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Does the film formed by the Bordeaux mixture on the leaf surface of fig trees affect photochemical processes?

Matheus Marangon DEBASTIANI[1], Angélica Alves GOMES[1], Angria Ferreira DONATO[1], Mariana PIZZATTO[1], Samuel Silva CARNEIRO[2], Andréa Carvalho da SILVA[1,2*]

[1] PosGraduate Program in Agronomy, Federal University of Mato Grosso, Sinop, MT, Brazil.
[1] Institute of Agricultural and Environmental Sciences, Federal University of Mato Grosso, Sinop, MT, Brazil.
*E-mail: andrea.silva@ufmt.br

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ABSTRACT: This work aimed to evaluate changes in gas exchanges and chlorophyll *a* fluorescence in fig plants due to the film formed on the leaf surface by Bordeaux mixture applied to control rust. The experiment was conducted in an orchard with 7-month-old fig trees of the cultivar Roxo de Valinhos, in April 2020. A completely randomized experimental design with four replications was used, consisting of two treatments (with and without application of Bordeaux mixture), evaluating leaves in three different parts of the branch (apical, middle, and basal) in five evaluations. The evaluated gas exchange parameters were: carbon, leaf temperature, transpiration, stomatal conductance, and photosynthesis. The evaluated chlorophyll fluorescence parameters were: maximum and effective quantum yield of the photosystem, electron transport rate, photochemical and non-photochemical quenching, and leaf area. The film formed by Bordeaux mixture application did not affect the photochemical phases of photosynthesis and chlorophyll *a* fluorescence. The leaf position on the branch affected internal CO2 concentration and net CO2 assimilation over time. Leaves in the middle part of the branch presented larger leaf areas than those in the apical and basal parts.
Keywords: *Ficus Carica L.;* chlorophyll *a*; rust; leaf area.

A película formada pela calda bordalesa na superfície foliar das figueiras interfere nos processos fotoquímicos?

RESUMO: O objetivo desse trabalho foi avaliar se a camada formada pela solução da calda bordalesa na superfície foliar altera as características das trocas gasosas, bem como a Fluorescência da clorofila A, quando aplicada no combate a ferrugem. O delineamento experimental utilizado foi o inteiramente casualizado com 2 tratamentos (com e sem calda bordalesa) com folhas em 3 partes distintas do ramo da figueira (apical, mediana e basal), sendo feitas 5 avaliações, com 4 repetições, em um pomar de 7 meses de idade da cultivar Roxo de Valinhos, no mês de abril de 2020. As avaliações das trocas gasosas foram referentes a: variação do carbono, temperatura da folha, transpiração, condutância estomática e fotossíntese. As avaliações da fluorescência da clorofila A, foram referentes a: rendimento quântico máximo e efetivo do fotossistema, taxa de transporte de elétrons, dissipação fotoquímica e não fotoquímica e área foliar. A película formada pela aplicação da calda bordalesa não interferiu nas etapas fotoquímicas da fotossíntese e na fluorescência da clorofila A. A Concentração interna, e a assimilação líquida do CO_2 foram influenciadas pela posição da folha no ramo ao longo do tempo. As folhas da parte mediana do ramo apresentam a maior área, em detrimento das partes apical e basal.
Palavras-chave: *Ficus Carica L.;* clorofila A; ferrugem; área foliar.

1. INTRODUCTION

Fig trees are rustic plants that present good edaphoclimatic adaptation, and excellent production and vegetative performance in different regions of Brazil; however, they are susceptible to rust disease (*Cerotelium fici*), which affects their leaves and causes severe damage, resulting in production losses and stunted plant growth (FREIRE et al., 2006). According to Pinheiro et al. (2021) and Medeiros (2002), it is a highly destructive and contagious disease, whose control requires the eradication of infected leaves and other plant parts, as well as intensive fungicide application to affected areas for preventing infestation and plant loss; therefore, preventive treatments and proper disposal of dead plant material from pruning and harvest are necessary.

One of the most efficient and low-cost methods for preventing and controlling rust on fig trees is the application of the Bordeaux mixture. This mixture is a chemical combination of copper sulfate and CaO, resulting in $CaSO_4$ (calcium sulfate), which strongly adheres to leaves and has fungicidal and bactericidal actions. Additionally, it has nutritional functions for plants by supplying copper and calcium through leaves, contributing to cell wall formation, physiological defense, and enzyme synthesis (PAULUS et al., 2001; REBELO et al., 2015).

However, the application of Bordeaux mixture leads to the accumulation of residues on the leaf surface over time, creating a bluish film that can thicken the leaf during dry periods. Therefore, the objective of this study was to evaluate whether the film formed on the leaf surface by the Bordeaux mixture applied to control rust affects gas exchange and chlorophyll *a* fluorescence in fig plants.

2. MATERIAL AND METHODS

This study was conducted at the plant production area of the Federal University of Mato Grosso (UFMT), Sinop campus, Brazil (11°51'S, 55°29' W, and altitude of 382 m), in an orchard previously planted with fig trees of the cultivar Roxo de Valinhos. The soil of the area was classified as Typic Hapludox (Latossolo Vermelho-Amarelo distrofico; SANTOS et al., 2018). The climate of the region is Aw, tropical hot and humid, according to the Köppen classification, with a well-defined dry season and mean annual rainfall depth of 2,000 mm, concentrated from October to March (SOUZA et al., 2013).

A completely randomized experimental design was used, consisting of two treatments (with and without application of Bordeaux mixture) to evaluate leaves in three different parts of the branch (apical, middle, and basal) in five evaluations (0, 1, 3, 5, and 7 days after application of Bordeaux mixture).

The experiment was conducted from April 23 to 30, 2020, in an orchard consisting of 210 seven-month-old fig plants, spaced at 2 × 2.5 m, grown with single branches, and irrigated through a drip system. Bordeaux mixture was applied to four morphometrically similar plants, whereas four other plants were grown without application. A total of 180 leaves were evaluated: 59 leaves from the upper (apical), 65 from the middle (middle), and 60 leaves from the lower (basal) part of the branch. A Bordeaux mixture solution at the ratio of 1:1 (copper sulfate and CaO) was prepared and applied on April 23, 2020, following the phytosanitary management commonly adopted by fig growers. The Bordeaux mixture solution was applied using a pressurized manual pump at a rate of 300 mL per plant in 30 seconds, covering all leaves of the branch (Motta, 2008).

Gas exchanges were measured on all leaves of plants in the treatments with and without Bordeaux mixture application, at 0, 1, 3, 5, and 7 days after application (DAA), using an infrared gas analyzer (IRGA) (LCi-SD; ADC BioScientific, Hoddesdon, UK). Readings were carried out between 8:00 am and 4:00 pm, with intervals of up to 15 minutes for cooling the device.

The leaves were placed inside the IRGA chamber, occupying an area of 6.25 cm^2, and subjected to an effective pulse of 1839 $\mu mol\ m^{-2}\ s^{-1}$ light intensity (Q_{leaf}) to obtain the following parameters: external carbon concentration (Cref; $\mu mol\ mol^{-1}$), internal carbon concentration (C_i; $\mu mol\ mol^{-1}$), carbon variation between the external environment and the chamber (ΔC; $\mu mol\ mol^{-1}$), leaf temperature (T; °C), transpiration rate (E; $mmol\ m^{-2}\ s^{-1}$), stomatal conductance (g_s; $mol\ m^{-2}\ s^{-1}$), and net assimilation rate (A; $\mu mol\ m^{-2}\ s^{-1}$).

Parameters of chlorophyll *a* fluorescence were evaluated using an OS5p modulated chlorophyll fluorometer (FP-100; Opti-Sciences, Hudson, USA), according to the following analysis protocols: maximum quantum yield (Fv/Fm protocol; measured in the dark-adapted state; and effective quantum yield (yield protocol), measured in the light-adapted state. The measurements were carried out at 0, 1, 3, and 7 DAA on a smaller number of leaves (45 apical leaves, 48 middle leaves, and 45 basal leaves) to obtain the following parameters of chlorophyll *a* fluorescence: effective quantum yield of PSII (ΦPSII), electron transport rate (ETR), photochemical quenching (qP), non-photochemical quenching (NPQ), and maximum quantum yield of PSII (Fv/Fm).

Leaf area (LA) was assessed at the first and last evaluations by measuring length and width (cm) and then applying the equation proposed by Souza et al. (2014).

The data were subjected to the Shapiro-Wilk normality test, analysis of variance at 1% and 5% probability levels, and Scott-Knott test, using the software SISVAR.

The climate data were obtained from a weather station installed in the UFMT, Sinop. The air temperature remained within the range of 20.5 to 33.5 °C, with means varying from 24 to 26 °C, within the optimal range for crop development: 20 to 25 °C (SOUZA and LEONEL, 2011). The relative air humidity decreased from the first (0 DAA) to the last (7 DAA) evaluation. The daily curves of photosynthetically active radiation (PAR), global radiation, and illuminance (Lux) exhibited the expected dynamics, with higher intensities between 10:00 am and 1:00 pm.

3. RESULTS

The analysis of variance (Table 1) showed a significant triple interaction (treatments, leaf position on the branch, and evaluation day) for stomatal conductance (gs) (gas exchange parameter) and quantum yield of PSII and electron transport rate (chlorophyll *a* fluorescence parameters).

Gas exchange parameters were not significantly affected by the Bordeaux mixture application; significant variations were found only for leaf position and evaluation day. Therefore, the comparison between treatments with and without Bordeaux mixture application was not necessary throughout the discussion.

Leaf internal temperature presented no statistically significant variation for treatments and branch parts (Table 2). Variations in CO_2 concentration between leaf external and internal environments (ΔC) and net CO_2 assimilation rate (A) presented higher means for leaves in the apical part of the branch (29.48 to 42.33 $\mu mol\ mol^{-1}$ and 9.75 to 13.68 $\mu mol\ m^{-2}s^{-1}$, respectively), followed by leaves in the middle part (25.59 to 33.84 $\mu mol\ mol^{-1}$ and 8.62 to 11.06 $\mu mol\ m^{-2}s^{-1}$) and basal part of the branch (19.08 to 26.87 $\mu mol\ mol^{-1}$ and 6.34 to 8.74 $\mu mol\ m^{-2}s^{-1}$, respectively). Transpiration rate and stomatal conductance showed low variation for leaf positions on the branch.

Significant statistical variation was found for gs (Table 1) for treatments with and without Bordeaux mixture application, mainly in apical leaves, except for the second evaluation (Table 2).

Chlorophyll A fluorescence showed no significant triple interaction for maximum photochemical efficiency of PSII (Fv/Fm), photochemical quenching (q_P), and non-photochemical quenching (NPQ); however, significant statistical variation was found for quantum yield of PSII (ΦPSII) and electron transport rate (ETR).

Chlorophyll *a* fluorescence parameters were not significantly affected by Bordeaux mixture application; the treatments and evaluation day were the factors with higher effects; therefore, discussions for treatments were unnecessary since no significant variation was found.

Table 1. Analysis of variance for parameters of gas exchange and chlorophyll *a* fluorescence: external carbon concentration (Cref), internal carbon concentration (C_i), carbon variation between the external environment and the analysis chamber (ΔC), leaf temperature (T), transpiration rate (E), stomatal conductance (g_s), net assimilation rate (A), maximum photochemical efficiency of PSII (Fv/Fm), photochemical quenching (q_P), non-photochemical quenching (NPQ), effective quantum yield of PSII (ΦPSII), and electron transport rate (ETR). Leaf area in the treatments with Bordeaux mixture application (BM) and without Bordeaux mixture application (WBM) in fig trees (cultivar Roxo de Valinhos).
Tabela 1. Análise de variância para os parâmetros das trocas gasosas e fluorescência da clorofila A referentes a: concentração de carbono no ambiente externo (Cref), concentração de carbono interno (C_i), variação de carbono entre ambiente externo e câmara de análise (ΔC), temperatura da folha (TF), taxa de transpiração (E), condutância estomática (g_s) e taxa de assimilação líquida (A); máxima eficiência fotoquímica de PSII (Fv/Fm), Quenching fotoquímico (q_P), Dissipação não fotoquímica (NPQ), Rendimento quântico efetivo do PSII (Φ PSII) e Taxa de transporte de elétrons (ETR). Área foliar nos tratamentos com aplicação de calda bordalesa (CC) e sem aplicação de calda bordalesa (SC), em plantas de Figueiras 'Roxo de Valinhos'.

	parameters of gas exchanges						
Source of variation	Cref	ΔC	C_i	T	E	g_s	A
Treatment (Treat)	5.136**	49.884*	1.269^{NS}	1.807^{NS}	5.301**	21.497*	46.928*
Leaf position (Leaf)	2.919^{NS}	171.550*	126.701*	2.708^{NS}	26.089*	17.146*	166.555*
Evaluation day (Day)	64.094*	11.037*	17.565*	9.717*	27.188*	25.959*	10.207*
Treat×Leaf	0.877^{NS}	2.971^{NS}	0.328^{NS}	0.949^{NS}	2.976^{NS}	11.734*	2.704^{NS}
Treat×Day	3.728*	1.136^{NS}	7.399*	1.264^{NS}	3.507*	6.189*	1.177^{NS}
Part×Day	0.307^{NS}	1.344^{NS}	1.091^{NS}	1.415^{NS}	1.025^{NS}	1.356^{NS}	1.285^{NS}
Treat×Leaf×Day	0.362^{NS}	1.242^{NS}	1.423^{NS}	1.257^{NS}	0.419^{NS}	2.169**	1.184^{NS}
	Parameters of Chlorophyll *a* Fluorescence					Leaf Area	
Source of variation	Fv/Fm	q_P	NPQ	ΦPSII	ETR	BM	WBM
Treatment (Treat)	16.366*	0.848^{NS}	0.086^{NS}	2.270^{NS}	0.145^{NS}		
Leaf position (Leaf)	15.550*	8.781**	1.941^{NS}	6.505*	4.127*	58.589**	90.892**
Evaluation day (Day)	2.978**	4.167**	13.430**	2.319^{NS}	3.740*	-	-
Treat×Leaf	1.798^{NS}	1.299^{NS}	2.694^{NS}	1.478^{NS}	0.843^{NS}	2.547^{NS}	0.874^{NS}
Treat×Day	0.559^{NS}	1.143^{NS}	1.459^{NS}	1.375^{NS}	1.441^{NS}	-	-
Part×Day	1.221^{NS}	4.798**	0.779^{NS}	4.698*	2.271*	3.666*	3.995*
Treat×Leaf×Day	1.249^{NS}	2.070^{NS}	0.076^{NS}	3.017*	2.474*		

* = significant at 5%; ** = significant at 1%; NS = not significant.

Table 2. Parameters of gas exchanges as a function of days after application (DAA) of Bordeaux mixture in fig trees (cultivar Roxo de Valinhos): external carbon concentration (Cref), internal carbon concentration (C_i), carbon variation between the external environment and the analysis chamber (ΔC), leaf temperature (T), transpiration rate (E), stomatal conductance (g_s), and net assimilation rate (A).
Tabela 2. Parâmetros de troca gasosas em função dos dias após aplicação ou não da calda bordalesa, em plantas de Figueiras 'Roxo de Valinhos': concentração de carbono no ambiente externo (Cref), concentração de carbono interno (C_i), variação de carbono entre ambiente externo e câmara de análise (ΔC), temperatura da folha (TF), taxa de transpiração (E), condutância estomática (g_s) e taxa de assimilação líquida (A).

Leaf position on	DAA	Cref	C_i	ΔC	T	E	g_s	A
				Bordeaux Mixture Application				
Apical	0	378.07 Ba	283.24 Bc*	29.48 Aa	37.49 Aa*	4.69 Bb	0.29 Cc*	9.75 Aa
	1	378.26 Ba	306.17 Ab*	31.82 Aa*	34.10 Bb*	4.70 Ba*	0.53 Aa	10.37 Aa*
	3	381.63 Ba	298.39 Ac	32.05 Aa	35.82 Ba	4.73 Bb*	0.41 Bb*	10.45 Aa
	5	387.01 Aa	286.20 Bb	34.86 Aa*	37.49 Aa	5.71 Ab	0.35 Bb*	11.38 Aa*
	7	392.11 Aa	302.30 Ab	32.72 Aa*	35.10 Ba	4.94 Bb	0.37 Bb*	10.72 Aa*
Middle	0	377.87 Ba	302.01 Bb	26.82 Aa	36.88 Aa	5.20 Ba	0.37 Bb*	8.78 Aa
	1	375.80 Ba	313.21 Ab*	26.10 Ab*	37.95 Aa*	4.91 Ba*	0.49 Aa	8.62 Ab*
	3	377.97 Ba	314.03 Ab	27.11 Ab	35.76 Ba	5.09 Bb	0.53 Aa	8.97 Ab
	5	384.37 Aa*	292.70 Bb	30.09 Ab	38.17 Aa	5.91 Ab	0.32 Bb	9.82 Ab
	7	387.60 Aa	324.53 Aa	25.59 Ab	35.27 Ba	5.28 Ba	0.50 Aa	8.38 Ab*
Basal	0	377.72 Ba	324.66 Aa	19.08 Ab*	36.83 Aa	5.54 Ba	0.45 Ba	6.34 Ab*
	1	377.32 Ba	326.88 Aa	22.04 Ac	35.25 Ab	5.10 Ba	0.56 Aa	7.23 Ac
	3	376.28 Ba	327.09 Aa	20.71 Ac	36.34 Aa	5.66 Ba	0.57 Aa	6.82 Ac
	5	385.37 Aa	315.73 Ba	24.59 Ac	37.47 Aa	6.32 Aa	0.44 Ba	8.13 Ac
	7	386.26 Aa	335.13 Aa	19.49 Ac	35.60 Aa	5.53 Ba	0.50 Ba	6.56 Ac
				Without Bordeaux Mixture Application				
Apical	0	380.23 Ba	299.76 Ab*	32.48 Ba	35.46 Aa*	4.79 Ba	0.53 Aa*	10.61 Ba
	1	374.54 Ca	287.29 Bb*	37.94 Aa*	35.90 Aa*	5.37 Ba*	0.49 Aa	12.34 Aa*
	3	381.11 Ba	299.82 Ab	35.80 Ba	36.08 Aa	5.21 Ba*	0.52 Aa*	11.67 Ba
	5	390.55 Aa	287.45 Bc	42.33 Aa*	36.58 Aa	5.92 Aa	0.46 Aa*	13.68 Aa*
	7	391.86 Aa	299.47 Ac	40.11 Aa*	34.54 Aa	5.19 Bb	0.51 Aa*	13.01 Aa*
Middle	0	378.54 Ba	308.30 Ab	27.79 Bb	35.98 Aa	5.10 Ba	0.47 Aa*	9.25 Bb
	1	373.60 Ca	293.80 Bb*	33.84 Aa*	36.21 Aa*	5.45 Aa*	0.49 Aa	11.06 Aa*
	3	380.48 Ba	316.88 Aa	27.17 Bb	35.87 Aa	4.90 Ba	0.52 Aa	8.77 Bb
	5	392.30 Aa*	303.82 Bb	32.22 Ab	37.00 Aa	5.75 Aa	0.37 Ba	10.52 Ab
	7	392.08 Aa	315.39 Ab	29.54 Bb	35.55 Aa	5.37 Ab	0.43 Ba	9.73 Bb*
Basal	0	377.86 Ba	319.62 Ba	23.90 Ab*	36.52 Aa	5.37 Ba	0.51 Aa	7.86 Ac*
	1	374.35 Ba	316.95 Aa	23.76 Ab	35.76 Aa	5.50 Ba	0.56 Aa	7.88 Ab
	3	378.90 Ba	327.12 Ba	22.22 Ac	36.33 Aa	5.42 Ba	0.58 Aa	7.35 Ac
	5	389.82 Aa	317.41 Ba	26.87 Ac	37.42 Aa	6.18 Aa	0.41 Ba	8.74 Ac
	7	391.29 Aa	333.51 Aa	23.69 Ac	35.70 Aa	5.87 Aa	0.51 Aa	7.76 Ac

*Means followed by the same letter in the row and in the column not statistically different by test the Skott-Knott test at 5% probability level.

Fv/Fm presented sporadic variations for evaluation days (Table 3), with decreases in apical and middle leaves on isolate days, denoting uniformity of results throughout the evaluations. The parameters qP, Fv/Fm, NPQ presented significant statistical differences at 7 DAA for the treatments. Basal leaves in both treatments (with and without Bordeaux mixture application) presented lower qP means (0.063 and 0.054, respectively) compared to middle (0.087 and 0.126, respectively) and apical (0.265 and 0.164, respectively) leaves (Table 3).

A similar result was found for NPQ, which showed significant variation only between evaluations of each treatment, mainly for the treatment with Bordeaux mixture application, which presented the highest mean at 0 DAA, whereas the other evaluations presented no significant differences from each other.

The triple interaction was significant for ETR and ΦPSII at 1% and 5% significance levels, respectively, as both parameters are closely correlated. ETR considers ΦPSII in its base equation, which provides consistent results.

The absence of significant statistical variations in the other evaluations of ETR and ΦPSII was similar for qP, NPQ, and Fv/Fm, which showed normality, with isolated significant statistical variations that did not unfold over time for leaf positions and treatments.

Leaf area (LA) showed significant statistical variation for evaluation days (0 DAA and 7 DAA) and leaf positions on the branch (Table 1). Regarding variations in LA for evaluation days, middle leaves in the treatment with Bordeaux mixture application showed decreases in LA from the first to the second evaluation, whereas apical leaves in the treatment without Bordeaux mixture application showed increases in LA from the first to the second evaluation. Regarding variations in LA for leaf positions on the branch, LA varied in both evaluations, with middle leaves showing the highest LA means (Table 4).

Table 3. Means of maximum photochemical efficiency of PSII (Fv/Fm), photochemical quenching (qP), non-photochemical quenching (NPQ), effective quantum yield of PSII (ΦPSII), and electron transport rate (ETR) referring to treatments (with and without Bordeaux mixture application), evaluation days (days after application – DAA), and leaf position on the branch (apical, middle, and basal parts) of fig trees.
Tabela 3. Valores médios da Máxima eficiência fotoquímica de PSII (Fv/Fm); Quenching fotoquímico (q_P); Dissipação não fotoquímica (NPQ); Rendimento quântico efetivo do PSII (Φ PSII) e Taxa de transporte de elétrons (ETR), referentes aos tratamentos, dias e segmentos da figueira.

Leaf position on the branch	DAA	Fv/Fm	qP	NPQ	ΦPSII	ETR
		With Bordeaux Mixture Application				
Apical	0	0.756 Aa	0.138 Ba	1.027 Aa	0.077 Ba	19.58 Aa
	1	0.755 Aa*	0.105 Ba	0.523 Ba*	0.070 Ba	17.800 Aa
	3	0.742 Ab	0.107 Ba	0.766 Ba	0.060 Ba	15.275 Aa
	7	0.717 Ab	0.265 Aa*	0.595 Ba	0.170 Aa*	20.120 Aa
Middle	0	0.746 Aa*	0.163 Aa	1.208 Aa	0.086 Aa	21.668 Aa
	1	0.751 Aa	0.108 Aa	0.744 Ba	0.066 Aa	16.604 Aa
	3	0.749 Ab	0.089 Aa	0.790 Ba	0.052 Aa	13.204 Aa
	7	0.718 Ab	0.087 Ab	0.837 Ba	0.053 Ab	13.413 Ab
Basal	0	0.752 Aa	0.153 Aa*	1.230 Aa	0.085 Aa*	21.515 Aa*
	1	0.761 Aa	0.077 Aa	0.594 Ba	0.051 Aa	12.840 Ab
	3	0.788 Aa	0.112 Aa	0.843 Ba	0.072 Aa	18.181 Aa
	7	0.757 Aa	0.063 Ab	0.542 Ba	0.040 Ab	10.030 Bb
		Without bordeaux mixture application				
Apical	0	0.730 Aa	0.167 Aa	1.036 Aa	0.097 Aa	24.591 Aa
	1	0.689 Ab*	0.105 Ba	0.867 Aa*	0.055 Aa	13.952 Ba
	3	0.713 Ab	0.084 Ba	0.904 Aa	0.048 Aa	12.177 Ba
	7	0.698 Aa	0.164 Aa*	0.785 Aa	0.082 Aa*	20.855 Aa
Middle	0	0.763 Ab*	0.142 Aa	1.049 Aa	0.065 Ab	16.386 Ab
	1	0.753 Aa	0.136 Aa	0.786 Aa	0.080 Aa	20.176 Aa
	3	0.765 Ab	0.100 Aa	0.698 Aa	0.059 Aa	14.876 Aa
	7	0.745 Aa	0.126 Aa	0.857 Aa	0.070 Aa	17.659 Aa
Basal	0	0.695 Aa	0.065 Ab	0.919 Aa	0.039 Ab*	9.977 Bb*
	1	0.732 Aa	0.112 Aa	0.519 Aa	0.079 Aa	19.963 Aa
	3	0.732 Aa	0.079 Aa	0.787 Aa	0.050 Aa	12.594 Ba
	7	0.713 Aa	0.054 Ab	0.634 Aa	0.034 Aa	8.561 Bb

*Means followed by the same letter in the row and in the column are not statistically different by the Skott-Knott test at 5% probability level.

Table 4. Means of leaf area (cm^2) in treatments with and without Bordeaux mixture application in fig trees (cultivar Roxo de Valinhos).
Tabela 4. Área foliar média dos tratamentos com aplicação de calda bordalesa e sem aplicação de calda bordalesa, em plantas de Figueiras 'Roxo de Valinhos'.

DAA	With Bordeaux Mixture Application			Without Bordeaux Mixture Application		
	Apical leaves	Middle leaves	Basal leaves	Apical leaves	Middle leaves	Basal leaves
0	270.04 Ba	359.73 Aa	200.75 Ca	309.02 Bb	377.82 Aa	195.25 Ca
7	294.97 Aa	309.20 Ab	183.31 Ba	367.15 Aa	362.47 Aa	186.72 Ba

* Means followed by the same letter in the row and column are not statistically different by the Skott-Knott test at 5% probability level.

4. DISCUSSION

Internal leaf temperature remained approximately 2 to 3 °C higher than the maximum environmental temperatures during the experiment (Figure 1). According to Taiz et al. (2017), this is due to continuous exposure to solar radiation and bright environmental conditions; this excessive accumulation is undesirable for plants, as high temperatures affect water balance and CO_2 assimilation.

Internal CO_2 concentration is a limiting factor for photosynthesis and stomatal regulation, mainly in C3 photosynthetic metabolism plants such as fig trees. Once inside the leaf, CO_2 diffuses from the intercellular airspaces to the chloroplast and is limited by resistances in gas and liquid phases of cytosol, as well as diffusion barriers, causing it to accumulate in intercellular spaces, mainly when stomatal conductance and assimilation rate are affected by external factors, such as air temperature and humidity (CHAVES et al., 2011; TAIZ et al., 2017).

Silva et al. (2010) evaluated gas exchange in young leaves (recently opened and near the branch meristem) of fig trees and found that the lowest net CO2 assimilation rates, transpiration, and stomatal conductance resulted in high CO_2 concentration in the substomatal chamber and low photosynthetic carbon assimilation. However, the results found in the present study showed that apical leaves had the lowest internal CO_2 concentrations and the highest means of net CO_2 assimilation, i.e., carbon dioxide was moving towards the carboxylation stage of the photosynthetic process, followed by middle and basal leaves.

Transpiration rate (E) refers to water loss through stomatal pores, combined with the guard cells, at the time of opening. González-Rodríguez and Peters (2010) evaluated leaf sprouting in pruned and unpruned fig trees in Spain and found transpiration rates ranging from 3 to 7.6 mmol m^{-2} s^{-1} over 200 days; the highest rates were found during the summer and were similar to the range of 4.6 to 6.1 mmol m^{-2} s^{-1} found in the present study (Table 2). Additionally, Silva et al. (2010), assessed gas exchange in leaves of fig trees of the cultivar the Roxo de Valinhos in Botucatu, SP, Brazil, and found transpiration rates ranging from 2.19 to 4.78 mmol m^{-2} s^{-1}, indicating that the transpiration rates found in the present study are consistent with those previously reported for the species.

The means of stomatal conductance (gs) varied from 0.280 to 0.584 mol m^{-2} s^{-1}, which are similar to results reported in the literature. Ammar et al. (2020) evaluated physiological dynamics in 5-year-old fig trees over 259 days in Tunisia and found maximum means of 0.370 and 0.435 mol m^{-2} s^{-1} during late spring when temperatures ranged from 28 to 31 °C; however, the lowest means (below 0.100 mol m^{-2} s^{-1}) were found during summer when temperatures were higher than 35 °C.

Can et al. (2008) and Ammar et al. (2020) reported that the maximum gs was found when daytime temperatures were around 30 to 32 °C, as at these temperatures, water viscosity decreases and mesophyll conductance increases, increasing guard cell turgor pressure and stomatal opening. Conversely, gas exchange rates were significantly lower during the hottest periods of the year compared to those found in early summer.

The net assimilation rate showed localized variations in leaf positions on the branch regarding the evaluation days, specifically in apical and middle leaves in the treatment without Bordeaux mixture application at 0 and 3 DAA. Regarding the variation among leaf positions within each treatment, a significant difference was found, with the highest rates in apical leaves and the lowest rates in basal leaves were inversely proportional to the results found for internal carbon concentration (Ci).

The results obtained differed from those reported by Silva et al. (2010), who found the lowest rates of net CO_2, transpiration, and stomatal conductance in younger leaves, resulting in higher CO_2 accumulation in the substomatal chamber. Only stomatal conductance and transpiration rate remained within the expected range, with the lowest rates found in apical leaves in the present study.

The lower CO_2 concentration found in apical leaves, combined with the higher assimilation rate, may be related to environmental conditions, mainly intense light and radiation, as leaf temperatures did not vary significantly and the lowest transpiration rate and stomatal conductance were found in apical leaves, denoting that the leaves maintained the CO_2 assimilation even with partially open stomata.

The mean assimilation rates found (6.345 to 13.018 µmol m^{-2} s^{-1}) are consistent with results reported in the literature for fig tree crops. Costa et al. (2020) found rates ranging from 6.06 to 10.49 µmol m^{-2} s^{-1} when studying photosynthetic dynamics in different numbers of branches of fig trees (cultivar Roxo de Valinhos) in Erechim, RS, Brazil.

According to Ferraz et al. (2020), the net assimilation rate represents the photosynthesis performed by the plant. Therefore, superior performance in CO_2 assimilation results in increased quantum efficiency and better utilization and conversion into light energy, leading to higher allocation of biomass and the formation of better plant architecture. The authors compared commercial accessions of fig trees and found means ranging from 5.74 to 12.94 µmol m^{-2} s^{-1} and a mean of approximately 12.59 µmol m^{-2} s^{-1} for the cultivar Roxo de Valinhos, which is similar to that found in the present study.

Regarding the evaluations of chlorophyll *a* fluorescence, the maximum photochemical efficiency of PSII (Fv/Fm) varied over time in the treatments, mainly with decreases in Fv/Fm on isolate evaluation days in the apical and middle leaves, without significant variations. These results were expected since characteristics such as cultivar, time, and leaf position on the branch do not affect Fv/Fm, but significant variations are due to environmental factors such as high radiation incidence (PALLIOTTI, et al. 2009).

The correlation between maximum fluorescence (Fm) and variable fluorescence (Fv) enables a better understanding of qualitative and quantitative analyses of light energy absorption and use by the photosystem II (PS II); it is an indicator of use efficiency of photochemical radiation and, consequently, carbon assimilation by plants, contributing to the diagnosis of integrity of the photosynthetic apparatus after exposure to environmental adversities, especially when combined with gas exchange analyses (TATAGIBA et al., 2014; FREIRE et al., 2014).

The means found for Fv/Fm (0.689 to 0.788) were consistent with other Fv/Fm results reported for arboreal species. Ammar et al. (2020) found means ranging from 0.493 to 0.741 in an experiment in Tunisia, with the lowest means found in summer and early autumn when temperatures and light incidence were higher. Similarly, Gomes et al. (2008) found Fv/Fm means close to 0.741 in a study characterizing the photosynthetic performance of fig trees in the state of Espirito Santo, Brazil; the authors noted that other fruit tree species grown in the same area, such as coconut and mango trees, had Fv/Fm means of 0.74 and 0.76, respectively, which are similar to the results found in the present study.

The triple interaction was significant for the electron transport rate (ETR) and effective quantum yield of PSII (ΦPSII) at 1% and 5% probability levels, respectively. It was significant for ΦPSII due to apical leaves, as the treatment with Bordeaux mixture application was the only one that showed variation among evaluations for apical leaves. The highest mean (0.170) was found at 7 DAA. Apical leaves had higher ΦPSII at 7 DAA than middle and basal leaves, which did not differ from each other (0.053 and 0.040, respectively). Apical and basal leaves presented significant variation between treatments at 0 DAA; apical leaves in the treatment with Bordeaux mixture application had higher ΦPSI at 7 DAA than those in the treatment without application, which did not differ among evaluations and leaf positions on the branch.

Similar results were found for ETR in basal leaves in the treatment without Bordeaux mixture application. Regarding the evaluation days within each treatment, the lowest ETR means were found at the 0 and 7 DAA. Significant variation between treatments was found only for basal leaves in the first evaluation, with the highest mean (21.52 μmol m^{-2} s^{-1}) found in the treatment with Bordeaux mixture application.

The absence of significant statistical variations in ETR and ΦPSII in the other evaluations is consistent with the results of qP, NPQ, and Fv/Fm, which showed normality with isolated significant variations that did not unfold over time within leaf positions and treatments.

The results found for all parameters, except Fv/Fm, were lower compared to those reported by Ranjbar-Fordoei (2019), who evaluated three stages of fig leaf ontogeny (young, mature, and senescent) in Iran for two production years and found qP and ΦPSII with significant differences in leaf growth and maturation, which was not found in the present study, and higher mean for all evaluations of qP (0.370 to 0.544) and ΦPSII (0.454 0.502); senescent leaves presented the lowest values.

According to Moreno et al. (2008) and Ranjbar-Fordoei (2018), low qP and ΦPSII (and consequently ETR) are associated with abiotic stresses, such as water stress, indicating that the PSII photosynthetic apparatus may have been damaged and lost its ability to dissipate heat, resulting in low efficiency in light energy transformation in PSII, mainly in the primary light capture when PSII reaction centers are partially deactivated; similarly, a decrease in qP may indicate damage to PSII reaction centers and collapse in the balance between excitation rate and electron transfer rate.

Leaf area (LA) differed significantly among leaf positions on the branch in both evaluations. Middle leaves had the highest mean LA, followed by apical and basal leaves. In the evaluation at 7 DAA, apical and middle leaves did not show significant differences from each other for LA.

Ferraz et al. (2020) reported that fig trees maintain constant leaf gains and LA until harvest and dormancy of the plant when these values decrease.

Leaves in the middle part of the branch had larger leaf areas compared to those in the apical and basal parts of the branch.

5. CONCLUSIONS

The film formed on the leaf surface due to the application of Bordeaux mixture did not affect photochemical stages of photosynthesis and chlorophyll *a* fluorescence.

Leaf temperature, transpiration, and stomatal conductance presented no significant variations in gas exchange among leaf positions on the branch (apical, middle, and basal parts) within each treatment.

Internal CO_2 concentration and net CO_2 assimilation were gas exchange parameters affected by the leaf position on the branch over time.

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