Scientific Research Publishing

Agricultural Sciences, 2023, 14, 725-738
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Impact of Fungicide Spray Timings on Foliar Diseases Control in Wheat Cultivars

João Victor de Mattos[1], Rafael Domingues[2], André Belmont Pereira[3*]

[1]Nutrien Agri-Solutions, São Paulo, SP, Brazil
[2]Institute of Agricultural Sciences & Technology, State University of Ponta Grossa, Paraná, Brazil
[3]Department of Soil Science & Agricultural Engineering, State University of Ponta Grossa, Paraná, Brazil
Email: joao.victor_mattos@hotmail.com, rafaeldomingues2@gmail.com, *abelmont@uepg.br

How to cite this paper: de Mattos, J.V., Domingues, R. and Pereira, A.B. (2023) Impact of Fungicide Spray Timings on Foliar Diseases Control in Wheat Cultivars. *Agricultural Sciences*, **14**, 725-738.
https://doi.org/10.4236/as.2023.146048

Received: April 23, 2023
Accepted: June 6, 2023
Published: June 9, 2023

Abstract

Wheat (*Triticum aestivum* L.) is grown throughout the winter time in Southern Brazil and turns out to be the main agricultural crop at such a year season in the State of Paraná. However, throughout the crop growing season foliar diseases significantly compromise commercial yields in such a manner as to justify the application of fungicides at the right time to control foliar diseases in production fields. The aim of the current manuscript was to assess the impact of different timings for fungicide application (epoxiconazole + pyraclostrobin) on the control of leaf rust (*Puccinia triticina* E.) and yellow spot (*Pyrenophora tritici-repentis*) diseases in two wheat genotypes featured by distinct levels of susceptibility in Southern Brazil. A field trial was conducted in Ponta Grossa, State of Paraná, Brazil, in light of split plot statistical design at an experimental area belonging to CESCAGE. The following treatments were imposed in the current study: control (with no sprays); sprays at the first node, booting and heading; sprays at stem extension and flowering; sprays at booting and heading. Throughout the entire crop growing season, the control treatment was conducive to the highest severity levels for both diseases. The increasing of the area under the diseases progress curve assessed herein substantially impinged upon yield components of both wheat genotypes under scrutiny. In general, fungicide sprays at the first node did not culminate in economical advantages. The best timing for fungicide application was the one ascribed to booting and heading stages.

Keywords

Triticum aestivum L. *Puccinia triticina E. Pyrenophora tritici-repentis*, Yield

1. Introduction

The total number of seasonal sprays in field crops, such as soybean, wheat, rice, and corn, is relatively lower than those required by high-value crops (e.g., tomato, apple, and grapes), which may justify the use of the calendar-based sprays in field crops, especially for defending against devastating foliar diseases in production fields. Beruski *et al.* [1] reported that soybean yield was generally higher with the increase in spray number, but the economic analysis showed no significant differences in the risk of not offsetting the costs of fungicide sprays regardless of the system.

Wheat (*Triticum aestivum* L.) is considered to be an important cereal as one of the richest staples in carbohydrates for the world population, depicting a source of starch and energy providing substantial amounts of a number of essential and beneficial components for health, notably protein, vitamins, dietary fiber, and phytochemicals [2]. In spite of its economic relevance at a world scale, the cultivated areas along with wheat yields have been significantly varying throughout the 2020 growing season with actual yield estimates corresponding to 768.5 million of tons. Brazil is envisioned as the largest producer of wheat, being the South region elected as the one quite amenable to cultivation during winter season in such a fashion as to enhance incomes for rural growers. In Southern Brazil, Paraná State encompasses the largest area for agriculture with crop production fields reaching mean commercial yields of 3.200 $kg \cdot ha^{-1}$ [3].

Cultivation areas for wheat in the State of Paraná are characterized by production fields under no-tillage system [4], which is grown throughout a short sowing period. Therefore, extensive areas managed in light of single crop farming with a plant population at the same physiological stages prevail at the region in such a way as to promote occurrence of plant diseases [5]. Moreover, at a local scale meteorological conditions are substantially conducive to high severity levels in wheat commercial production fields: a fact that might trigger severe epidemics in conjunction with high yield gaps.

Among the main plant diseases that considerably impinge upon yield from wheat production fields foliar diseases, such as leaf rust (*Puccinia triticina* E.) and yellow spot (*Pyrenophora tritici-repentis*), are to be borne in mind. Leaf rust is caused by a biotrophic fungus induced by air temperatures ranging from 15˚C to 20˚C along with a high air relative humidity [6]. Peculiar infection symptoms, such as circular and slightly oval pustules featured by a dark yellow to brown coloration spreading on both abaxial and adaxial sides of leaves, take place at production fields in order to compromise marketable yields. Conversely, yellow spot infecting wheat leaves is brought about by a necrotrophic fungus, which manifests in shape of small browned, oval and lenticular spots with yellow borders. In the face of disease evolution, lesions become light brown and, in many cases, coalesce and, therefore, induce senescence of leaves [7] [8]. Favorable local environmental conditions for proliferation of such a pathogen turn out to be air temperature varying from 18˚C to 28˚C in conjunction of a 30-hour leaf wetness duration for the infectious process to be triggered in wheat commercial production fields [6].

Cultural practices currently adopted to control wheat foliar diseases include genetic resistance and application of fungicides [9]. Chemical control comes to being the most utilized strategy to be taken into consideration by growers in light of fungicides composed by a commercial mixture of strobilurin and triazoles. Nevertheless, responsiveness of wheat cultivars to fungicide sprays depends on disease severity index, degree and type of genotype resistance, management cultural practices, environmental conditions, and also on spray timing [10].

For Souza [11], a successful chemical control depends on the following factors, such as fungicide spray timings; use of products with a long residual period; products promoting a good target covering and bereft of delays on fungicide application. The latter in compliance with findings reported by Pinto *et al.* [12] turns out to be a determining factor for successful chemical control because plant diseases often possess a high progress and, therefore, spray timings must be envisioned as a decision-making factor in order to assure efficiency of such a control method at commercial production fields.

Disease monitoring is vital for decision-making concerning definition of the ideal initial fungicide spray timing, once characterization of agricultural environment comes to being crucial to establish the most suitable time interval to be borne in mind among sprays. Sprays performed for controlling soybean rust in plots with high levels of severity did not culminate in both economic and biological returns, since crop yield was quite similar to that obtained from plots subjected to control treatment [13].

Taking into account that chemical control is just one of the cultural practices largely adopted by growers in order to guarantee sustainable remarkable yield in wheat production fields, particularly throughout years favorable to foliar disease epidemies, the current manuscript aimed to assess crop biological responsiveness faced with different fungicide spray timings on two cultivars with distinct susceptibility levels to the main foliar diseases that compromise wheat crop growing season at a given site, as well as to come up with the best spray timing of epoxiconazole + pyraclostrobin formulation for each one of the cultivars under scrutiny aiming at reduction in costs of production.

2. Material and Methods

A field experiment was carried out throughout the 2016 crop growing season at an experimental area belonging to the Campos Gerais College, CESCAGE, in Ponta Grossa, State of Paraná, Brazil. The geographical coordinates of the studied site are as follows: 25˚5'40"S, 50˚9'48"W and altitude of 956 meters above sea level. The Köppen climatic classification is Cfb [14], and the soil considered herein was a typical dystrophic red latosol comprising the prevailing soil type for the studied region.

Sowing was performed on July 7th of 2016. Soil fertilization and cultural practices not related to disease management were made on the basis of technical recommendations published by the Brazilian Agricultural Research Corporation [15]. The experimental design was a split-plot statistical design with four replications. Each single experimental plot was comprised by twelve sowing lines spaced at 0.17-m among themselves and with 5-m long totaling a useful area corresponding to 10 m^2. Such a useful area featuring, therefore, each one of the plots was defined in light of elimination of two lines from each side and 0.50-m away from the extremity.

The main plots of the field experiment were grown with different wheat cultivars that represent the commercial production fields of wheat in the State of Paraná, Brazil. The cultivars at issue are TBIO Toruk and Quartzo, which possess a medium vegetative cycle duration (130 days between sowing and harvest), low stature, lodging-resistance, and evidencing a moderate susceptibility to leaf rust and yellow spot diseases.

Within the main plots, sub-plots were allotted in such a way as to promote the imposition of treatments constituting four fungicide-spray programs in comparison to the control treatment under which no fungicides were applied to both wheat cultivars in order to prevent foliar diseases from occurring at the specific-site in study (**Table 1**).

Disease control strategies were adopted by making use of the commercial product Opera® (BASF) along with mineral oil Assist® (BASF) at a dose of 0.5 $L \cdot ha^{-1}$. Sprays were performed by means of a CO_2 pressurized coastal sprayer from the Herbicat® Inc. containing four even flat spray tips (XR 8002/TEEJET), spaced at a 0.45-m distance. The spray speed was corresponding to 4.5 $km \cdot h^{-1}$ so that the volume of spray solution for the fungicide applied had been of 200 liters per hectare. All of fungicide sprays were made in the morning, aiming at the best possible application efficiency under regime of suitable air temperature, relative humidity and wind speed for disease control in the field.

Monitoring of the main phenological stages of wheat crop, particularly concerning those ones allowing for spray timings, hinged on disease scale proposed by Feeks in 1940 and modified by Large in 1954 [17]. We observed throughout

Table 1. Scheduling of fungicide sprays for two wheat varieties to control leaf rust and yellow spot, Ponta Grossa, State of Paraná, Brazil.

Spray schedule*	Dose i.a. ($g \cdot ha^{-1}$)	Phenological stages* for sprays	Overall of sprays
Control treatment	-	-	0
Schedule 1	30 + 133	first node + booting + heading	3
Schedule 2	30 + 133	stem extension + flowering	2
Schedule 3	30 + 133	booting + heading	2

*Opera® (Epoxiconazole + Pyraclostrobin) was the commercial product utilized for disease management at the wheat field in light of the phenological stages proposed by LARGE [16].

the conduction of the field trial that the main diseases occurring at a significant severity index were leaf rust and yellow spot. This might be ascribed to a high inoculum pressure at the region where both wheat cultivars were grown.

Disease severity assessments were scrutinized on the basis of visual detection of quintessential symptoms promoted by both diseases in study. To determine the percentage of leaf area damaged by either leaf rust or yellow spot in wheat cultivars the diagrammatic scales proposed by Alves *et al.* [18] and James [19] were employed, respectively. Such severity assessments were made throughout the vegetative stage of wheat growing season on 20 plants randomly chosen from each experimental unity. The mean severity index of the selected plants was considered to be the average of disease in the plots. At the reproductive stage, severity from 20 plants was evaluated on the flag leaf, flag 1 and flag 2, as well as on three leaves to come up with a mean severity index for each plot. Weekly evaluations were performed in order to identify the first visual symptoms. The aforementioned procedure was maintained up until maturation had been reached given by the overall loss of leaves of wheat plants. By means of severity data collected from the experimental area, the Areas under the Disease Progress Curve (AUDPC) for both foliar diseases were determined herein.

During physiological maturation stage, harvest of wheat plants was done in light of a semi-automatized procedure. At such a final crop subperiod, grain yield in grams was assessed by weighing grain total production to be obtained from each plot and converting it into kilograms per hectare. Thousand-seed weight was determined by the counting of a thousand of grains and its weight was measured by a precision scale.

Shortly after verification upon normality of the experimental data by means of the Shapiro-Wilk test, analysis of variance was proceeded along with the F test application aiming at detection of effects of treatments on the occurrence and disease severity, as well as on yield components of two wheat cultivars. In order to examine which treatment has led to the best agricultural performance, Tukey test was applied to the experimental data at a 5% reliability.

For quantification of the impacts of foliar diseases on wheat actual yield, a linear regression analysis study was performed between data related to area under the progress curve of leaf rust (AUPCLR), area under the progress curve of yellow spot (AUPCYS) and response-variables, such as wheat yield and thousand-seed weight. The magnitude of the correlations was expressed by the Pearson correlation coefficient (r), and all statistical analyses applied to the experimental data were provided by the SAS software.

3. Results and Discussion

Local weather conditions monitored during wheat growing season were conducive to occurrence of leaf rust and yellow spot as illustrated by the sequential climatological water balance elaborated throughout 2016/2017 agricultural seasons (**Figure 1**). The first symptoms were detected on October 4th of 2016 for the

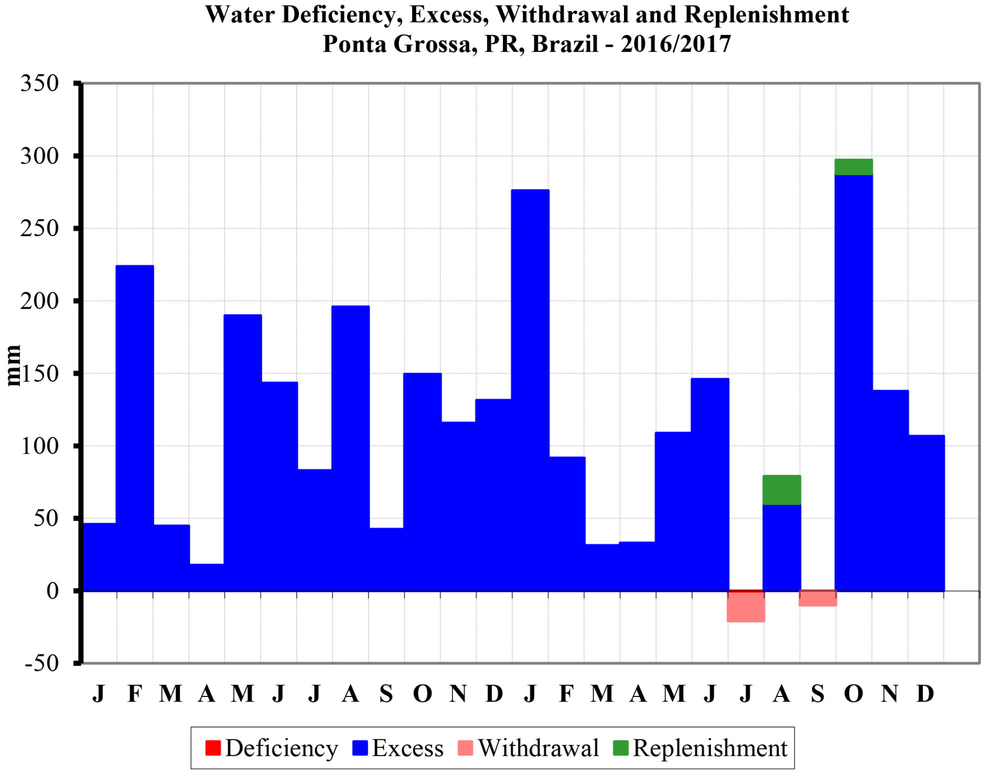

Figure 1. Sequential climatological water balance elaborated for the municipality of Ponta Grossa, PR, Brazil throughout 2016/2017 agricultural growing seasons [25].

Quartzo cultivar, whereas such initial symptoms for the TBIO Toruk cultivar took place on October 11th. It took longer for the yellow spot disease to manifest in the field for both genotypes, with its first symptoms being noted on October 18th 2016.

Among the meteorological variables that might substantially impinge upon spray efficacy of fungicides via foliar applications in production fields, precipitation turns out to be the most important, as long as rainfall episodes occur shorty after fungicide sprays [20] [21] [22]. Moreover, dew also affects the efficacy of fungicide application techniques during nocturnal, dawn and beginning of morning periods [22].

For the crop yield and thousand-seed weight response-variables, there was not any significant interaction between the cultivars and spray timings, revealing an independence relationship between such factors. In the view of analysis of variance with application of the F test, a significant effect of the scrutinized factors on wheat crop yield along with thousand-seed weight was detected for both genotypes (**Table 2**).

Wheat, as well as any winter cereal crop, presents either vegetative or reproductive development stages highly dependent on daily mean air temperature throughout the whole crop growing season [23]. Usually, decision-making strategies are related to prevailing local weather conditions along with prices to be paid for marketable yield, minimum commercial product prices, and agricultural financing issues stipulated by the government [24].

Table 3 demonstrates that the TBIO Toruk cultivar rendered a mean yield higher than that obtained for the Quartzo cultivar. Such an outcome was already expected owing to the fact that the latter has been selected as the most productive genotype under the soil type and prevailing weather conditions of the State of Paraná [26]. Conversely, a reverse agricultural crop responsiveness was observed with regard to thousand-seed weight, which turned out to be higher for the Quartzo cultivar due to the size of grains.

As to the levels of spray timing factor, all treatments resulted in both yield and thousand-seed weight statistically superior to control (Table 2). Treatments featured by sprays at the first node + booting + heading along with booting + heading promoted a better agricultural performance depicted by yields, respectively, corresponding to 40.86% and 40.01% higher than control treatment, as well as equivalent to 13.54% and 12.33% higher than stem extension + flowering treatment.

With regard to spray timings, chemical control adopted as management practice to mitigate disease severity in the field at the first node physiological stage did not bring about economic benefits, since crop yield and thousand-seed weight under the influence of such a treatment culminated in similar agricultural

Table 2. Thousand-seed weight (TSW) and wheat crop yield (WCY) as a function of the cultivars under scrutiny. Ponta Grossa, Paraná State, Brazil.

Cultivar	TSW (g)	WCY (kg·ha^{-1})
TBIO Toruk	29.45^{b}	4591.46^{a}
Quartzo	30.85^{a}	3457.41^{b}
CV (%)	2.97	3.01

Averages followed by the same letter in the columns did not differ between themselves by means of the Tukey test at 5% reliability.

Table 3. Thousand-seed weight (TSW) and wheat crop yield (WCY) as a function of different spray timings for a fungicide composed by triazole + strobilurin mixture (epoxiconazole + pyraclostrobin). Ponta Grossa, Paraná State, Brazil.

Spray timings	TSW (g)	WCY (kg·ha^{-1})
Control	26.57^{c}	2765.90^{c}
Timing 1	32.86^{a}	4676.57^{a}
Timing 2	29.36^{b}	4043.27^{b}
Timing 3	31.82^{a}	4612.01^{a}
CV (%)	2.97	503.01

Averages followed by the same letter in the columns did not differ between themselves by means of the Tukey test at 5% reliability. Treatments: control (no sprays); Timing 1 (at the first node + booting + heading); Timing 2 (at the stem extension + flowering); Timing 3 (at the booting + heading).

responsiveness in light of fungicide sprays throughout booting + heading treatment. This probably might be attributed to the lack of inoculum source at levels which would galvanize starting occurrence of foliar diseases in the specific-site under scrutiny, once local climatic and weather patterns were not conducive to both occurrence and severity of either leaf rust and yellow spot in wheat cultivars grown in the Southern Brazil.

Nevertheless, for the variables, such as area under the progress curve of leaf rust (AUPCLR) and area under the progress curve of yellow spot (AUPCYSP), we came up with a significant interaction ($p < 0.05$) between the cultivar and spray timing factors as to evidencing that chemical control efficiency was quite dependent on the cultivar and vice-versa.

By evaluating performance of the cultivars within levels of spray timing factor, it was possible to verify that AUPCLR was lower for the TBIO Toruk. This might be explained by peculiar attributes concerning disease susceptibility of such a variety when compared to the Quartzo cultivar (**Figure 2**).

AUPCYS values for all treatments were lower than those ones calculated under

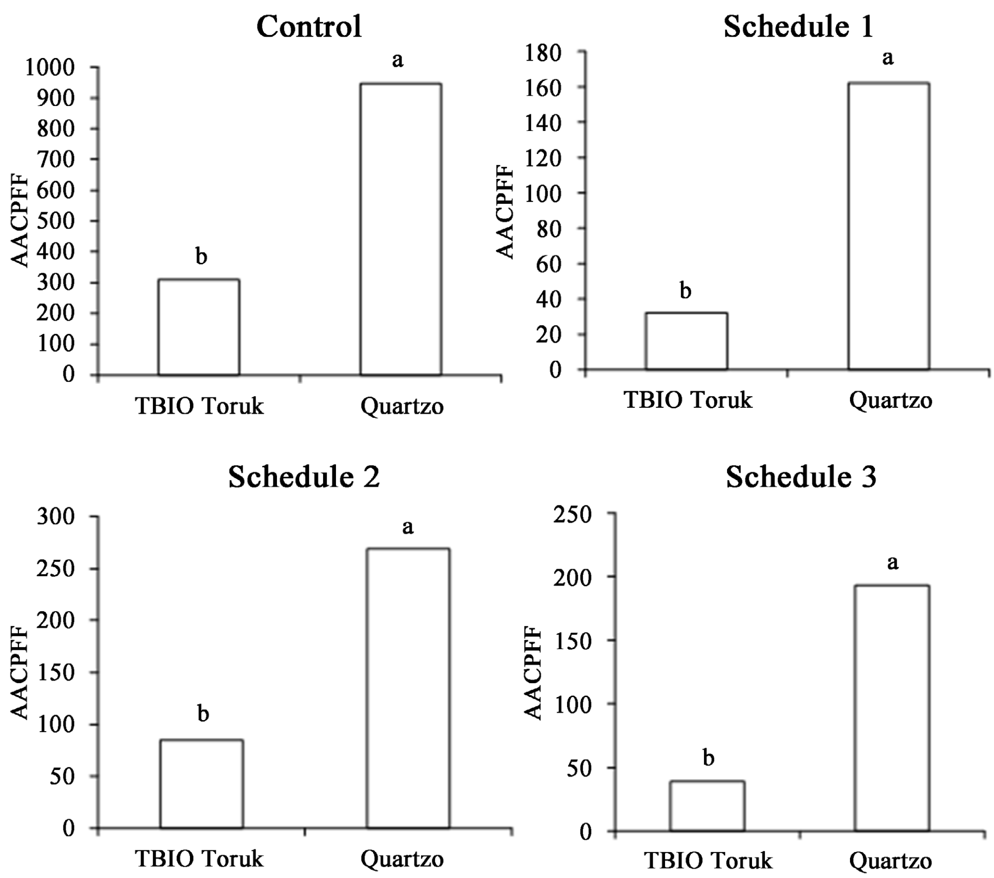

Figure 2. Comparison between averages of cultivar factor within the factor levels timing for the area under the progress curve of leaf rust (AUPCLR). Treatments: control (no sprays); Timing 1 = first node + booting + heading; Timing 2 = stem extension + flowering; Timing 3 = booting + heading. Averages followed by the same letters did not differ between themselves by means of the Tukey test at 5% reliability.

control treatment. The lowest AUPCYS threshold was ascribed to the spray timing at the first node + booting + heading, being such a treatment the one considered as the most effective to control foliar diseases in wheat fields (Figure 3).

Figure 4 shows that all spray timings of epoxiconazole + strobilurin mixture were equal among themselves and inferior to control as to the AUPCLR for both cultivars. Such an outcome confirms control efficiency of the fungicide to be utilized.

Figure 5 illustrates that all spray timings of epoxiconazole + strobilurin mixture were equal among themselves and inferior to control treatment as to the AUPCLR only for the TBIO Toruk cultivar. However, for the Quartzo cultivar chemical control was by far more efficient as opposed to control treatment with the spray timing regarding the first node + booting + heading the one that provided the best agricultural performance.

Existence of negative linear correlations between either AUPCLR or AUPCYS and wheat cultivars grown in Southern Brazil was detected to indicate that foliar disease occurrence and severity index remarkably compromised crop yield at the specific-site in study (Table 4).

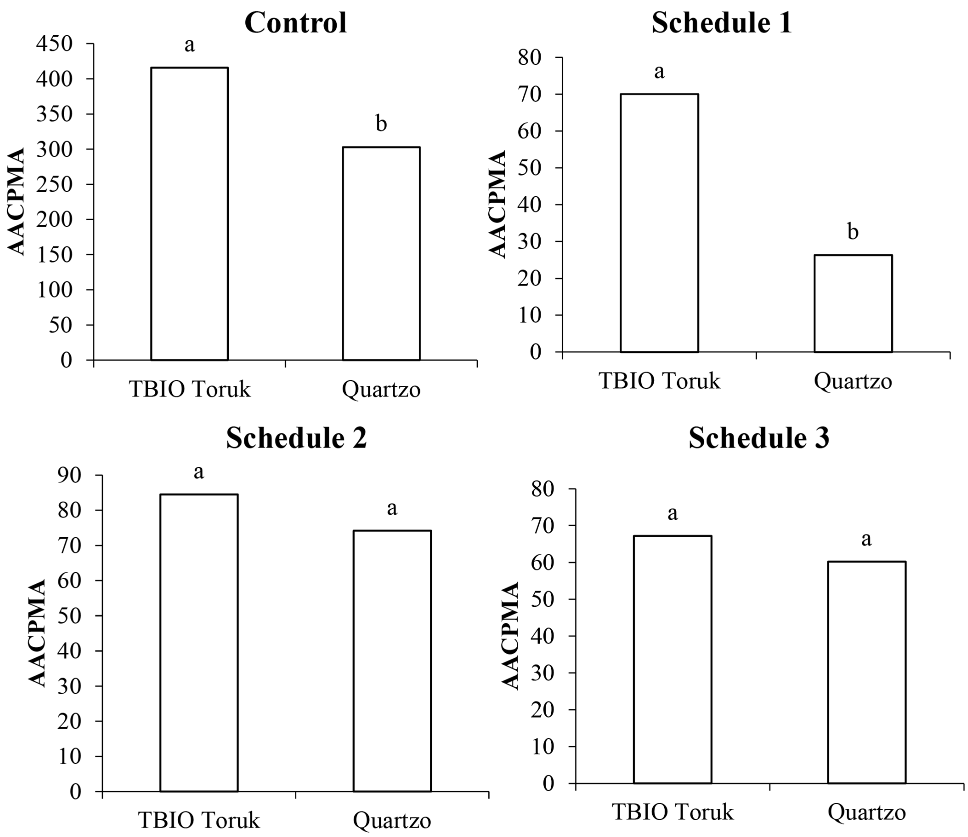

Figure 3. Comparison between averages of cultivar factor within the factor levels timing for the area under the progress curve of yellow spot (AUPCYS). Treatments: Control (no sprays); Timing 1 = First node + booting + heading; Timing 2 = stem extension + flowering; Timing 3 = booting + heading. Averages followed by the same letters did not differ between themselves by means of the Tukey test at 5% reliability.

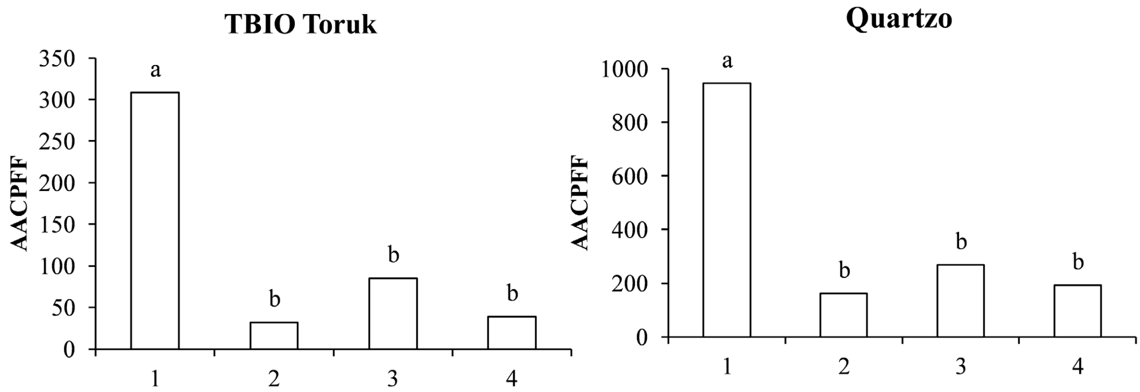

Figure 4. Comparison between averages of timing factor within the factor levels cultivar for the area under the progress curve of leaf rust (AUPCLR). Treatments: Control (no sprays); Timing 1 = First node + booting + heading; Timing 2 = stem extension + flowering; Timing 3 = booting + heading. Averages followed by the same letters did not differ between themselves by means of the Tukey test at 5% reliability.

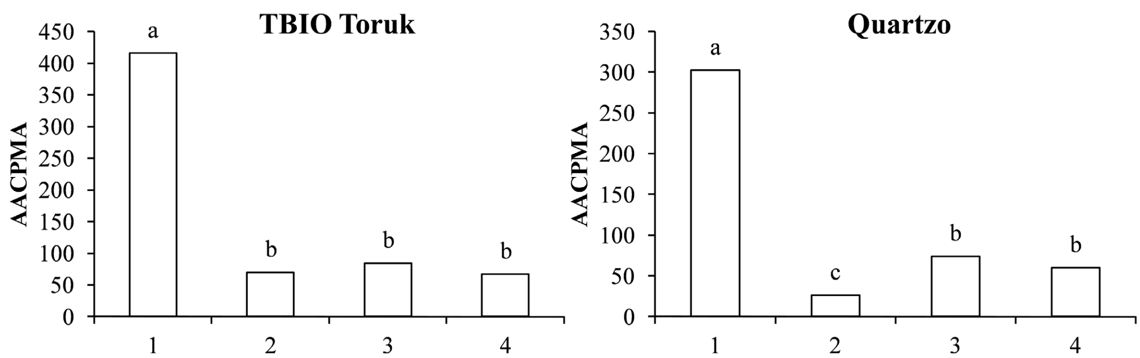

Figure 5. Comparison between averages of timing factor within the factor levels cultivar for the area under the progress curve of yellow spot (AUPCYS). Treatments: Control (no sprays); Timing 1 = First node + booting + heading; Timing 2 = stem extension + flowering; Timing 3 = booting + heading. Averages followed by the same letters did not differ between themselves by means of the Tukey test at 5% reliability.

Table 4. Coefficients of determination (R^2) and Pearson correlation (r) between the area under progress curve of rust leaf (AUPCRL), area under progress curve of yellow spot (AUPCYS), wheat crop yield (WCY), and thousand-seed weight (TSW). Ponta Grossa, State of Paraná, Brazil.

Variables	R^2	r
AUPCRL × WCY	0.79	−0.89
AUPCRL × TSW	0.27	−0.52
AUPCYS × WCY	0.42	0.65
AUPCYS × TSW	0.72	−0.85
AUPCRL × AUPCYS	0.37	0.61

Monitoring of plant diseases aims, at the highest possible rentability to be obtained at farm levels by means of considerable reductions in the number of fungicide sprays in conjunction with the best timing sprays, to provide a more efficient chemical control of foliar diseases with high yields and low costs of production in order to assure sustainable agriculture at a given specific-site. Assessments of diseases at commercial wheat fields promote a decrease in occurrence risks of severe epidemics in such a way as to mitigate detrimental impacts on crop growth, development and yield, which might eventually take place as a function of environmental conditions favorable to foliar disease infestation in production fields. In addition, it also prevents negative environmental effects in light of a less frequent use of chemical products in order to control foliar diseases [27].

By means of analysis of correlation of Pearson elaborated with the purpose of examining dependence relationship between agricultural performance variables, such as crop yield and thousand-seed weight and severity index factor for the scrutinized foliar diseases in wheat cultivars (AUPCRL and AUPCYS), moderate and strong correlations were found among such variables. In the view of confrontation between AUPCRL and yield, AUPCRL and thousand-seed weight, AUPCYS and yield, AUPCYS and thousand-seed weight, the following coefficients of correlation (r) were, respectively, found: −0.89, −0.52, −0.65, and −0.85. The aforementioned statistical indices evidenced that crop yield and thousand-seed weight turn out to be considerably affected by increases in AUPCRL and AUPCYS. Such outcomes are corroborated by the association between AUPCRL and AUPCYS expressed by a coefficient of correlation corresponding to 0.61 (**Table 4**).

Beruski *et al.* [28], working on white mold disease compromising soybean crop yield in production fields of the same specific-site studied herein, reached the conclusion that Pearson correlation coefficients expressing the relationship between environmental factors and rates of apparent infection did not condition progress curve of such a disease as a function of local weather conditions.

Khan *et al.* [29] assessed yield losses in wheat caused by leaf rust in cultivar trials at five locations in Mississippi, USA, over a 4-year period from 1986 through 1989. There was no significant interaction between location and cultivar when yield data were collected from sites in the north and central areas of the state. A model derived from data for eight cultivars at two different locations showed a negative linear relationship between yield and leaf rust. Such a model proposed by the aforementioned authors along with rust ratings from three additional sites predicted yields statistically similar to recorded wheat actual yields.

4. Conclusions

Control treatment assured the highest disease severity index, revealing that wheat cultivars grown under the weather conditions of Southern Brazil responded to fungicide sprays recommended to control both leaf rust and yellow spot.

In general, fungicide application did not promote economic advantages, once crop yield, thousand-seed weight, and area under the progress curve of leaf rust for both wheat cultivars did not show significant differences as a function of fungicide spray timings.

The best fungicide spray timing was at the booting + heading, which resulted in the highest crop yield and a best control of foliar diseases, followed by the spray timing at the first node + booting + heading with one application less to reduce production costs.

The use of fungicides reduces disease severity and avoids losses in yield and grade caused by occurrence of foliar diseases in wheat crop, especially in susceptible cultivars.

Acknowledgements

The authors are very grateful to Jaqueline Jaguela for the conduction of the field trial and completion of her Agronomy Monograph, to Gustavo Beruski for the logistical support, and also to the technical staff of CESCAGE, FA and FAPESP in light of the concession of fellowships that made the current research possible.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Beruski, G.C., Del Ponte, E.M., Pereira, A.B., Gleason, M.L., Câmara, G.M.S., Araújo Júnior, I.V. and Sentelhas, P.C. (2020) Performance and Profitability of Rain-Based Thresholds for Timing Fungicide Applications in Soybean Rust Control. *Plant Disease*, **104**, 2704-2712. https://doi.org/10.1094/PDIS-01-20-0210-RE

[2] Shewry, P.R. and Hey, S.J. (2015) The Contribution of Wheat to Human Diet and Health. *Food and Energy*, **4**, 178-202. https://doi.org/10.1002/fes3.64

[3] CONAB-Companhia Nacional de Abastecimento (2020) Acompanhamento da safra brasileira de grãos 2020/2021: Décimo segundo levantamento. *Brasília*, **3**, 1-182.

[4] Navarini, L. and Balardin, R.S. (2012) Foliar Diseases and Control by Fungicides on Yield and Quality of Wheat Grains. *Summa Phytopathologica*, **38**, 294-299. (Summary in English) https://doi.org/10.1590/S0100-54052012000400004

[5] Reis, E.M., Casa, R.T., Bianchin, V. and Danielli, A.L. (2010) Manejo Integrado de Doenças do Trigo. In: Santos, H.P., Fontaneli, R.S. and Spera, S.T., Eds., *Sistemas de produção para cereais de inverno sob plantio direto no sul do Brasil*, Embrapa Trigo, Passo Fundo, 161-206.

[6] Bohatchuk, D.A., Casa, R.T., Bogo, A., Kuhnem Junior, P.R., Reis, E.M. and Moreira, E.N. (2008) A Critical-Point Model to Estimate Damage Caused by Wheat Leaf Diseases in a Multiple Pathosystem. *Tropical Plant Pathology*, **33**, 363-369. (Summary in English) https://doi.org/10.1590/S1982-56762008000500004

[7] Lau, D., Santana, F.M., Maciel, J.L.N., Fernandes, J.M., Costamilan, L.M., Chaves, M.S. and Lima, M.I.P.M. (2011) Doenças de trigo no Brasil. In: Pires, J.L.F., Vargas, L. and Cunha, G.R., Eds., *Trigo No Brasil: Bases para produção competitiva e sustentável*, Embrapa Trigo, Passo Fundo, 283-323.

[8] Prestes, A.M. (2011) Manchas Foliares de plantas de plantas de trigo. In: Cunha, G.R., Ed., *Trigo No Brasil: História e tecnologia de produção*, Embrapa Trigo, Passo Fundo, 127-137.

[9] Tormen, N.R., Lenz, G., Minuzzi, S.G., Uebel, J.D., Cezar, H.S. and Balardin, R.S. (2013) Reaction of Wheat Cultivars to Leaf Rust and Yellow Spot and Responsiveness to Fungicides. *Ciência Rural*, **43**, 239-246. (Summary in English) https://doi.org/10.1590/S0103-84782013000200008

[10] Oliveira, G.M., Pereira, D.D., Camargo, L.C.M., Balan, M.G., Canteri, M.G., Igarashi, S. and Saab, O.J.G.A. (2013) Control of Wheat Leaf Rust (*Puccinia triticina*) at Different Timings of Fungicide Application. *Plant Pathology*, **80**, 436-441. https://doi.org/10.1590/S1808-16572013000400010

[11] Souza, L.L.P. (2015) Effect of Spray Timing of Fungicide and Sowing Time on the Control of Soybean Rust. Master's Thesis, University of Brasília, Brasilia, 52. (Summary in English)

[12] Pinto, F.F., Uebel, J.D., Foggiato, L., Ebone, A., Serafini, P.T. and Dalla Favera, D. (2012) Balardin, R.S. Resposta de cultivares ao controle erradicante da ferrugem asiática da soja (*Phakopsora pachyrhizi*). Congresso Brasileiro de Soja, Cuiabá.

[13] Godoy, C.V., Flausino, A.M., Santos, L.C.M. and Del Ponte, E.M. (2009) Asian Soybean Rust Control Efficacy as a Function of Application Timing under Epidemic Conditions in Londrina, PR. *Tropical Plant Pathology*, **34**, 56-61. (Summary in English) https://doi.org/10.1590/S1982-56762009000100011

[14] Alvares, C.A., Stape, J.L., Sentelhas, P.C., Gonçalves, J.L.M. and Sparovek, G. (2014) Köppen's Climate Classification Map for Brazil. *Meteorologische Zeitschrift*, **22**, 711-728. https://doi.org/10.1127/0941-2948/2013/0507

[15] Bacaltchuk, B., Chaves, M.S., Lima, M.I.P.M., Costamilan, L.M., Maciel, J.L.N., Salvadori, J.R. and Gambatto, A. (2006) Características e cuidados com algumas doenças de trigo. Embrapa Trigo, Passo Fundo, 13.

[16] Large, E.C. (1954) Growth Stages in Cereals. Illustration of the Feekes Scale. *Plant Pathology*, **3**, 128-129. https://doi.org/10.1111/j.1365-3059.1954.tb00716.x

[17] Lima, M.I.P.M. (2002) Métodos de amostragem e avaliação de giberela usados na Embrapa Trigo. Embrapa Trigo, Passo Fundo. (Embrapa Trigo. Documentos On-Line, 27) http://www.cnpt.embrapa.br/biblio/p_do27.htm

[18] Alves, C.G.S., Santos, L.C., Duarte, H.S.S., Dias, V., Zambolim, L. and Rocha, M.R. (2015) Diagrammatic Scale for Quantifying the Wheat Leaf Rust. *Multi-Science Journal*, **1**, 128-133. https://doi.org/10.33837/msj.v1i1.59

[19] James, W.C. (1974) Assessment of Plant Diseases and Losses. *Annual Review of Phytopathology*, **12**, 27-48. https://doi.org/10.1146/annurev.py.12.090174.000331

[20] Mcdowell, L.L., Willis, G.H., Southwick, L.M. and Jr Smith, S. (1987) Fenvalerate Wash-Off from Cotton Plants by Rainfall. *Pesticide Science*, **21**, 83-92. https://doi.org/10.1002/ps.2780210202

[21] Schepers, H.T.A.M. (1996) Effect of Rain on Efficacy of Fungicide Deposits on Potato against *Phytophthora infestans*. *Potato Research*, **39**, 541-550. https://doi.org/10.1007/BF02358473

[22] Stefanello, M.T. (2014) Performance of Fungicide in Soybean Plants under Different Water Regimes and Times Application. Master's Thesis, Federal University of Santa Maria, Santa Maria, 122. (Summary in English)

[23] Silva, R.R., Benin, G., Silva, G.O., Marchioro, V.S., Almeida, J.L. and Matei, G. (2011) Adaptability and Stability of Wheat Cultivars at Different Sowing Dates in the State of Paraná, Brazil. *Pesquisa Agropecuária Brasileira*, **46**, 1439-1447. (Summary in English) https://doi.org/10.1590/S0100-204X2011001100004

[24] Santi, A., Vicari, M.B., Pandolfo, C., Dalmago, G.A., Massignam, A.M. and Pasina-

to, A. (2017) Impact of Climate Future Scenarios by Agroclimatological Zoning of Wheat at the Southern Brazil. *Agrometeoros*, **25**, 303-311. (Summary in English)

[25] Rolim, G.S., Sentelhas, P.C. and Barbieri, V. (1998) Spreadsheets in Excel Environment for Calculation of Water Balance: Sequential, Crop and Potential, Real Productivity. *Revista Brasileira de Agrometeorologia*, **6**, 133-137. (Summary in English)

[26] Show Rural Coopavel (2017) Safra Trigo 2016: Maior Produtividade Reduz custo por hectare. http://www.showrural.com.br/inovacao/safra-trigo-2016-maior-produtividade-reduz-custo-por-hectare/

[27] Bergamim Filho, A. and Amorim, L. (1995) Sistemas de previsão e avisos. In: Bergamim Filho, A., Kimati, H. and Amorim, L., Eds., *Manual de fitopatologia*, 3rd Edition, Ceres, São Paulo, 627-646.

[28] Beruski, G.C., Pereira, A.B., Jaccoud, F.D.S., Sartori, F.F. and Sentelhas, P.C. (2016) Effects of Climate and Agricultural Practices on Temporal Progress of *Sclerotinia sclerotiorum* for Soybean in Brazil. *Agricultural Sciences*, **7**, 425-438. https://doi.org/10.4236/as.2016.77044

[29] Khan, M.A., Trevathan, L.E. and Robbins, J.T. (1997) Quantitative Relationship between Leaf Rust and Wheat Yield in Mississippi. *Plant Disease*, **81**, 769-772. https://doi.org/10.1094/PDIS.1997.81.7.769