamento de diferentes cores nos elementos microclimáticos em ambiente protegido coberto com polietileno de baixa densidade transparente (LDPE). O experimento contou com cinco tratamentos: malha termorrefletora (T1); testemunha – sem malha (T2); tela vermelha (T3); tela azul (T4) e tela preta (T5), todas com 70% de sombreamento. Um sistema automático de aquisição de dados micrometeorológicos foi instalado em cada tratamento, obtendo-se dados contínuos de temperatura do ar (T), umidade relativa do ar (UR), radiação solar global (Qg), radiação fotossinteticamente ativa (RFA) e saldo de radiação (Rn). O tratamento testemunha (T2) e a malha vermelha (T3) proporcionaram os maiores valores de transmitância de radiação solar global, respectivamente 56,3 e 27%; já a malha preta (T5) teve a menor transmitância de radiação solar, da ordem de 10,4%; para a RFA e o Rn, a mesma tendência foi observada. A maior temperatura do ar foi constatada sob a malha azul (T4), em média 1,3 °C superior à do ambiente externo. O mesmo tratamento também sinalizou a maior diferença de umidade relativa entre o ambiente coberto e a condição externa.

Palavras-chave: radiação solar, temperatura do ar, cultivo protegido

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Introduction

In agricultural greenhouses, the microclimate can be controlled or modified so that the environment becomes as suitable as possible for crop development. One of the most common tools used by the growers for such environmental modifications is managing the covers, by the use of shading screens. During the last decades, the use of plastic screens as covering material has expanded, offering many advantages and benefits (Castellano et al., 2006; Briassoulis et al., 2007; Castellano et al., 2008).

The reduction of air temperature is one of the main objectives of greenhouse use in the tropical regions, where high temperatures occur. For Al-Helal & Abdel-Ghany (2011), some of the advantages of using shading screens are: (i) reduction of the energy consumption for cooling the environment; (ii) crop transpiration reduction resulting in reduced water consumption for irrigation; (iii) less occurrence of pests, reducing the use of pesticide; and (iv) diffusion of the solar radiation, allowing its better use by crops. Thus, shading screens, when correctly chosen and installed, can contribute to optimize crop production in periods or places when/where climatic conditions are adverse. According to Briassoulis et al. (2007), shading screens not only contribute to the production increase, but also have a positive effect on the quality and homogeneity of the production. For Al-Helal & Abdel-Ghany (2010), this effect is more intense in hot and sunny regions.

The control of the meteorological variables inside the greenhouses is an extremely dynamic process. Moreover, not all the microclimatic modifications are beneficial to the crops. Therefore, for the success of the crop in greenhouses it is essential to know the optical properties of the coverings used and the crop requirements. The properties associated with the transmission of the solar radiation are the most important factors for the production and can be used to characterize the different types of shading screens. For Pezzopane et al. (2004), the knowledge of the actual transmissivity of the covering material is of basic importance for a better operation of the greenhouse, indicating the most appropriate shading for each crop. Thus, the knowledge of these properties must be of great interest for growers (Al-Helal & Abdel-Ghany, 2011).

The use of different combinations of materials in greenhouses has gotten the interest of growers, especially those who cultivate ornamental plants, looking for the ideal conditions for production. There have been innumerable studies for characterizing the physical conditions of the environment under plastic coverings. Currently, there is an extensive variety of plastic coverings, with different optical characteristics. In such a way, the producers can get specific advantages with the use of different shading screens, with special optical properties able to modify the composition of the transmitted solar radiation to the interior of the greenhouse, improving the performance of the crops (Oren-Shamir et al., 2001). According to Robledo & Martin (1981), the color and transparency of the covering materials affects their absorption, reflection and transmission for short and long wave radiations.

The plastic screens differ from each other as regards to solidity, level of shading, chemical composition and coloration. The use of colored shading screens in the protected crops stimulates specific morphological and physiological reactions, improving the efficiency of the plants, resulting in qualitative and economically advantages (Shahak et al., 2002). For Nomura et al. (2009), the use of colorful screens becomes an alternative to substitute the vegetal regulators, since they have the capacity to modify the spectrum of the solar radiation, beyond promoting a physical protection of the plants.

Although the colored covering materials are popular in the markets and widely used by producers around the world, the choice of them is still made based on empirical or economical criteria, and not in accordance with technical and/or scientific principles (Al-Helal & Abdel-Ghany, 2011). In part, this situation is a result of the little or no technical information available about the optical properties of the different plastics and shading screens and how these materials affect the microclimate. Castellano et al. (2008) verified that the producers do not have a clear idea of how to select a type of covering for a specific application and that the characterization of the different types of screens in accordance with the diverse specific objectives needs to be better researched. In this context, the elaboration of an international standard of assay to identify the properties of these materials would be useful for growers.

Based on what was discussed above, the objective of this study was to evaluate the influence of five different types of shading screens on the microclimate of greenhouses cultivated with bromeliad (*Aechmea fasciata*), aiming to better understand and to add more referring information about the optical properties of the shading screens.

Material and methods

The experiment was installed in the experimental area of the Department of Biossystems Engineering, of the Escola Superior de Agricultura “Luiz de Queiroz”, University of São Paulo (ESALQ/USP), in Piracicaba, State of São Paulo, Brazil, located in the following geographic coordinates: latitude of 22º 42' 40" S, longitude of 47º 37' 30" W and altitude of 546 m.a.s.l. In accordance with the Köppen classification, the climate of the region is Cwa, which means tropical humid with dry winter. The experiment was conducted in a greenhouse with the following dimensions: length 17.5 m, width 6.4 m, height 3.5 m, being covered with a transparent polyethylene of low density (LDPE) plastic film, of thickness 0.15 mm.

The bromeliad plants were cultivated in all treatments inside the greenhouse, which were differentiated by the use of shading screens with distinct characteristics. In the first treatment (T1), the thermo-reflective screen was installed 1.0 m above the bench. Treatment (T2) corresponded to the control which was not covered with shading screen. The third (T3), fourth (T4) and fifth (T5) treatments were covered, respectively, by red, blue and black screens, installed with the same height above the plants adopted in the first treatment. All the screens had 70% of shading and are the most used by the growers. Each treatment was composed by 60 pots cultivated with bromeliad in each treatment (6 lines and 10 columns), in an single group of benches, with dimensions of 3.0 m x 1.2 m and height of 1.0m.

The physical analysis of the environmental conditions was done by micrometeorological measurements with automatic sensors. These sensors were installed for the period of one week in each treatment, in a system of rotation. The sensors were connected to a datalogger CR10x model (Campbell Sci.), which continuously recorded air temperature (T) and relative humidity (RH), with a thermocouple psicrometer of forced ventilation. Moreover, a sensor was used for the measurement of incoming solar radiation (Rg - model CM3, Kipp & Zonen) and another (NR-lite model, Kipp & Zonen) for net radiation (Rn). For the measurement of the photosynthetically active radiation (PAR), a Licor LI190SB-Quantum sensor (spectral band 400 - 700 nm) was used. The micrometeorological data was collected from 27/12/2005 to 30/06/2006.

The micrometeorological data of each treatment was compared to weather data from an automatic weather station, installed outside (about 800 m from the experimental area), in order to detect the changes caused by the microenvironments. The following analyses were carried out: determination of the percentages of incoming solar radiation (Rg), photosynthetically active radiation (PAR) and net radiation (Rn) transmitted into each treatment; determination of percentage of photosynthetically active radiation (PAR) in relation to global solar radiation (Rg) in all the treatments inside greenhouse and outside; determination of differences of air temperature (°C), relative humidity (RH), current water vapor pressure (ea) and saturation water vapor pressure (es) between inside and outside conditions.

Results and discussion

Table 1 presents the percentage of the solar radiation that effectively achieved the plants inside the greenhouse for each treatment, considering global solar radiation (Rg), photosynthetically active radiation (PAR) and net radiation (Rn). The T2 (control treatment) presented the highest percentages, since it does not have the effect of the screens. In this treatment the values of transmissivity were, on average, of 56% for Rg and 43% for PAR. Among the other treatments, the T3 (red screen) presented the highest transmissivity values for Rg (27%) and PAR (12%). Very similar results were found by Jeong et al. (2009), studying begonias cultivated in a greenhouse in the region of Columbus (Ohio, U.S.A.), obtaining Rg transmissivity around 24% for screens of 80% of shading. The smallest transmissivity occurred in the T5 (black screen), followed by thermo-reflective (T1) and blue (T4) screens, as presented in Table 1.

The smaller PAR transmissivity observed in the black screen (T5), thermo-reflective screen (T1) and blue screen (T4) treatments was also obtained by Al-Helal & Abdel-Ghany (2010), which indicate that the darker the color of the screen and lesser its porosity, greater is the capacity of the screen to absorb PAR. These values are similar to those obtained by Pandorfi (2006), which verified that the PAR measured inside

Table 1. Percentages of incoming solar radiation (Rg), photosynthetically active radiation (PAR) and net radiation (Rn) transmitted into each treatment

Variable	Treatment (%)*				
	T1	T2	T3	T4	T5
Rg	13.6	56.3	27.0	22.9	10.4
PAR	8.4	43.1	12.0	8.8	7.0
Rn	19.1	71.5	30.5	20.4	10.7

* T1 - thermo-reflective screen; T2 - control; T3 - red screen; T4 - blue screen e T5 - black screen

the greenhouses covered with plastic and thermo-reflective screen had been reduced to 20.6% in relation to outside conditions. Lugassi-Ben-Hamo et al. (2010), studying the effect of the shading in *lisianthus* caused by clear plastic screens installed inside greenhouse in the southern region of Israel, observed solar radiation transmissivity between 12 to 33%.

Throughout the experiment it was observed for the treatments with screen covering that T3 (red screen) was the one with the greatest Rn average representing around 31% in relation to the outside conditions. The smallest value was observed again in the T5 (black screen), with around 11%, as a function of the highest solar radiation absorption. Treatments 1 (thermo-reflective screen) and 4 (blue screen) presented intermediate values of transmissivity, around 20%.

Figure 1 presents the ratio between photosynthetically active radiation (PAR) and solar radiation (Rg) for each treatment and for outside condition. It was noticed that outside the greenhouse PAR/Rg is about 50%. In the control treatment (T2), which is only affected by the plastic cover, the PAR/Rg fell to 34%. For treatments with screen covering, T5 (black screen) was the one with the highest ratio (30%), very similar to the value obtained without screen. According to Shahak (2008), black shading screen reduces the amount of light transmitted to the plants, but it does not affect the quality of the light, which means the spectral composition. PAR/Rg of

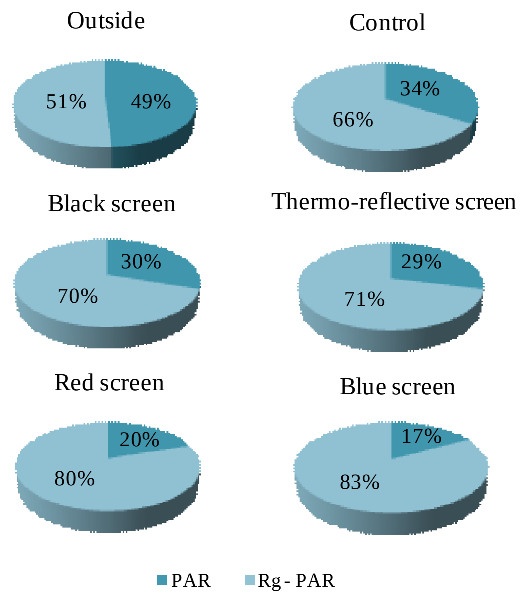
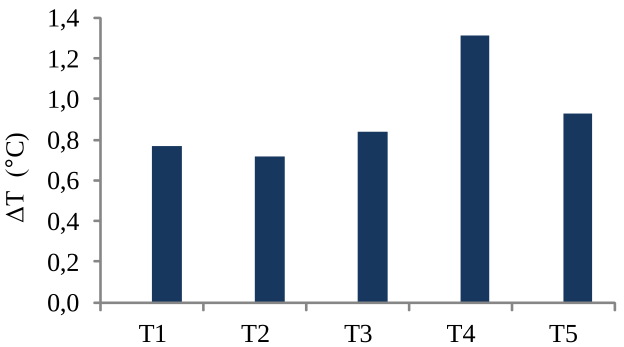


Figure 1. Percentage of photosynthetically active radiation (PAR) in relation to global solar radiation (Rg) in all the treatments inside greenhouse and outside

the T1 (thermo-reflective screen) was also very similar to that obtained for T5 (black screen). In this context, Al-Helal & Abdel-Ghany (2010) observed that the shading screens with more shiny colors had raised the levels of reflection, reflecting almost all the incident PAR specter, in relation to the dark screens, that reflect the incident PAR only in the spectral band of the color and absorb the incident PAR of the remaining complementary colors of the spectrum. Also Kittas et al. (1999) observed that the use of thermo-reflective screen tended to diminish PAR/Rg whereas black screen were neutral. Pandorfi (2006) observed the same for thermo-reflective screen for PAR/Rg values mentioned by Kittas et al. (1999), which means reduction of PAR ratio inside the greenhouse. The T3 (red screen) and the T4 (blue screen) were the ones that presented the smallest PAR/Rg since the blue and red colors promote greater reflection in the wave lengths of the visible light spectrum.

The air temperature (T), differences between the each one of the treatments and the outside condition are presented in Figure 2. In daily evaluations, the air temperature inside the greenhouses was higher than observed outside with an average always above 0.7 °C. These small differences occured because, the efficiency of the screens in promoting temperature reduction and also the ventilation promoted by the laterals of the greenhouse which were constituted of black screen (50%), allowed the exchange of energy between inside and outside conditions.



(T1 - thermo-reflective screen; T2 - control; T3 - red screen; T4 -blue screen and T5 - black screen) and the outside condition

Figure 2. Average values of the difference of air temperature (ΔT, °C) between different greenhouse treatments

The use of plastic (LDPE) and screens as greenhouse covering normally promotes temperature increase which is associated with the change in the convection process inside the greenhouse, resulting in retention of sensible heat. According to Buriol et al. (2000), the change of air temperature inside greenhouses is a function of the transmitted solar radiation, the ventilation, and the size of the greenhouse.

Other authors had also found higher temperatures inside the greenhouses in relation to the outside conditions. Farias et al. (1993) found differences ranging from 0.5 to 9.0 °C. Such variation occurs due to the differences of greenhouse management and the weather conditions of the local. As example, Lugassi-Ben-Hamo et al. (2010), in the Southeastern region of Israel, obtained, when studying different shading screens inside greenhouse, with 67 to 88% of shading, differences of 5.7 ± 2.5 °C.

The temperature differences (ΔT) of treatments 1 and 2 (thermo-reflective screen and control) in relation to outside conditions, were very small, however when no screen was used the air temperature was a little bit higher, demonstrating the effect of plastic greenhouse on sensible air retention. The average of air temperature in T1 (thermo-reflective screen) was very similar to the outside conditions. According to Altafin (2005), the use of thermo-reflective screen is responsible for alterations of the solar radiation properties, increasing its reflection, which allows the temperature control. Pandorfi (2006) observed that when thermo-reflective screen is installed, internally at the ceiling height, the differences between inside and outside air temperature was 1.2 °C, very similar to the values of this study. Guiselini (2002) observed differences of 6 °C between the greenhouse covered with white plastic and thermo-reflective screen. For the treatment with white plastic and black screen, the author observed lower temperatures, however, still 3 °C higher than outside. Abak et al. (1994), evaluating different materials of covering in greenhouses, observed that the temperature under thermo-reflective screen was higher than under the plastic without the screen. This effect is explained by Guiselini & Sentelhas (2004) which considered the higher temperature under the screen as a consequence of the partial barrier promoted by it to the convection process. In the present study such an effect was minimized since the greenhouse had a taller ceiling height favoring air circulation and resulting in less sensible heat accumulation near the sensors.

The T3 (red screen) and the T5 (black screen) presented very similar average temperature, around 0.9°C higher than outside. Contrasting results were reported by Unemoto et al. (2010) under black screen in Londrina (State of Paraná, Brazil). These authors observed an average temperature reduction of about 1.3 °C in relation to outside condition. The T4 (blue screen) showed to be the covering that promoted the highest temperature, on average, 1.3 ºC more than outside.

The Table 2 presents the differences of air relative humidity (RH), actual water vapor pressure (ea) and saturation water vapor pressure (es) between inside each one of the treatments and outside. The variation of RH inside greenhouses depends on temperature and air circulation. The higher the temperature, the lower the RH; the more intense the air circulation, the lower the RH (Buriol et al., 2000; Rocha, 2002). It was observed that inside the greenhouse temperature was higher than outside, therefore the UR tended to be lower. On average, the T4 (blue

Table 2. Differences of relative humidity (RH), actual vapor pressure (ea) and saturation vapor pressure (es) among the treatments

Variable	Treatment*				
	T1	T2	T3	T4	T5
RH	4.1	5.4	4.3	7.1	5.6
ea	-1.5	1.0	-1.3	-0.4	-0.2
es	5.0	4.9	5.4	8.4	6.0

* T1 - thermo-reflective screen; T2 - control; T3 - red screen; T4 - blue screen and T5 - black screen, and outside conditions

screen) presented the highest difference of es and RH among the micro-environments. The other treatments presented very similar RH values among them. When ea was evaluated, the differences were negative indicating that there is more water vapor in absolute terms inside the greenhouse.

The lowest RH differences among outside and the micro-environments was observed in T1 (thermo-reflective screen) and T3 (red screen) being, respectively, 4.1 and 4.3%. Similar results were reported by Unemoto et al. (2010), who found RH differences between inside and outside conditions of 4.4%. Pandorfi (2006) observed differences of RH between 2.5 to 3.6%, and Rocha (2007) found RH values under shading screens on average 7.5% higher than outside.

Conclusions

1. The type and color of the shading screens, when used as greenhouse covers associated to plastic, affect the microclimate, mainly the intensity and quality of solar radiation.

2. The black screen showed to be more efficient for solar radiation reduction than the others, but mainly in relation to red screen.

3. The screens promoted few differences between inside and outside air temperature and relative humidity, which are associated with the effect of the screens on solar radiation as well as to the good air circulation inside the greenhouse.

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