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Gas exchanges of tomato hybrids cultivated in protected environments and open field

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ABSTRACT

The effects of adverse climate constrain vegetable production, and protected cultivation has shown to be a promising technique in maximizing yield. However, protected environments might change with meteorological elements, particularly solar radiation, consequently affecting gas exchanges. The aim of this study was to assess gas exchanges of tomato hybrids cultivated in different environments in the Sub-medium region of the São Francisco River Valley. The experiment was conducted from August to December 2006, in the experimental area of DTCS/UNEB, Juazeiro, BA, in a 5 x 2 (environments x tomato hybrids) factorial experiment design with randomized blocks with ten treatments and four replicates. The factor environment was subdivided in open field and four covered environments with shading screens, and tomato hybrids were C-5240 e D-4768. Gas exchanges were evaluated in the period ranging from October 24 to 10, 2006 (flowering/fruiting stage). Variables analyzed were: PAR radiation, net CO2 assimilation rate, leaf transpiration rate, stomatal conductance, and leaf temperature. There was significant difference between tomatoes cultivated in open field and in protected environments for all variables, except for leaf temperature. Regardless of type of cover, there was a positive effect of shading on decreased PAR radiation compared to open field, in favor of gas exchanges, under the climatic conditions of the Sub-medium region of the São Francisco River Valley.

Introduction

Tomato originated from the subtropical regions of South America (Ploeg e Heuvelink, 2005). It is considered the most widespread oleracea crop, ranking as one of the most important crops in the agro-industrial chain, and one of the most consumed vegetables worldwide, both *in natura* and processed (Zeist, 2015). It occupies the second position in cultivated area worldwide, and it is the first one in industrialized volume (Pereira et al., 2007). Along with potato, tomato is the most produced and cultivated solanaceous plant in Brazil (Matos et al., 2012). In 2016, its production was 3,737,925 tons in an area of 58,548 ha, resulting in a yield of 63.844 tons ha^{-1} (IBGE, 2016).

The production of this vegetable in the Brazilian Northeast has outstood, notably in the states of Pernambuco and Bahia, largest producers of industrial tomatoes in the region; yet, its mean yield is considered low due to the high climatic instability of the region and to the occurrence of long dry periods, resulting in a substantial negative impact on crop growth and development (Soares et al., 2012).

The optimal climate for tomato cultivation is mild temperature during the day and cold nights; regions with mean temperature above 30 °C are not recommended for the cultivation of this vegetable (Luz et al., 2002). At mean temperatures higher than 28 °C fruits with yellow coloration are formed due to the decrease in lycopene synthesis (pigment responsible for the typical red color of fruits) and increase in carotene concentration (pigment that provides the yellow color to the pulp) (Giordano e Silva, 2000). In the Submedium São Francisco River Valley, tomato plantations in spring-summer, which is a season characterized by high incidence of sunlight and high temperature in the region, are subject to significant decreases in yield due to the negative effect of these factors on plant physiology.

As an alternative to mitigating adverse effects of climate on vegetable production, and due to its contribution to high quality products and increased offer throughout the year, protected cultivation has been gaining space among Brazilian producers, mostly because of its relatively easy management of cultivation conditions compared to conventional open field system (Carrijo et al., 2004).

The use of protected environment in horticulture allows for a better exploitation of physiological factors such as photosynthesis, evapotranspiration, respiration, water and mineral absorption, and their transport, which thus increases earliness, yield, and out-of-season production (Santana, 2012). However, protected environments change with meteorological elements, particularly solar radiation, consequently affecting gas exchanges.

According to Taiz e Zeiger (2004), plant development and growth depend on physiological factors: transpiration, respiration, and photosynthesis; and on physical factors: light, temperature, humidity, and CO_2. Among the physical factors, light is the one that most affects gas exchanges, and it might have a great impact on CO_2 assimilation rates (Kim et al., 2004).

The aim of this study was to analyze gas exchanges in hybrid tomatoes cultivated in environments covered with shading screens and in open field, in the Sub-medium region of the São Francisco River Valley.

Material and Methods

The experiment was conducted from August to December, 2006, in the experimental area of the Department of Technology and Social Sciences - DTCS of the State University of Bahia – UNEB, in the municipality of Juazeiro (09° 24' 50" S; 40° 30' 10" W; altitude: 368 m), Brazil. Four 240 m² ridge and furrow greenhouses (10 m x 24 m) were built, with 3.0 m of ceiling, with North-South exposure, covered with the following low-density polyethylene screens: thermal reflective (T1), white (T2), black (T3), and Chromatinet diffuser (T4). According to technical specifications, all the screens had transmittance around 60% (40% shading). Two tomato hybrids with determined growth C-5240 (Santa Cruz) and D-4768 (Plum type) were cultivated in these environments and in open field (OF). A 5 x 2 (environments x tomato hybrids) factorial experiment design was used with randomized blocks with ten treatments and four replicates (tomato hybrids).

Seedlings were protected grown in an environment with black shading screen (30% shading) and transplanted on August 4, 2006, when plants had four to five definitive leaves. The spacing used was 1.0 x 0.40 m with one seedling per den in the plantation furrow. Each plot was comprised of 2 rows of 9 plants and each environment was comprised of 216 plants, including those on the borders.

Plants were conducted with no pruning and no sprouting throughout their cycle. Tutoring was performed by using 2.0 m tall posts, 1.8 m apart with four number 18 wires horizontally distanced 0.30 m from each other. Plants were weekly tied with ribbon starting in the first week after transplanting, to prevent fruits from having contact with the soil and the consequent fruit depreciation. A dripping irrigation system was used, with emitters spaced 0.20 m from each other. Irrigation management in the different environments was performed based on data obtained from a class-A tank installed at the meteorological station of DTCS/UNEB, located 40 m from the experimental area, and based on crop coefficients proposed by Doorenbos e Kassam (1979) for the different tomato development stages.

Fertilization was performed based on soil analysis and following the recommendation by the Manual of Fertilization and Liming for the State of Bahia (1989). Weeding was performed twice to keep the crop free from invasive plants throughout its cycle. Phytosanitary treatments were performed based on recommendations for the crop according to infestation level. Gas exchanges were evaluated in the period ranging from October 24 to 26, 2006, when the crop was in the flowering/fruiting development stage.

To analyze gas exchanges, each central leaflet of fully developed new leaves was measured, using a portable photosynthesis analyzer (IRGA) with an open system Li-COR 6400 model (USA). Measurements were performed from 8:00 AM to 12:00 PM, as this is the period where the highest photosynthetic activity occurs in plants. Variables analyzed were: photosynthetically active radiation (PAR) (μmols m^{-2} s^{-1} photons); net CO_2 assimilation rate of leaves (μmol m^{-2} s^{-1}); leaf transpiration rate (μmol m^{-2} s^{-1}); leaf stomatal conductance (mmol m^{-2} s^{-1}), and leaf temperature (°C). Statistical analysis was performed using an analysis of variance (F test) and by comparing mean values between treatments (Tukey's test, 0.05 of probability).

Results and Discussion

The analysis of variance (Table 1) showed a significant interaction between environments and tomato hybrids, only for the variable net CO_2 assimilation rate. Considering the factors separately, only environments produced significant effects on the variables, except for leaf temperature.

Photosynthetically active radiation (PAR) did not significantly differ between shaded environments; which differed, however, from open field cultivation. Open field PAR values external (OF) were between 1000 and 2100 μmols m^{-2} s^{-1} of photons. The different covers caused lighting to reduce by 64%, 53.7%, 67.9%, and 68.5% for environments T1, T2, T3, and T4, respectively, compared to open field cultivation (Figure 1). Ilic et al. (2012) showed that excessive attenuation of solar radiation and the consequent decrease in inner temperature allow for certain crops to grow with higher quality, yield, and soundness. The type of material used in the screens played a significant role, affecting radiation flow density inside the cultivation environment, according to variation in transmissivity (Steidle Neto et al., 2008). CO_2 recorded in the environments by the IRGA during measurements was 352 ± 2.4 mg L^{-1}.

In the period ranging from 8:00 AM to 12:00 PM, net CO_2 assimilation rate in open field cultivation remained with low assimilation indices, between 6 and 8 μmols CO_2 m^{-2} s^{-1} (Figure 2). These low assimilation rates might be associated to a lowe water availability in the soil at open field cultivation. That is due to the fact that the same irrigation rate was applied in all environments; and open field environment is prone to a higher evaporation rate compared to shaded environments. According to Silva et al. (2010), water availability in the soil might cause stomatal closure, thus limiting stomatal conductance and transpiration, which consequently reduces photosynthesis rate. Another explanation for low assimilation rates might be provided by analyzing the response of net CO_2

Figure 1. Mean Photosynthetically Active Radiation values (PAR) (μmols m-2 s-1 photons) in the different cultivation environments (thermal reflective screen - T1, white screen - T2, black screen - T3, Chromatinet diffuser screen - T4, and open field - OF). Columns with the same letter do not statistically differ from each other (Tukey's test, 0.05 of probability).

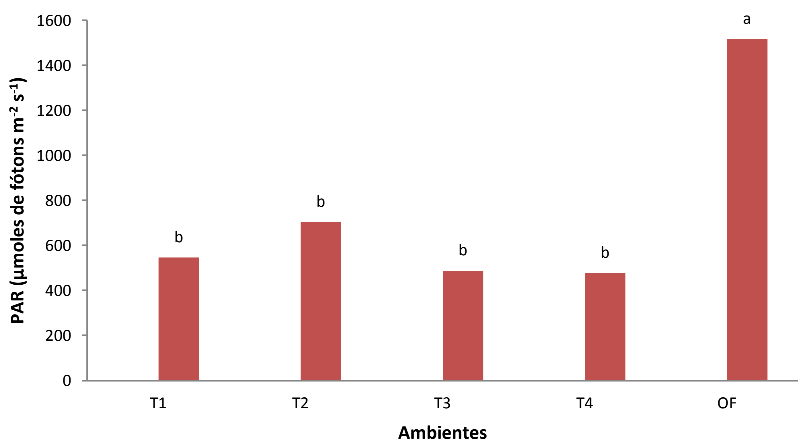
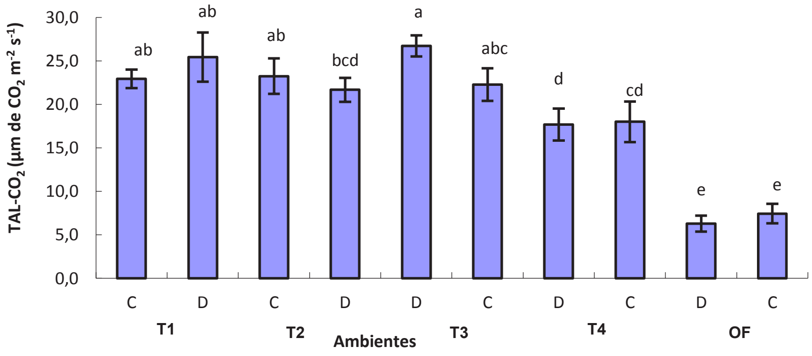


Table 1. Summary of the analysis of variance for: photosynthetically active radiation (PAR) in the different cultivation environments; net CO2 assimilation rate (TAL-CO2), stomatal conductance (gs), plant transpiration (PT), and leaf temperature (Tleaf) of the two tomato hybrids cultivated in the different environments.

SV	Mean Square					
	GL	PAR	TAL-CO2	gs	PT	Tleaf
Environment (A)	4	1549372.34**	434.93**	0.120448 **	45.495954**	2.678044ns
Hybrid (H)	1	252333.23ns	1.66ns	0.000640ns	0.178222ns	3.147210ns
A x H	4	38627.79ns	14.52**	0.007540ns	1.742316ns	2.826991ns
CV%		56.26	9.60	30.71	18.41	5.50

SV Source of variation; ns not significant; * significant at 5% probability; ** significant at 1% probability using the F test.

Figure 2. Mean net CO2 assimilation rates (TAL-CO2) (μmols CO2 m^{-2} s^{-1}) of the two tomato hybrids (C and D) in the different cultivation environments (T1, T2, T3, T4 and OF). Columns with the same letter do not statistically differ from each other (Tukey's test, 0.05 of probability).

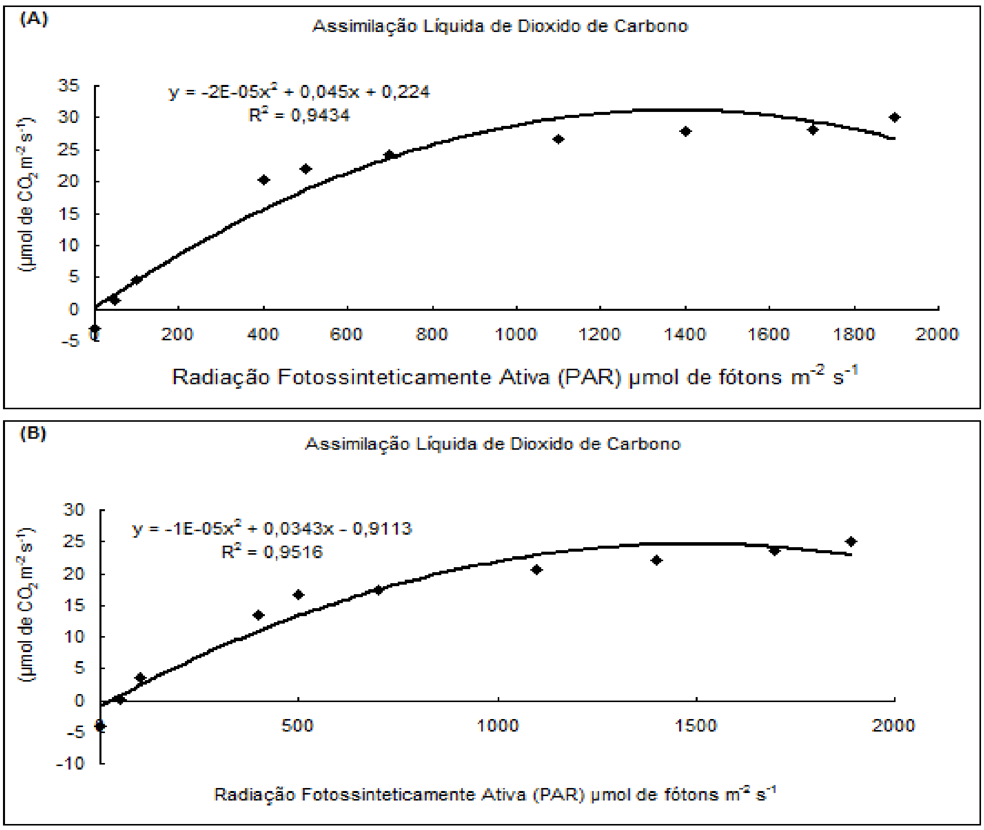


assimilation rate (μmol CO_2 m^{-2} s^{-1}) of both hybrids (C-5240 e D-4768) in terms of PAR radiation (Figure 3). The figure shows that the two genotypes have light saturation values between 700 and 1100 μmols m^{-2} s^{-1} photons, showing reduced tomato leaf photosynthetic activity in the open field (Figure 2). These results, associated to the mean PAR values (1000 to 2100 μmols m^{-2} s^{-1} photons) in open field, obtained in the period ranging from 8:00 AM to 12:00 PM clearly show excessive PAR radiation on plants, which results in low yield over time.

Regarding net CO_2 assimilation rates in shaded environments, there was no statistical difference between genotypes in the same environment, which significantly differed from open field cultivation, with mean values varying from 17.68 μmol CO_2 m^{-2} s^{-1} (hybrid D-4768, T4 cover) to 26,73 μmol CO_2 m^{-2} s^{-1} (hybrid D-4768, T3 cover). Therefore, regardless of the type of shading used, there was a positive effect on PAR radiation reduction (Figure 1), characterized by high CO_2 assimilation values (Figure 2). These results are in accordance with Radin (2002), who observed that, in plastic-covered protection structures, the decrease of approximately 30% in PAR radiation caused an increase of 33 and 43% in its effective use by tomato plants during spring-summer and summer-autumn, respectively.

Photosynthetically active radiation values observed at 8:30 AM in open field cultivation were higher than 1300 μmols CO_2 m^{-2} s^{-1}; exceeding 2000 μmols CO_2 m^{-2} s^{-1} near 9:30 AM. In other words, plants under full sunlight already showed restraints (stress) early in the morning, quickly reducing stomatal opening (Figure 4). This is a striking

Figure 3. Net CO2 assimilation response (μmols m^{-2} s^{-1}) to different amounts of PAR (μmols m^{-2} s^{-1} photons) for hybrids D-4768 (A) and C-5240 (B) cultivated in open field.



fact as, according to Taiz e Zeiger (2004), the best period for plants to perform photosynthesis is from 9:00 AM to 10:00 AM, due to light rates and relative air humidity contents. However, results in our study showed that the best moment for tomato plants to perform photosynthesis was between 7:00 AM and 8:00 AM.

Stomatal conductance values (*gs*) varied between 0.20 and 0.45 mmols m^{-2} s^{-1} over the monitoring period. Sharp drops were observed in both hybrids in open field cultivation, statistically differing from shaded environments, with emphasis on hybrid D-4768 (Figure 4), which showed the lowest stomatal conductance, 0.02 mmol m^{-2} s^{-1}. In shaded environments, this hybrid had the highest conductance in the environment covered with thermal reflective screen (T1), 0.38 mmol m^{-2} s^{-1}, significantly differing from the conductance of hybrids in the environment covered with chromatinet diffuser screen (T4). Therefore, it is observable that plants cultivated in open field had a rapid stomatal closure (Figure 4). Guerra et al. (2017) observed a higher stomatal conductance in shaded environments.

Tomato transpiration rate responses (Figure 5A) showed the same trend, compared to net carbon dioxide assimilation rates (Figure 2) and to stomatal closure - stomatal conductance (Figure 4), and reduced transpiration of plants cultivated in open field was evident, statistically differing from those in shaded environments. This is due to the fact that stomata are the path through which CO_2 enters the plant, and at the same time, through which water exits the leaf. In shaded environments, there was no significant difference in the transpiration of hybrids in the same environment; between environments, transpiration of hybrid D-4768 covered with black screen (T3) differed from that of hybrids in environment T4. When transpiration flux is higher than plant water flux, stomata close in order to reduce water loss to the atmosphere. Nevertheless, stomatal closure also reduces CO_2 entry, thus decreasing photosynthesis (Andriolo, 1999; Paiva et al., 2005). Decreased CO_2 assimilation rate during water stress is caused by the reduction in CO_2 available inside the plant because stomata close in response to reduced availability of soil water (Rosa et al., 1991).

Regarding leaf temperature, there was no significant difference between environments or between hybrids (Figure 5B). The fact that this difference is not significant is of great importance, as it reveals that these plants, hybrids D-4768 and C-5240, have found a way to physiologically adapt to the adverse conditions of open field environment. For Oliveira et al. (2002) plants have adaptation mechanisms that decrease water loss when they are submitted to moderate water stress conditions. Silva et al. (2015) reported that, among the numerous physiological mechanisms correlated with water conditions in the plants, foliar temperature might be used as a relevant indicator of water deficit level in the plant.

Stomatal control is an important physiological property through which plants limit their water loss, causing reduction in stomatal conductance, and generally reducing gas exchanges as a response to several factors, including water stress (Paiva et al., 2005). This fact raises the question of whether there could be more factors involved in restraining stomatal opening, such as higher evaporation from the soil caused by higher sunlight incidence, and also by higher wind action, enabling more effective processes of advection and convection in that environment, promoting water stress in plants and maintaining leaf temperature at levels equivalent to shaded environments. Pillar (1995) states that leaf withering induced by water stress might cause the incidence angle of solar radiation to change, thus reducing radiation absorption, and avoiding increase in foliar temperature.

Conclusions

Reduced light provided by the Chromatinet diffuser screen resulted in lower carbon dioxide assimilation rates by tomato hybrids, compared to the other shaded environments. There was significant difference between open field cultivated tomatoes and cultivation in shaded environments in the variables: PAR radiation, net CO_2 assimilation rate, leaf transpiration rate, and stomatal conductance. Regardless of type of cover, there was a

Figure 4. Mean stomatal conductance values (gs) (mmol m^{-2} s^{-1}) of two tomato hybrids submitted to different cultivation environments. Columns with the same letter do not statistically differ from each other (Tukey's test, 0.05 of probability).

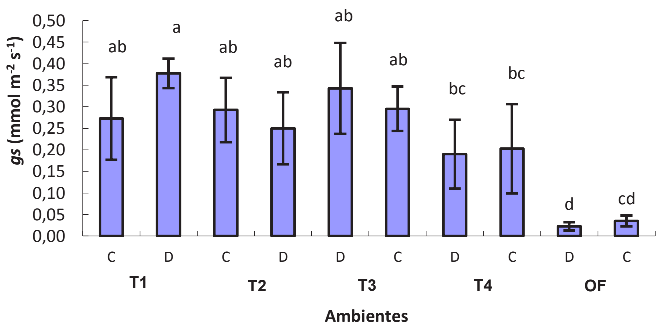
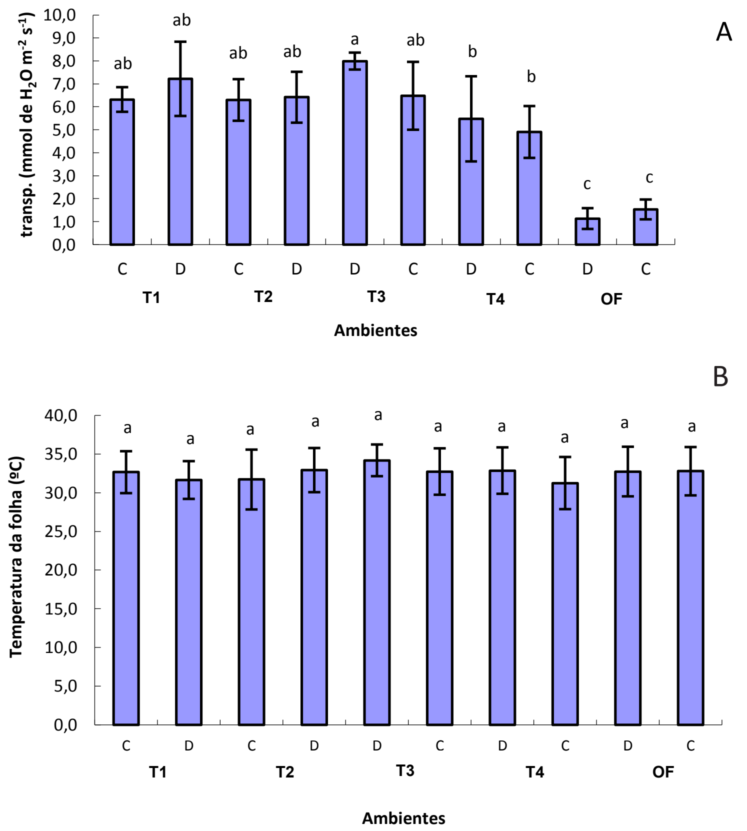


Figure 5. Mean transpiration values (mmol H2O m-2 s-1) of tomato plants (A) and mean leaf temperature values of tomatoes (B) cultivated in different environments. Columns with the same letter do not statistically differ from each other (Tukey's test, 0.05 of probability).



positive effect of shading on decreased PAR radiation compared to open field, in favor of gas exchanges, under the climatic conditions of the Sub-medium region of the São Francisco River Valley.

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Trocas gasosas em híbridos de tomate cultivados em ambientes protegidos e campo aberto

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RESUMO

Efeitos adversos do clima limitam a produção de hortaliças, e para maximizar a produtividade, a técnica de cultivo protegido tem-se mostrado promissora. Entretanto, o ambiente protegido modifica entre os elementos meteorológicos, principalmente a radiação solar, afetando consequentemente, as trocas gasosas. O presente trabalho teve como objetivo, avaliar as trocas gasosas em híbridos de tomate cultivados em diferentes ambientes na região do Submédio São Francisco. O experimento foi conduzido de agosto a dezembro de 2006 em área experimental do DTCS/UNEB, Juazeiro, BA, com delineamento experimental em blocos ao acaso com dez tratamentos, em esquema fatorial 5 x 2 (ambientes x híbridos de tomate), com quatro repetições. O fator ambiente foi subdividido em campo aberto e quatro ambientes cobertos com telas de sombreamento e os híbridos de tomate foram: C-5240 e D-4768. A avaliação das trocas gasosas foi realizada no período de 24 a 26/10/2006 (estádio floração/frutificação). As variáveis analisadas foram: radiação PAR, taxa de assimilação líquida de CO2, taxa de transpiração nas folhas, condutância estomática e temperatura da folha. Com exceção da temperatura da folha, para as demais variáveis, houve diferença significativa entre cultivo do tomateiro a campo aberto e em ambientes cobertos. Para as condições ambientais do Submédio São Francisco, independente do tipo de cobertura utilizada, notou-se efeito positivo do telado na redução da radiação PAR em relação ao campo aberto, favorecendo as trocas gasosas.

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