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Physiological, biochemical, and nutritional parameters of wheat exposed to fungicide and foliar fertilizer

Parâmetros fisiológicos, bioquímicos e nutricionais em trigo exposto a fungicida e fertilizante foliar

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Abstract

Agronomic improvements in grain yield and quality of wheat crops could be obtained through the application of strategies, such as using foliar fungicides with fertilizers, to protect the leaves against pathogens and delay senescence during grain filling. However, few studies have reported the effect of these practices on wheat, although these treatments could represent a new method of increasing wheat production and profits. The objective of this study was to evaluate the effects of foliar fertilizer, applied alone or in combination with a fungicide, on the photochemical, biochemical, and nutritional parameters of wheat plants. The experiment was conducted under greenhouse conditions in a 2 × 3 factorial design (fungicide × foliar fertilizer) with four replications. The fungicide treatment used was azoxystrobin + cyproconazole + mineral oil; the control was left untreated. The foliar fertilizer was used at two different rates, and the control was not treated. Plants were sprayed at the GS29/GS30, GS45, and GS60 growth stages, and the plants were assessed ten days after the last spray. Chlorophyll *a* fluorescence, the photochemical efficiency of photosystem II (F_v/F_m), and electron transport rate were positively influenced by fertilizer. Fertilizer spraying significantly increased the leaf pigment content (chlorophylls *a* and *b* and carotenoids) and the nitrogen, phosphorus, and potassium concentration in flag leaves. When used in mixture, the fertilizer mitigates the stresses generated by the fungicide.
Key words: Amino acids. Azoxystrobin. Cyproconazole. *Triticum aestivum* L.

Resumo

Melhorias no rendimento e qualidade de grãos na cultura do trigo poderiam ser obtidas através da implementação de estratégias, como a utilização de fungicidas com fertilizantes foliares, para proteção das folhas contra patógenos e retardo da senescência durante o enchimento de grãos. Entretanto, poucos estudos têm reportado o efeito destas práticas em trigo, embora estes tratamentos possam representar incrementos na produção de trigo e maiores lucros. O objetivo deste trabalho foi avaliar o efeito do fertilizante foliar aplicado isolado ou em associação com fungicida, em parâmetros fotoquímicos, bioquímicos e nutricionais em plantas de trigo. O ensaio foi conduzido em condições de casa de vegetação em esquema fatorial 2 × 3 (fungicida x fertilizante) com quatro repetições. O fungicida

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utilizado foi azoxistrobina + ciproconazol + óleo mineral; o controle foi deixado sem tratamento. O fertilizante foliar foi utilizado em duas doses, e o controle não foi tratado. As plantas foram pulverizadas nos estágios GS29/GS30, GS45 e GS60, e as plantas foram avaliadas dez dias após a última aplicação. Os parâmetros da fluorescência da clorofila *a*, eficiência fotoquímica máxima do fotossistema II (F_v/F_m) e taxa de transporte de elétrons foram positivamente influenciados pelo fertilizante. A aplicação do fertilizante significativamente incrementou o conteúdo de pigmentos foliares (clorofilas *a* e *b* e carotenóides) e a concentração de nitrogênio, fósforo e potássio em folhas bandeira. Quando aplicados em mistura, o fertilizante teve efeito mitigatório dos estresses gerados pelo fungicida.
Palavras-chave: Aminoácidos. Azoxistrobina. Ciproconazol. *Triticum aestivum* L.

Introduction

Fungal diseases can cause significant reductions in the yield and quality of wheat grains. Most wheat cultivars lack genetic resistance, which makes chemical management with fungicides necessary for effective disease control. However, fungicides, as well as other products used in the preparation of the solution, such as mineral oils and adjuvants, may be phytotoxic.

Phytotoxicity is the ability of pesticides to cause temporary or permanent damage to a plant through physiological and morphological changes (VUKOVIĆ et al., 2014). Paradoxically, the use of fungicides in wheat is an indispensable practice that drastically reduces disease-induced damage (BLANDINO; REYNERI, 2009; DIMMOCK; GOODING, 2002; NAVARINI; BALARDIN, 2012).

Although some phytotoxicity studies report no negative effects of fungicides on plants, several studies at the cellular level have reported damage to the photosynthetic apparatus, which can be attributed to changes at the physiological level, such as the parameters of chlorophyll *a* fluorescence (KRUGH; MILES, 1996; PETIT et al., 2008; SALADIN et al., 2003), reduction of CO_2 assimilation (XIA et al., 2006), and carboxylation (NASON et al., 2007; PETIT et al., 2008). Similarly, other reports have found that fungicide application can change nitrogen and carbon metabolism, which is reflected in the reduced growth and development of reproductive organs (SALADIN et al., 2003). Thus, reducing the stresses caused by fungicide application may improve grain productivity.

One way to reduce the stressful effects on plants is to use protective molecules that increase antioxidant capacity (ASTHIR et al., 2012; KHALIL et al., 2009; SONG et al., 2006). Several studies have shown that exogenous application of protectors such as osmoprotectants (proline, glycine, and betaine), vegetable phytohormones (abscisic, gibberellic, jasmonic, and salicylic acids), and signaling molecules (nitric oxide) improves plant tolerance to stress induced by high temperatures (HASANUZZAMAN et al., 2012; RASHEED et al., 2011; WANG et al., 2010).

The mineral nutrition and nutritional status of plants are also highly correlated with their stress tolerance. The beneficial effects of calcium (Ca^{2+}), for example, include the regulation of physiological processes at the cellular and molecular level (WARAICH et al., 2011). The application of micronutrients in low concentrations is also associated with increased tolerance to high temperature stress (WARAICH et al., 2012). Other studies suggest that selenium reduces the effect of cell-membrane damage by improving the antioxidant defense of sorghum plants (DJANAGUIRAMAN et al., 2010).

Foliar fertilizers containing amino acids are a new class of products that can reduce stresses in plants (CASTRO et al., 2008). Lambais (2011) found that application of amino acids had positive effects such as increased protein content in the leaves, facilitation of the absorption of macroelements and microelements by chelating action, and reduction of glyphosate stress in soybeans.

Therefore, the aim of this study was to evaluate the effect of foliar fertilizer, applied alone or in combination with fungicides, on photochemical, biochemical, and nutritional parameters of wheat.

Material and Methods

The experiment was conducted in a greenhouse located in the experimental area of the Phytus Institute, municipality of Itaara, RS, Brazil. The test was conducted free of disease infestation to isolate the effects of the treatments. Plants were grown in plastic pots with 5 L of soil as the base substrate, with rice husk (3:2) and liming filler PRNT > 90% at a dose of 2000 kg ha^{-1}. We also used 300 kg ha^{-1} of NPK fertilizer, formula 8-28-18.

The seeds of the cultivar 'Quartzo' were pretreated with difenoconazole (Spectro® BASF) at a dose of 30 g a.i. 100 kg^{-1} of seeds and thiamethoxam (Cruiser®, Syngenta) at a dose of 35 g a.i. 100 kg^{-1} of seeds. Each experimental unit consisted of two plants per pot with four replicates. The plants received irrigation in an automated manner, twice daily for 15 min each at a flow rate of 1 L h^{-1}. Each plant received two applications of nitrogen, at 30 days after emergence (DAE) (the tillering stage) and at 50 DAE (the elongation stage), both at a dose of 150 kg ha^{-1} of urea diluted with water.

The experimental design was completely randomized with two factors (2 × 3). Factor A was the presence or absence of the fungicide treatment, azoxystrobin + cyproconazole (Priori Xtra®, Syngenta, at a dose of 60 + 24 g i.a. ha^{-1}, respectively) + oil (Nimbus®, Syngenta, at a dose of 0.75 L ha^{-1}). The fungicide was chosen because of its broad scope and efficacy in culture. Factor B comprised two doses (1.0 and 3.0 L ha^{-1}) of the foliar fertilizer Quantis® (Syngenta) and a control with an application of water.

The treatments were applied in three stages, with the first application at 40 DAE, between the end of tillering and the beginning of elongation (GS29/GS30); the second application on the seventeenth day after the first, at the booting stage (GS45); and the third on the seventeenth day after the second, at flowering (GS60) (ZADOKS et al., 1974). We used a knapsack sprayer, with a CO_2 pressurized application bar with four spray nozzle (TeeJet XR 11002 flat) spaced at 0.5 m and calibrated to a flow rate of 150 L h^{-1}.

The evaluations were performed 10 days after the last application. The parameters evaluated included measures of chlorophyll *a* fluorescence—initial fluorescence (F_0), maximum fluorescence (F_m), ratio of variable fluorescence/maximum fluorescence (photochemical efficiency of PSII) (F_v/F_m)—and the electron transport rate (ETR_{1500}). Readings were taken from the flag leaves of three plants per replicate using a pulse modulated JUNIOR-PAM fluorometer (Walz, Germany).

The leaves were pre-adapted in the dark for 30 min to determine the F_0, and were subsequently subjected to a saturating light pulse (10,000 µmol m^{-2} s^{-1}) for 0.6 s, thereby determining F_m. F_v/F_m was calculated as the ratio of variable fluorescence ($F_m - F_0$) and maximum fluorescence (F_m). The ETR_{1500} was determined by light curves (electron transport rate *versus* PAR), which were constructed by subjecting each sample to nine levels of irradiation (0, 125, 190, 285, 420, 625, 820, 1150, and 1500 µmol electrons m^{-2} s^{-1}) for 10 sec.

The height of the main stems was also determined (ground level to the base of the flag leaf) and the number of green leaves per plant. Flag leaves and $F_{-1} + F_{-2}$ leaves (mixed to form a composite sample) were sampled to determine the concentrations of macronutrients (N, P, K, Ca, and Mg). Nutritional analysis was based on 2 g of the dry mass of the flag leaves and $F_{-1} + F_{-2}$ leaves. Analyses were processed at the Forest Ecology Laboratory (LABEFLO) of the Federal University of Santa Maria (UFSM).

The plant material collected was dried in a forced-air oven at 70°C to constant weight, and then ground in a Wiley mill (2 mm sieve) and placed in sealed

containers for subsequent chemical analysis. The N content was determined by the Kjeldahl method; P content was determined by visible spectrometry; and the K, Ca, and Mg content was determined by atomic absorption spectrophotometry. Values were expressed in grams of nutrients per kilogram of dry matter (g kg^{-1}).

Finally, flag leaves were also sampled to quantify cellular damage by lipid peroxidation and to determine the concentration of leaf pigments (chlorophyll *a* [Chl *a*], chlorophyll *b* [Chl *b*], and carotenoids). Lipid peroxidation was also carried out in F_{-1} + F_{-2} leaf samples (pooled sample). After collection, the leaves were placed in aluminum foil envelopes, immediately frozen in liquid N_2, and sent to the Plant Physiology Laboratory at UFSM for analysis. Lipid peroxidation was measured in plant tissues reactive to thiobarbituric acid (TBARS) as described by El-Moshaty et al. (1993). A sample was mixed with a 1:1 solution of thiobarbituric acid (5%) and trichloroacetic acid (20%). The reaction between the reagents was activated by heating the mixture in a water bath at 95°C for 30 min, and was stopped by abrupt cooling in an ice bath. The mixture was then centrifuged at 10,000 *g* for 10 min and the absorbance of the supernatant was read at wavelengths of 532 and 600 nm. The photosynthetic pigments Chl *a*, Chl *b*, and carotenoids were measured following the methodology described by Hiscox and Israeslstam (1979) and estimated using the formula described by Arnon (1949). The samples were heated to 65°C with dimethyl sulfoxide for 2 h, and the absorbance of the supernatant at 480, 645, and 663 nm was determined using a spectrophotometer, model SF325NM (Bel Engineering, Italy).

Data were subjected to analysis of variance (ANOVA), and the means were compared using Tukey's test ($p < 0.01$), using the statistical package Assistat 7.7 Beta (SILVA; AZEVEDO, 2002).

Results and Discussion

The fungicide and fertilizer did not alter the initial fluorescence (F_0) and maximum fluorescence (F_m). However, the photochemical efficiency of PSII (F_v/F_m) and the electron transport rate (ETR) were significantly influenced by the application of the fungicide and fertilizer (Table 1).

Table 1. Chlorophyll (Chl) *a* fluorescence parameters, initial fluorescence (F_0), maximum fluorescence (F_m), maximum quantum efficiency of PSII photochemistry (F_v/F_m), and electron transport rate through PSII (ETR) influenced by a fungicide and foliar fertilizer in wheat.

Fertilizer rates (L ha^{-1})	F_0		Means	F_m		Means
	Fungicide	Control		Fungicide	Control	
0.0	293.0^{NS}	296.3	294.7^{NS}	889.6^{NS}	865.0	877.3^{NS}
1.0	309.6	316.6	313.6	969.0	851.3	910.7
3.0	310.3	244.6	277.5	903.0	965.0	934.0
Means	304.3^{NS}	285.8	-	920.5^{NS}	893.7	-
CV%		8.68			10.73	
Fertilizer rates (L ha^{-1})	**F_v/F_m**		Means	**ETR**		Means
	Fungicide	Control		Fungicide	Control	
0.0	0.64 bB*	0.65 bA	0.64 c	166.1 bA	172.2 aA	169.2 b
1.0	0.68 aA	0.66 bB	0.67 b	148.2 bB	181.2 aA	164.7 b
3.0	0.69 aB	0.77 aA	0.73 a	221.0 aA	176.3 aB	198.7 a
Means	0.67 B	0.69 A	-	178.5^{NS}	176.6	-
CV%		1.05			7.49	

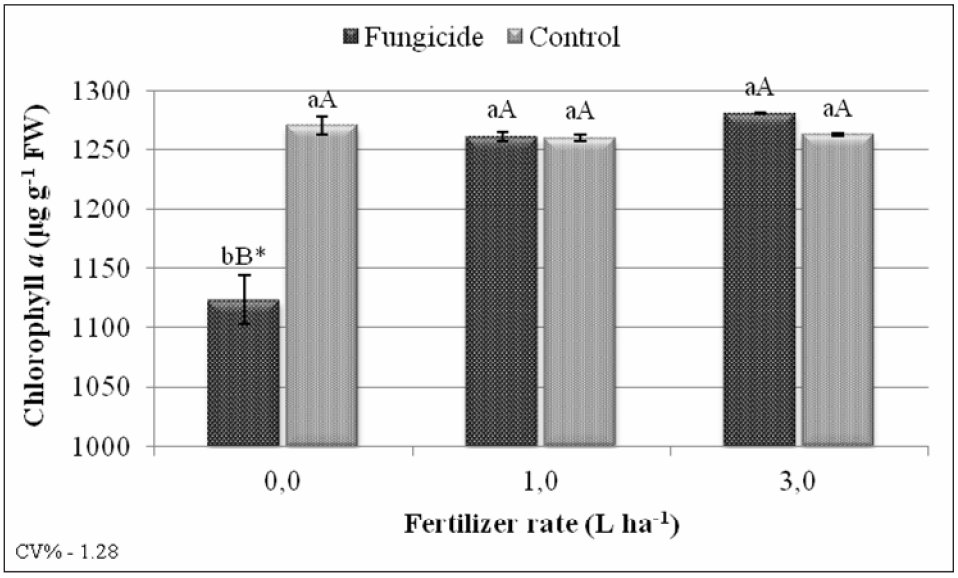
* Means followed by the same letter, lowercase in the columns and uppercase in the rows, do not differ by Tukey's test ($p < 0.01$).
^{NS} Not significant.

The application of the fungicide in the absence of fertilizer lowered the F_v/F_m ratio. According to Kalaji and Guo (2008), reductions in photochemical capacity (F_v/F_m) indicate stressful effects on plants. Furthermore, the low values recorded for this parameter may indicate the occurrence of photo-inhibition. Moreover, it is noted that the application of foliar fertilizer increased F_v/F_m. This occurred in both the presence and the absence of the fungicide.

The ETR was also lower in plants treated with the fungicide alone and the combination of fungicide and fertilizer (1.0 L ha^{-1}) than in control plants. However, only the second situation was significantly different. The combination of the highest dose of fertilizer with the fungicide increased ETR values by 33.1% compared to the control without fertilizer. In plants without fungicide application, there were no significant changes in the ETR due to foliar fertilizer.

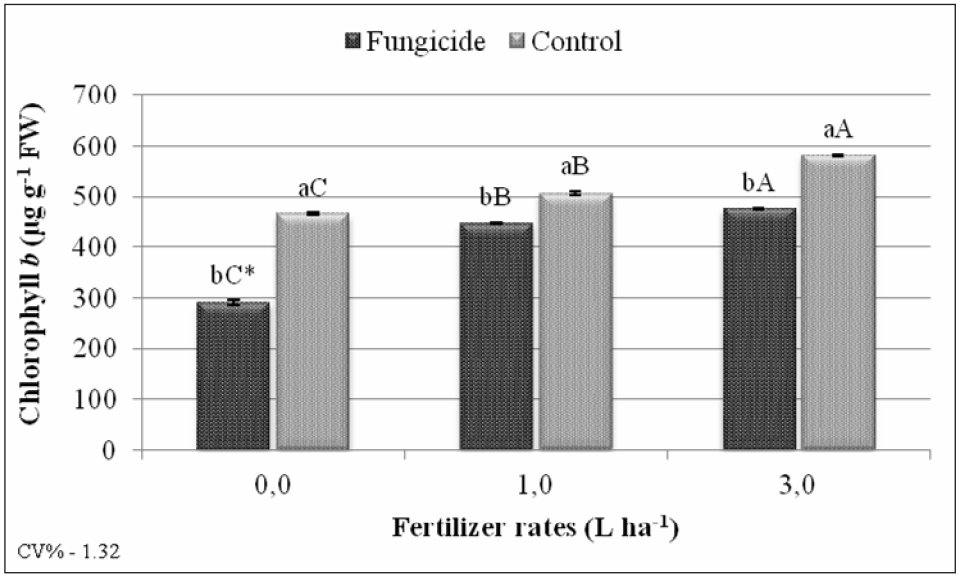
The concentration of photosynthetic pigments was significantly affected by the fungicide as well as by the fertilizer (Figures 1, 2, and 3). A reduction in the Chl *a* (Figure 1) and Chl *b* (Figure 2) concentrations was observed in plants treated with the fungicide. Similarly, the carotenoid concentrations in flag leaves (Figure 3) were 44% lower in plants treated with fungicide than in control plants. The temperature in the greenhouse consistently remained above the external temperature because of the lower air circulation, which might have affected the plants and intensified the stressful effects of the fungicide. The chlorophyll concentration can be used as a sensitive indicator of the cellular metabolic state, and hence its reduction may indicate toxicity in plant tissues (KHOSRAVINEJAD et al., 2008).

Figure 1. Chlorophyll *a* (Chl *a*) content in flag leaves of wheat ('Quartzo' cultivar) with fungicide and foliar fertilizer treatments.



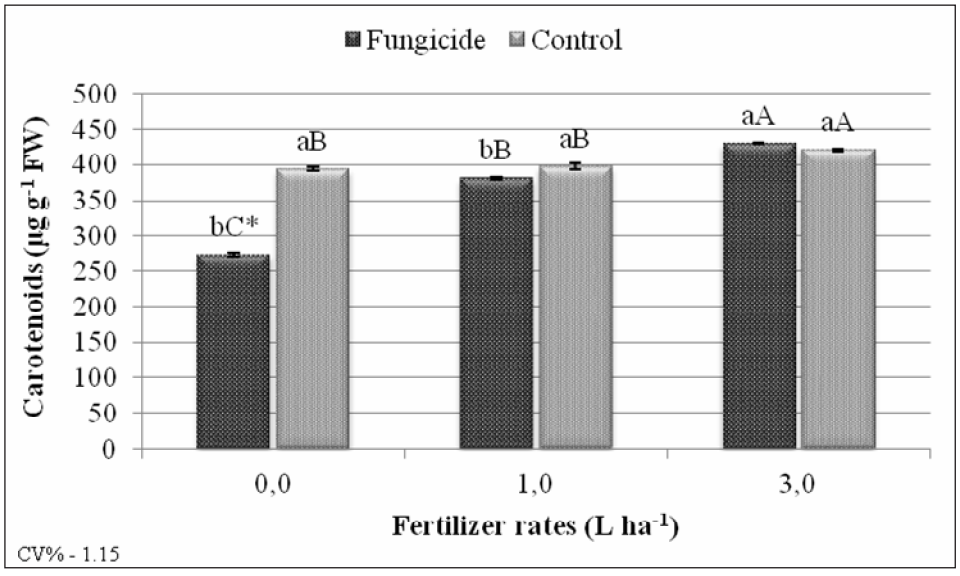
* Means followed by the same letter, lowercase between fungicides and uppercase between fertilizer rates, do not differ by Tukey's test ($p < 0.01$). Each column corresponds to the average of four replicates and the bars show the standard error of the mean (± SE). FW: fresh weight.

Figure 2. Chlorophyll b (Chl *b*) content in flag leaves of wheat ('Quartzo' cultivar) with fungicide and foliar fertilizer treatments.



* Means followed by the same letter, lowercase between fungicides and uppercase between fertilizer rates, do not differ by Tukey's test ($p < 0.01$). Each column corresponds to the average of four replicates and the bars show the standard error of the mean (± SE). FW: fresh weight.

Figure 3. Carotenoid contents in flag leaves of wheat ('Quartzo' cultivar) with fungicide and foliar fertilizer treatments.



* Means followed by the same letter, lowercase between fungicides and uppercase between fertilizer rates, do not differ by Tukey's test ($p < 0.01$). Each column corresponds to the average of four replicates and the bars show the standard error of the mean (± SE). FW: fresh weight.

The application of foliar fertilizer increased the pigment contents of flag leaves in plants treated with and without fungicide (Figures 1, 2, and 3). It strongly reduced the negative effects of the fungicide when applied in combination with it. In this case, increasing the dose of fertilizer affected chlorophyll *b* and carotenoid concentrations, but not the chlorophyll *a* concentration.

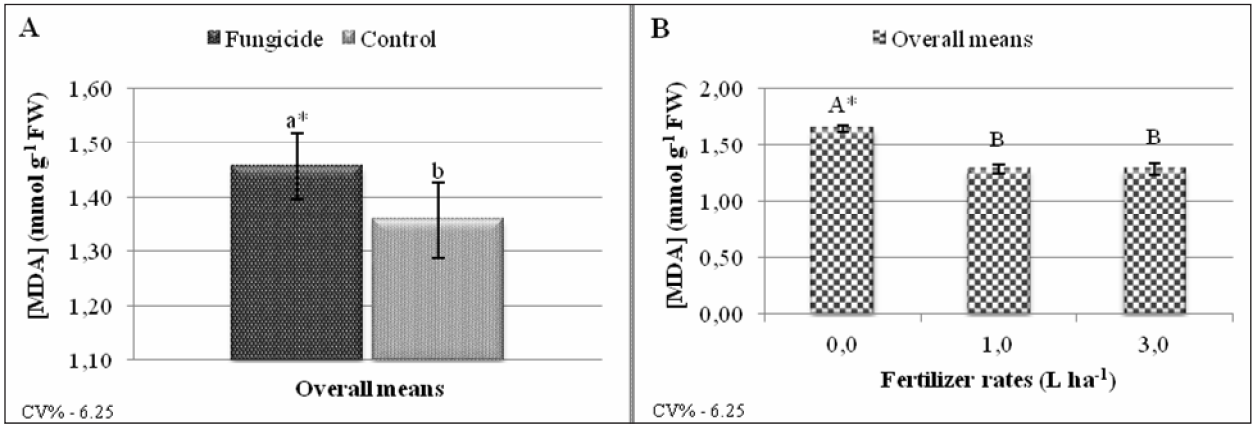
On the other hand, plants without fungicide application benefited from the fertilizer, as shown by their higher chlorophyll *b* and carotenoid levels. Bahari et al. (2013) found higher concentrations of chlorophyll *a* and *b* and carotenoids in unstressed wheat plants treated with amino acid base fertilizer than in plants that were not treated. The authors reported that the response to the application of foliar fertilizers was higher when plants were grown under normal conditions.

Treatments with fungicide and fertilizer at different doses (0.0, 1.0, and 3.0 L h^{-1}), showed a high correlation between the chlorophyll fluorescence parameters and the concentration of leaf pigments. The photochemical efficiency of PSII (F_v/F_m) had correlations of r = 0.96, r = 0.95, and r = 0.98 with chlorophyll *a*, chlorophyll *b*, and carotenoids, respectively. There was no significant correlation between ETR and carotenoid levels (r = 0.51). In this context, it is important to highlight the importance of carotenoids in photo-protective activity and the mitigation of photo-inhibition. Thus, the higher values of F_v/F_m with foliar fertilization could be attributed to higher levels of carotenoids.

The maintenance of green leaf area in flag leaves is extremely important for wheat plants (ZHANG et al., 2006). It is estimated that the flag leaf alone can account for up to 50% of the assimilates for grain filling (SYLVESTER-BRADLEY; SCOTT, 1990). Thus, application of foliar fertilizer can significantly contribute to the delay of early senescence.

Biotic and abiotic stresses are responsible for the increased production of reactive oxygen species (ROS) in plants due to interruptions in cellular homeostasis. When the ROS level exceeds the defense mechanisms, the cellular damage appears in the form of lipid peroxidation. The TBARS level has been widely used as an indicator of damage to cell membranes under stressful conditions (SHARMA et al., 2012). In accordance with this, TBARS levels increased in wheat leaves treated with the fungicide (Figure 4A and 5). This indicates, as reported in previous work, that the fungicide also works as a stressor under the conditions of this experiment.

Figure 4. Main effect of fungicide (A) and main effect of fertilizer rates (B) in the lipoperoxidative activity expressed as malondialdehyde (MDA) concentrations in wheat $F_{-1} + F_{-2}$ leaves ('Quartzo' cultivar).

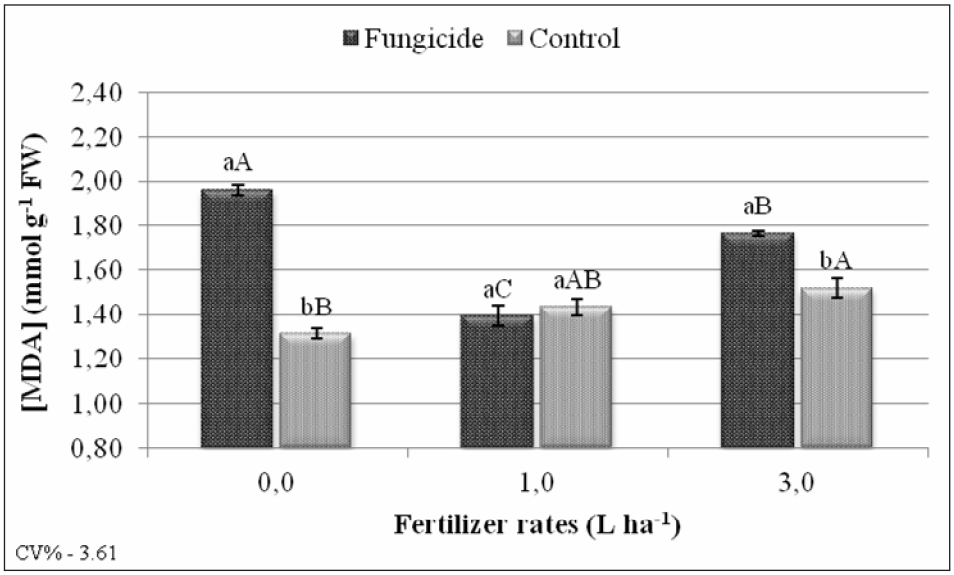


* Means followed by the same letter do not differ by Tukey's test ($p < 0.01$). Each column corresponds to the average of 12 replicates in Figure A and 8 in figure B. The bars show the standard error of the mean (± SE). FW: fresh weight. MDA – malondialdehyde.

Hunt et al. (2008) observed phytotoxic effects of tebuconazole applied to wheat in the dry season. These authors also reported that effects of this nature are common for this and other triazole fungicides. High temperatures and the application of mineral oil in the spray solution, such as in this experiment, may compound these effects.

In contrast, cell damage, characterized by the concentration of TBARS, was significantly reduced by the application of a foliar fertilizer in admixture with the fungicide (Figure 4B). When the main effect of fertilizer doses in $F_{-1} + F_{-2}$ leaves was analyzed, no difference was observed between the doses tested, which differed only from the no-fertilizer control. There was an interaction between factors in flag leaves (Figure 5). In the presence of the fungicide, there was a significant reduction in TBARS levels when fertilizer was present. In this case, the best response was obtained with the lowest dose tested (1.0 L h^{-1}). Similar data were obtained in a study in Chile, which reported that the toxicity of Dithane M-70 was significantly reduced by applying it along with a complex fertilizer (Mortonijc Plus®) (VUKOVIĆ et al., 2014).

Figure 5. Alterations in the lipoperoxidative activity expressed as malondialdehyde (MDA) concentrations in wheat flag leaves ('Quartzo' cultivar) due to fungicide and foliar fertilizer.



* Means followed by the same letter, lowercase between fungicides and uppercase between fertilizer rates, do not differ by Tukey's test ($p < 0.01$). Each column corresponds to the average of four replicates and the bars show the standard error of the mean. FW: fresh weight. MDA – malondialdehyde.

Increased activity of the catalase enzyme in plants treated with amino-acid fertilizer has been reported, which indicates a potential route of action for these products (BAHARI et al., 2013). Catalase is strongly linked to a plant's defenses against oxidative stress, directly modulating the amount of ROS.

The application of foliar fertilizer significantly increased the N, P, and K in flag leaves (Table 2). Such increases were observed in both the fertilizer treatment groups, which differed from the control treatment but not from each other. In $F_{-1} + F_{-2}$ leaves, only N and P changed. Calcium and magnesium content was not influenced by fertilizer application (data not shown). The application of fungicide did not affect the concentrations of nutrients in the leaves, as was expected.

With regard to mineral macronutrients, N, P, and K concentrations have the greatest influence on plant development (BOJOVIĆ; STOJANOVIĆ, 2005). The concentration of nitrogen in leaves is strongly related to chlorophyll content and therefore indirectly to photosynthesis. P is involved in many metabolic processes essential for photosynthesis,

and it influences the stability of the chlorophyll molecule. K is also essential for photosynthesis because it activates many enzymes involved in this process. Most of the production of cultivated plants is the work of the photosynthetic apparatus, in which the chlorophyll molecule occupies a prominent place.

Table 2. Interactions and main effects of a fungicide and foliar fertilizer on nitrogen, phosphorus, and potassium concentrations (g kg^{-1} DW) in wheat flag and F_{-1} + F_{-2} leaves.

Fertilizer rates	Flag leaves		Means	F_{-1} + F_{-2} leaves		Means
L ha^{-1}	Control	Fungicide		Control	Fungicide	
			Nitrogen			
0.0	41.5 ^{NS}	42.3	41.9 b*	32.6 ^{NS}	33.6	33.1 b*
1.0	44.9	44.7	44.8 a	38.2	39.5	38.8 a
3.0	45.1	45.7	45.4 a	37.9	38.6	38.3 a
Means	43.8 ^{NS}	44.2	-	36.2 ^{NS}	37.2	-
CV%		1.86			4.85	
			Phosphorus			
0.0	2.6 ^{NS}	2.68	2.66 b*	2.22 ^{NS}	2.17	2.19 b*
1.0	2.93	2.99	2.96 a	2.32	2.47	2.40 a
3.0	2.92	3.00	2.96 a	2.37	2.49	2.43 a
Means	2.83 ^{NS}	2.89	-	2.30 ^{NS}	2.38	-
CV%		2.76			3.18	
			Potassium			
0.0	18.1 ^{NS}	19.8	18.9 b*	18.7 ^{NS}	20.1	19.4 ^{NS}
1.0	22.8	24.7	23.7 a	20.4	20.8	20.6
3.0	24.6	24.7	24.6 a	20.4	19.6	20.0
Means	21.8 ^{NS}	23.1	-	19.8 ^{NS}	20.2	-
CV%		5.93			9.49	

* Means followed by the same letter, lowercase in columns and uppercase in rows, do not differ by Tukey's test ($p < 0.01$). ^{NS} Not significant. DW: Dry weight.

These results suggest that foliar fertilizer can contribute to production. The application of these products with amino acid additives can be a good alternative, especially in applications in more advanced phases of the cycle. Amino acid-based fertilizer may act by increasing the absorption of mineral nutrients by the plant and improving the efficiency of nutrient use (VERNIERI et al., 2005). The same authors also claim that biostimulants can be applied to the soil or leaves, and can, in both cases, affect the nitrogen metabolism and growth of plants.

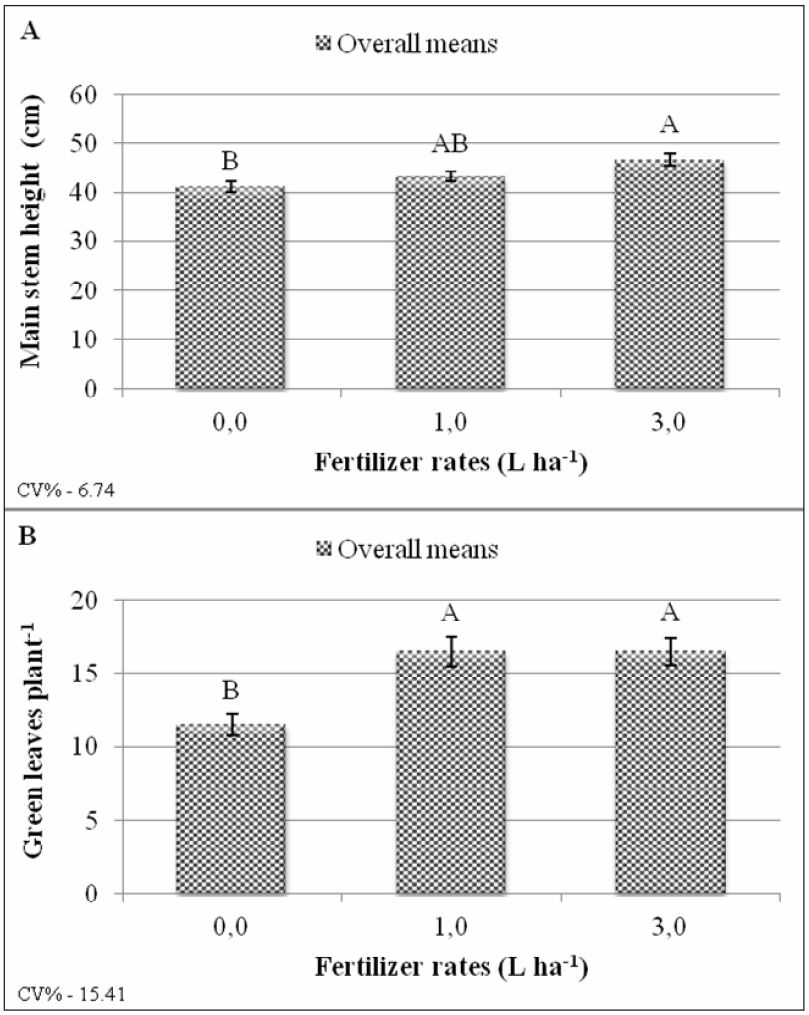
This was verified in the present study by the higher main-stem heights and the greater number of green leaves per plant as a result of fertilizer application (Figure 6). The increased growth and maintenance of green leaf area and photosynthetic capacity reflect a number of potential contributions from the foliar application of fertilizer. Such contributions are connected, and they mitigate the effects of stressors, in this case, the fungicide and the increase in NPK status. These aspects contributed to the increased levels of leaf pigments and higher photosynthetic efficiency.

The foliar absorption of elements can be optimized by the presence of amino acids in the formulation. Dromantienė et al. (2013) reported that this positive effect is a result of the formation of organic chelates of amino acids and mineral elements. Thus, the absorption and transport of nutrients within the

plant is facilitated by the chelating action and the effect on the permeability of the cell membrane (KÖKSAL et al., 1999). In experiments with pears, it was observed that the iron content in leaves increased with amino acid application (KÖKSAL et al., 1999). Positive increase in the concentrations of N, P, and K was also found in soybean leaves with the application of foliar fertilizer with amino acids (LAMBAIS, 2011).

During their evolution, plants have developed different mechanisms to counteract the damage caused by stress. Stresses disrupt the normal physiological functioning of plants by inhibiting processes such as CO_2 uptake through the stomata and by reducing carboxylation and the transport of electrons, which accelerates leaf senescence (LAWLOR, 2002). Accelerated leaf senescence in wheat is wholly undesirable since the sequence of events that occurs involving the disruption of membrane proteins leads to the degradation of chlorophylls and finally the dismantling of the photosynthetic apparatus. Consequently, the productivity and the quality of wheat, which are directly correlated with the green, healthy leaf area during grain filling, can be adversely affected.

Figure 6. Effects of fertilizer rates on main stem height (A) and the number of green leaves per plant (B) in wheat ('Quartzo' cultivar).



* Means followed by the same letter do not differ by Tukey's test ($p < 0.01$). Each column in the figures corresponds to the average of eight replicates. The bars show the standard error of the mean (± SE).

Conclusions

The application of foliar fertilizer positively affected photochemical, biochemical, and nutritional parameters in wheat as shown by increase in photosynthetic pigments, improved parameters of chlorophyll *a* fluorescence, and increased concentrations of nitrogen, phosphorus, and potassium in flag leaves. When used in combination, the fertilizer mitigated the stress generated by the fungicide treatment.

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