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Management of fungicides can affect resilience of cultivars to foliar diseases in oats

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Abstract

The entry and progression of oat foliar diseases affect yield potential, requiring a combination of genetic resistance and management technologies. The objective of the study is implementing a management system to reduce the use of fungicide in oats by the anticipation of the application and a longer interval from the last application to the grain harvest, together with the identification of cultivars that are more resilient to disease**.** The study was developed in 2018 and 2019, in soil of type Typical Dystroferric Red Latosol and Cfa (humid subtropical) climate, in Augusto Pestana, RS, Brazil. The experimental design was randomized blocks with three replications in a 23 x 5 factorial, for 23 oat cultivars and 5 conditions of fungicide use: control (no application); one application 60 days after emergence (DAE); two applications at 60 and 75 DAE; three applications at 60, 75 and 90 DAE and four applications at 60, 75, 90 and 105 DAE, with measurement of grain productivity. In oat cultivation, the early and sequential application of fungicide at 60, 75 and 90 days after emergence guarantees satisfactory productivity with a long interval from the last application to harvest for greater food security. The cultivars URS Altiva and IPR Artemis show resilience in the presence of foliar diseases in the absence and reduced use of fungicide, facilitating the transition between conventional and agroecological agriculture in oat cultivation.

Keywords: *Avena sativa* L. *Puccinia coronata*. *Drechslera avenae*. Productivity. Food safety. Linear regression.
Abbreviations: CF_with fungicide; DAE_days after emergence; GY_grain yield; I_inferior; S_superior.

Introduction

The functional food properties of white oat contribute to this cereal being widely consumed in human food. Thus, oats have hypocholesterolemic effects, glycemic control and a positive impact on the intestinal microbiota, in addition to having an exceptionally higher protein content compared to most other cereals (Mel and Malalgoda, 2022). Regarding this, for grain production to be satisfactory and meet nutritional expectations, the correct use of management techniques is a decisive factor in the development and harvest with productivity and grain quality for different purposes (Mantai et al., 2021).

Due to the increase in oat cultivation area, the species is more susceptible to pathogens that cause foliar diseases (Carvalho, 2012). Among these diseases, more attention is given to leaf rust (*Puccinia coronata* Cda. f.sp. *avenae* E.) and helminthosporiose (*Drechslera avenae* E.) which are not totally controlled by genetic resistance, and the appearance and progression of fungi influenced by the increase in temperature and relative air humidity (Dornelles et al., 2021). These favorable conditions for the development of the fungus are commonly found in the spring period, when the crop is at the beginning of paniculation and grain filling (Silva et al., 2019). Therefore, the decisive phase in which the use of fungicides is carried out, mainly from the systemic action group, seeking to inhibit the progression of the fungus and foliar necrosis and guarantee satisfactory grain productivity (Baibakova et al., 2019). Systemic fungicides, when applied to plants, are translocated through the xylem and spread to plant tissues in order to reach the target fungus (Tsalidis, 2022). However, the grain filling phase is characterized by the mobilization of photoassimilates transferred from the leaves to the reproductive structures, generating a risk of pesticide residues in the harvested grains (López-González et al., 2022). Most of the harvested oat grains are sent to processing industries, generating various products with the grains "in natura" or even processed (Silva et al., 2015). Therefore, the risks of contamination are increased when fungicide application in grain filling is intensified and/or when the withdrawal period between application and harvest is not respected (Souza et al., 2019). Several studies show that the use of these chemicals causes adverse effects on public health, such as the occurrence of intoxications and the emergence of diseases, in addition to the presence of pesticides in various environmental compartments, contaminating the air, water and soil, with negative impacts on biodiversity (Malalgoda & Simsek, 2020).

From the perspective of oat production with a guarantee of satisfactory productivity with reduced use of fungicide, the management of anticipation of fungicide application in the control of fungi can reduce the presence of the pathogen and the pressure of infection and disease progression, mainly in the filling of grains, as well as ensuring a longer interval from application to harvest with cultivars that are more resilient to fungi in reducing the number of pesticide applications. Thus, a condition that may represent an alternative to reduce the use of fungicide in oat with lower environmental impacts and food security in cereal cultivation. The objective of the study is implementing a management system to reduce the use of fungicide in oats by the anticipation of the application and a longer interval from the last application to the grain harvest, together with the identification of cultivars that are more resilient to disease.

Results and Discussion

Meteorological elements and nitrogen fertilizer management

In Figure 1, the year 2018 shows adequate distribution of precipitation throughout the cycle, with minimum and maximum temperatures around 0 and 30ºC, respectively. At the time of nitrogen application, there was adequate soil moisture for nutrient use. In 2019, there was a restriction of soil moisture at the time of nitrogen application, with a wide interval without adequate rainfall. After application of the nutrient, rainfall with values above 40 mm was observed, a condition that tends to promote nutrient losses through leaching and surface runoff. It was also observed a greater amplitude of variation of minimum and maximum temperatures, ranging from -4 to 36ºC, configuring a greater stress in the biology of this species. The results presented show the most favorable agricultural condition in 2018 for oat cultivation, corroborating the highest average values of grain yield.

In wheat and oat cultivation, the crop year condition is defined by the volume and distribution of rainfall and the variation in air temperature (Marolli et al., 2017). Thus, well-distributed rainfall throughout the cycle and in smaller amounts favor adequate soil moisture, characterizing an ideal condition for management and better use of nitrogen at the highest expression of grain yield (Silva et al., 2020). On the other hand, in unfavorable years characterized by the occurrence of high volumes of precipitation, excess moisture in the soil can harm the development of plants in addition to compromising the absorption of nutrients, mainly nitrogen, due to the loss of fertilizer by leaching (Weitzman et al., 2022). It is noteworthy that due to the mobility of this nutrient, it is easily transported by terrestrial ecosystems, contributing to the occurrence of adverse impacts on ecosystem services, climate change and human health (Cameron et al., 2013). Air temperature also has a strong effect on plant development dynamics and the use of nitrogen on productivity (Kraisig et al., 2020). Higher temperatures favor nutrient losses by volatilization in the form of ammonia, reducing the production of new tillers, a component directly related to grain yield (Scremin et al., 2020). It is noteworthy that temperature acts as a catalyst for biological processes, which is why plants need a minimum and maximum temperature for normal physiological activities (Mamann et al., 2020). According to Spasova et al. (2013), the minimum temperature for oat emergence is 4 to 5°C, with an optimal temperature of 25°C, and a maximum of 30°C. In oats and wheat, milder temperatures with radiation quality favor tillering and grain filling, significantly improving the efficiency of nitrogen use in the elaboration of productivity components (Trautmann et al., 2020).

Grain yield as a function of fungicide use conditions

The analysis of variance (not presented), the effects of fungicide and cultivars changed the expression of grain yield in 2018 and 2019, with effects of this interaction confirmed, showing the need to present the individual performance of each cultivar under different agrochemical management conditions.

In Table 1 of averages, in the year 2018, there is the formation of two large groups of cultivars “a” and “b”. The analysis was complemented by the use of descriptive statistics using the mean plus or minus one standard deviation, for the identification of superior cultivars within the “a” group. Thus, in the condition without fungicide use (SF) superior performances were identified in the cultivars URS Altiva, URS Brava, URS Guará and IPR Artemis. In the condition with only one fungicide application (CF1), performed 60 days after emergence, with a long interval from application to grain harvest, the formation of three groups “a”, “b” and “c” was obtained, however, within the “a” group, only the cultivars URS Brava and URS Tarimba were in the superiority group.

In the use of two fungicide applications (CF2) at 60 and 75 days after emergence (Table 1), also for a long period from application to harvest, six cultivars showed superiority in the average plus one standard deviation, representing group “a” of the averages test. They are: URS Altiva, URS Brava, URS Torena, URS Tarimba, URS Taura and IPR Artemis. From the third (CF3) and fourth (CF4) application of fungicide, the cultivars IPR Afrodite and URS Taura begin to form the superiority group, indicating a greater dependence on the use of the fungicide. Although IPR Artemis showed superiority with greater use of pesticides, it also showed outstanding points with two and without fungicide application. In general, among the applications, the cultivars URS Altiva, URS Brava and IPR Artemis stand out, with superiority in the absence of fungicide and in at least the first or second application of the pesticide, configuring a long interval between application and harvest. It should be noted that the third and fourth applications did not show any change in grain yield between cultivars.

Regarding the effectiveness of genetic performance under the conditions of fungicide use, Table 1 presents the linear regression function for the analysis of the superiority of the linear coefficient (a), which indicates the starting point of performance in the absence of the fungicide, and the coefficient angular (b), which indicates the degree of dependence of the genotype on the fungicide (Dornelles et al., 2021). Therefore, it is assumed that the most resilient genotype to fungicide reduction is the one with superior linear coefficient and mean or inferior slope coefficient. These conditions were only found in the cultivars URS Altiva, URS Brava and IPR Artemis, showing potential in the recommendation for transition cultivation to the organic system or reduction of fungicide use.

The superiority of the regression angular coefficient (b_1) of URS Taura, FAEM 5 Chiarasul, Barbarasul, Fapa Slava, IPR Afrodite and UPFA Gaudéria stands out, indicating great dependence of these cultivars in the use of fungicide. In this approach, for example the cultivar with superior linear coefficient performance, URS Brava, showing that each

Table 1. Average and linear regression of grain yield of oat cultivars under fungicide use conditions in 2018.

Genotype	Grain yield (GY, kg ha^{-1})					Regression (GY, kg ha^{-1})	
	SF	CF1	CF2	CF3	CF4	a+bx	R^2
	(-)	(60)	(60/75)	(60/75/90)	(60/75/90/105)		
URS Altiva	B1535^{S}a	B1956b	A2962^{S}a	A3077a	A2964b	1703^S+397^I*x	79
URS Brava	C1477^{S}a	B2284^{S}a	A3055^{S}a	A2933a	A2848c	1841^S+339^I*x	67
URS Guará	C1309^{S}a	B2000b	B2309b	A3012a	A3177b	1412+474*x	96
URS Estampa	D1172a	C2022b	B2426b	A3170a	A3207b	1356+521*x	94
URS Corona	D1153a	C1668c	B2149b	A2963a	A2940b	1201+486*x	94
URS Torena	B1087a	B1519c	A2832^{S}a	A3038a	A3049b	1216+544*x	85
URS Charrua	D741b	C1865b	B2389b	A3071a	A3069b	1054+586*x	90
URS Guria	D670b	C1773c	B2218b	A2573^{I}b	A2699c	1015+485*x	87
URS Tarimba	C634^{I}b	B2587^{S}a	B2873^{S}a	A3158a	A3133b	1363+556*x	69
URS Taura	D1078a	C1863b	B2856^{S}a	A3353^{S}a	A3337^{S}b	1296+600^S*x	90
URS 21	C1099a	B2057b	B2144b	A2456^{I}a	A2622^{I}c	1386+344^I*x	84
FAEM 007	D716b	C1522c	B2224b	A2926b	A2998b	884^I+596*x	94
FAEM 006	C773b	B2036b	A2438b	A2732a	A2826c	1200+480*x	82
FAEM 5 Chiarasul	D803b	C1369^{I}c	B2445b	A2985a	A3053b	907+611^S*x	92
FAEM 4 Carlasul	D767b	C1625c	B2175b	A2667b	A2709c	1003+492*x	91
Brisasul	C675b	B2016b	B2261b	A2652b	A2631^{I}c	1137+454*x	78
Barbarasul	D729b	C1626c	B2445b	A3125a	A3108b	955+625^S*x	92
Fapa Slava	D740b	C1566c	B2393b	A2992a	A3042b	941+602^S*x	93
IPR Afrodite	D690b	C1861b	B2484b	A3441^{S}a	A3707^{S}a	913+761^S*x	96
UPFPS Farroupilha	D690b	C1676c	B2267b	A2733b	A2994b	939+566*x	94
UPFA Ouro	C797b	C1218^{I}c	B1606^{I}c	A2015^{I}c	A2172^{I}d	852^I+354^I*x	98
UPFA Gaudéria	C975b	C1235^{I}c	B2329b	A3136a	A3253b	894+645^S*x	94
IPR Artemis	D1497^{S}a	C2045b	B2810^{S}a	A3575^{S}a	A3630^{S}a	1552^S+579*x	95
Average	948	1800	2439	2947	3007	1175	526
Standard Deviation	293	327	333	339	329	277	74
Average + 1DP	1241	2127	2771	3286	3337	1452	600
Average – 1DP	655	1472	2106	2609	2678	898	421

Averages followed by the same vertical lowercase letters constitute a statistically homogeneous group. Averages followed by the same horizontal capital letters constitute a statistically homogeneous group. PG= grain yield; SF= no fungicide application; CF1= with a fungicide application at 60 days after emergence; CF2= with two fungicide applications at 60 and 75 days after emergence; CF3= with three fungicide applications at 60, 75 and 90 days after emergence; CF4= with four fungicide applications at 60, 75, 90 and 105 days after emergence; SD= standard deviation; S= superior (genotype with mean value plus one standard deviation); I= inferior (genotype with mean value minus one standard deviation); *= significant at 5% probability of error; R^2 = coefficient of determination.

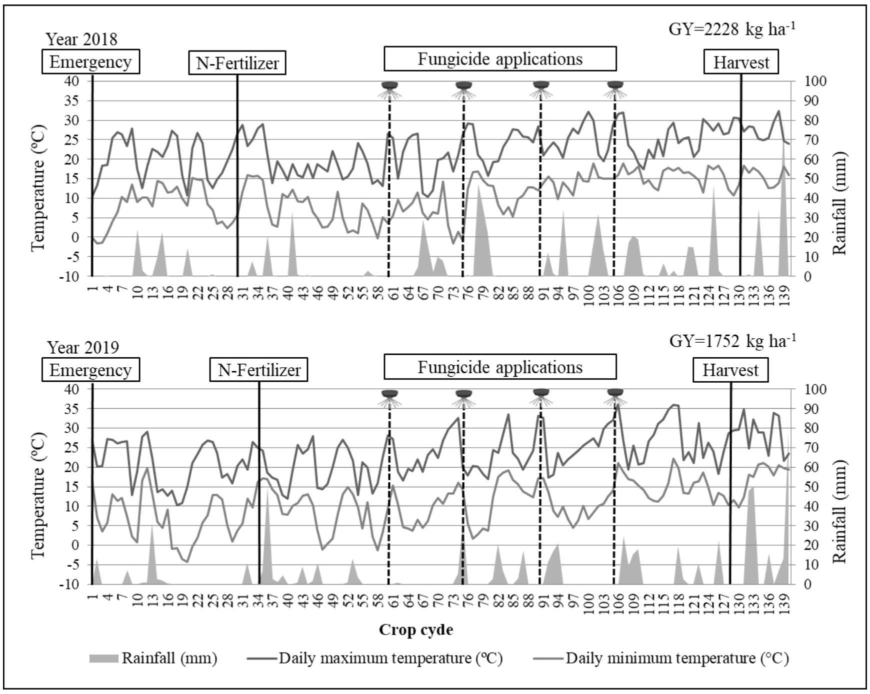

Fig 1. Daily precipitation and temperature data during the oat crop cycle in the years 2018 and 2019. GY = grain yield.

Table 2. Averages and linear regression of grain yield of oat cultivars under fungicide use conditions in 2019.

Genotype	Grain yield (GY, kg ha^{-1})					Regression (GY, kg ha^{-1})	
	SF (-)	CF1 -60	CF2 (60/75)	CF3 (60/75/90)	CF4 (60/75/90/105)	a+bx	R^2
URS Altiva	C1097^{S}a	C1409b	B1891b	A2356b	A2470b	1106^{S}+369*x	97
URS Brava	C825b	B1549b	A2168a	A2367b	A2330b	1082+382*x	84
URS Guará	C746b	B1185c	A1962b	A1903^{I}b	A1917c	931+305^{I}*x	77
URS Estampa	C719b	B1712^{S}b	A2034a	A2129b	A2229c	1077+343*x	77
URS Corona	C702b	C1141^{I}c	A2018a	A2097b	A2105c	860+376*x	83
URS Torena	C556b	B1307c	A2133a	A2144b	A2289c	825+430*x	84
URS Charrua	C1026^{S}a	B1553b	A2114a	A2278b	A2201c	1219^{S}+307*x	82
URS Guria	C507^{I}b	B1061c	A1719^{I}b	A2045b	A1970^{I}c	678^{I}+391*x	88
URS Tarimba	D655b	C1506b	B2144a	A2557^{S}a	A2583^{S}b	907+490^{S}*x	90
URS Taura	C645b	B1468b	A2043a	A2232b	A2391b	904+425*x	89
URS 21	D672b	C1247c	B1869b	A2239b	A2473b	781+459*x	96
FAEM 007	C678b	B1295c	A1955b	A1994b	A1984^{I}c	905+334*x	80
FAEM 006	C867a	B1586b	B1744^{I}b	A2037b	A2033c	1096+278^{I}*x	83
FAEM 5 Chiarasul	C540^{I}b	B1526b	A2273^{S}a	A2358b	A2373b	914+449*x	80
FAEM 4 Carlasul	C571b	B1319c	A2114a	A2197b	A2198c	854+413*x	81
Brisasul	C593b	B1442b	B1803b	A2194b	A2193c	828+401*x	89
Barbarasul	C555b	B1300c	A2114a	A2260b	A2217c	832+428*x	82
Fapa Slava	C535^{I}b	B1130^{I}c	A2173a	A2266b	A2370b	734^{I}+480^{S}*x	86
IPR Afrodite	C773b	B1605b	A2514^{S}a	A2842^{S}a	A2766^{S}a	1055+522^{S}*x	86
UPFPS Farroupilha	C746b	B1283c	A1713^{I}b	A2018b	A1953^{I}c	913+314*x	88
UPFA Ouro	A1030^{S}a	C1488b	B2329^{S}a	A2912^{S}a	A2922^{S}a	1094+520^{S}*x	93
UPFA Gaudéria	B1140^{S}a	A2340^{S}a	A2281^{S}a	A2577^{S}a	A2535b	1529^{S}+312^{I}*x	71
IPR Artemis	C974^{S}a	B1537b	B1722^{I}b	A1955^{I}b	A2036c	1136^{S}+254^{I}*x	90
Average	746	1434	2036	2259	2284	968	391
Standard Deviation (SD)	192	262	214	261	262	132	76
Average + 1DP	938	1696	2250	2520	2546	1100	467
Average – 1DP	554	1172	1822	1998	2022	781	314

Averages followed by the same vertical lowercase letters constitute a statistically homogeneous group. Averages followed by the same horizontal capital letters constitute a statistically homogeneous group. PG= grain yield; SF= no fungicide application; CF1= with a fungicide application at 60 days after emergence; CF2= with two fungicide applications at 60 and 75 days after emergence; CF3= with three fungicide applications at 60, 75 and 90 days after emergence; CF4= with four fungicide applications at 60, 75, 90 and 105 days after emergence; SD= standard deviation; S= superior (genotype with mean value plus one standard deviation); I= inferior (genotype with mean value minus one standard deviation); *= significant at 5% probability of error; R^2 = coefficient of determination.

fungicide application increases grain productivity by 339 kg ha^{-1}, starting from 1841 kg ha^{-1} in the absence of the input. And the one with superior angular coefficient performance, IPR Aphrodite, with an increase of 761 kg ha^{-1} of grain productivity with each fungicide application, however, starting from a production of only 913 kg ha^{-1}, in the absence of fungicide.

In Table 2, in the absence of fungicide use in 2019, although two distinct groups of averages were observed, the superiority by the average plus one standard deviation within group "a" was obtained in the cultivars URS Altiva, URS Charrua, UPFA Ouro, UPFA Gaudéria and IPR Artemis. The application in a single moment, 60 days after emergence, showed three classes of means, however, only the cultivars URS Estampa and UPFA Gaudéria represented the group above the mean of the distribution. In the condition with two fungicide applications, at 60 and 75 days after emergence, the vast majority of cultivars represented group "a", however, the superiority of the mean plus one standard deviation was observed only in cultivars FAEM 5 Chiarasul, IPR Afrodite, UPFA Ouro and UPFA Gaudéria. It stands out in the absence, one and two applications of fungicide, which configure a large interval of application and harvest, with superiority of the cultivar UPFA Gaudéria. In the same condition, the cultivar UPFA Ouro also shows a highlight of superiority in all application conditions, with the exception of one application. In the analysis with three and four fungicide applications, superiority was obtained for the cultivars URS Tarimba, IPR Afrodite and UPFA Ouro. In general, most cultivars showed grain yield with two applications similar to the third and fourth application, which indicates that the use of a greater number of applications leads to management inefficiency, greater environmental pollution and risks of occupational contamination and residues of grains, raw material used for several food products.

In table 2, the cultivars URS Altiva, URS Charrua, UPFA Gaudéria and IPR Artemis, indicated superiority in the linear coefficient of the regression. Among these, the cultivars URS Altiva and IPR Artemis also showed this superiority in the previous year, providing subsidies for the cultivation potential in conditions of absence or reduced use of fungicide. On the other hand, the cultivars URS Tarimba, Fapa Slava, IPR Afrodite and UPFA Ouro showed superior angular coefficient, indicating greater dependence on the use of pesticides. The results presented show changes in the behavior of the cultivars to the use of fungicide by the conditions of the agricultural year. Therefore, results found in a given year on a given genotype do not necessarily follow the same pattern in another year. On the other hand, it is important to highlight that the cultivars URS Altiva and IPR Artemis, which, regardless of the agricultural year, showed superiority of linear coefficient, a parameter considered as a criterion in the identification of the most resilient genotype to the fungicide. Possibly these cultivars show genes that provide greater stability in the face of meteorological conditions, at the same time providing response mechanisms to withstand the pressure of pathogens.

However, although it was not presented, a negative correlation was obtained between the increase in necrotic leaf area analyzed at 105 days after plant emergence and grain yield (r = -0.91), regardless of the year of cultivation. Therefore, justifying that the increase in leaf damage significantly interferes in the reduction of oat productivity. In genetic improvement programs, white oat cultivars with genetic resistance to foliar diseases are the focus of selection (Cruz et al., 2001; Silva et al., 2015). However, an analysis of the possibility of reducing the use of fungicide, with an interval between harvest and the last application is not observed in the referenced studies. These conditions could help in the identification of genotypes more resilient to the use of fungicide, configuring the release of cultivars adjusted to managements with no or fewer applications. It is noted that the cultivars URS Altiva and IPR Artemis in both years studied showed superior performance for grain yield, even in 2019 considered an unfavorable agricultural year. These results also configure potential for use in crossing blocks, in the selection of new genotypes with these genetic characteristics. Nerbass Junior et al., (2010) developed critical point models for leaf rust and helminthosporiosis through the relationship between disease intensity and grain yield. They emphasize that the damages in the yield are due to the reduction of the photosynthetic leaf area considering the occurrence of fungal diseases. Hikishima et al., (2010) also used linear regressions to quantify the damage caused by the Asian rust leaf disease on soybean yield. Ranzi and Forcelini (2013) used regressions to estimate the expansion of necrotic leaf area (yellow spot) in wheat, under different conditions of fungicide use, confirming the need to recommend more resistant cultivars to reduce the progression of fungal diseases.

Agricultural activity has been one of the main causes of deforestation, a source of greenhouse gas emissions and loss of biodiversity. However, agricultural practices have become more sustainable after the adoption of the National Low Carbon Agriculture Program. The increase in production together with environmental protection shows that the country has the potential to generate more sustainable cultivation processes and meet global food security goals (Chaplin-Kramer et al., 2015; Dias et al., 2016). In this perspective, information is needed about cultivars that are more suited to more sustainable processes, a condition that makes it possible to identify genes that can be inserted in the development of new cultivars. Currently, the diseases are not satisfactorily controlled by the genetics of the cultivars, as they do not present total or long-lasting resistance under field conditions and guarantee economic return (Kiran et al., 2016; Li et al., 2020). Pesticides applied in crop fields can reach the aquatic environment through leaching, through rainwater and irrigation, surface runoff, soil percolation, among other ways, reaching groundwater (Manasa & Mehta, 2020). A serious consequence of the presence of these chemicals in the air are the negative impacts on the abundance of pollinating insects, which tend to have lower pollination efficiency, reducing the quantity and quality of available food (Rosa et al., 2019; Lopes & Sales, 2020).

The research carried out by Montagner et al., (2021) reported that 30% of the research participants understood accidental exposure to pesticides through environmental exposure, ingestion of contaminated water and food and handling contaminated clothing. In addition, many family members end up exposed to chemical compounds indirectly, when washing contaminated clothes along with others, or when washing spray equipment near homes. Novais et al, (2021) in the research in the state of Mato Grosso, found that serious problems to public health can be caused by the contamination of water resources, especially when they are used for supply, in addition to compromising the existing biodiversity in springs. It should be noted that public health problems arising from the use of pesticides, despite their harmfulness, grow on an unsustainable scale and the current way of producing food contributes to the increase in the occurrence of these diseases. In addition, the emergence of other complications over the years due to the continuous use of pesticides in agriculture (Mariyono et al., 2018; Frota & Siqueira, 2021). Bearing this scenario and the numerous problems caused by the excessive use of pesticides in mind, there is a need to develop new alternatives that promote more sustainable agriculture in order to reduce and/or avoid the incidence and severity of fungal diseases in oats and the strong dependence on fungicide application (Silva et al., 2015; Corcino et al., 2019).

Materials and Methods

Plant materials

The research was carried out in 2018 and 2019, in the municipality of Augusto Pestana, RS, Brazil (28° 26' 30'' latitude S and 54° 00' 58'' longitude W). The soil of the experimental unit is characterized as a Typical Dystroferric Red Latosol, with a deep, well-drained profile, dark red color and high clay contents. The climate of the region, according to the Köppen classification, is Cfa (humid subtropical), with well-distributed rainfall throughout the year, with an average annual volume close to 1600 mm and an average air temperature in the cold season of the year around - 3°C and in the hot season around 22°C.

Ten days before sowing, soil analysis was performed showing the following chemical characteristics (pH= 6,0; P=33,3 mg dm^{-3}; K= 205 mg dm^{-3}; MO= 3,1 %; Al= 0 cmolc dm^{-3}; Ca = 6,7 cmolc dm^{-3} and Mg=2,8 cmolc dm^{-3}). Sowing was carried out with a seeder-fertilizer in a soybean/oat cropping system between the second and third week of June in the different years, using a population density of 400 viable seeds m^{-2}, as recommended. The experimental plot consisted of 5 lines of 5 meters in length and 0.20 meters spacing for the composition of the experimental unit of 5 m^2. In order to meet the expected yield of 4000 kg ha^{-1}, a total of 60 kg ha^{-1} nitrogen was applied, with 10 and 50 kg ha^{-1} directed at sowing and coverage, respectively. The top-dressing application was carried out at the expanded fourth leaf phenological stage. Based on soil P and K contents, 45 and 30 kg ha^{-1} of P_2O_5 and K_2O were applied at sowing, respectively.

Experimental design and experimental procedure

The experimental design was randomized blocks with three replications following a 23 x 5 factorial scheme, for 23 white oat cultivars and 5 fungicide application conditions, respectively. The oat genotypes used for the research represent recommended cultivars and no longer present in the current Brazilian recommendation: Barbarasul, Brisasul, FAEM 006, FAEM 007, FAEM 4 Carlasul, FAEM 5 Chiarasul, IPR Afrodite, IPR Artemis, UPFA Gaudéria, UPFA Ouro, UPFPS Farroupilha, URS 21, URS Altiva, URS Brava, URS Charrua, URS Corona, URS Estampa, URS Fapa Slava, URS Guará, URS Guria, URS Tarimba, URS Taura and URS Torena. The conditions of use of fungicides were defined in the time scale and applied in a cumulative sequential way, as follows: [control (no application); one application 60 days after emergence (DAE); two applications at 60 and 75 DAE; three applications at 60, 75 and 90 DAE and four applications at 60, 75, 90 and 105 DAE]. The conditions for using fungicides were proposed based on the possibility of increasing the interval between harvest and the last application of the pesticide (fungicide). The dynamics of cumulative sequential application was considering the residual time of action of the product, which according to the recommendation acts for approximately 15 days. The fungicide used was tebuconazole, commercial name FOLICUR® CE at a dose of 0,75 L ha^{-1}. In crop management, weed control was carried out by using the herbicide metsulfuron-methyl, commercial name ALLY® at a dose of 2,4 g ha^{-1} of the commercial product and weeding whenever necessary.

Traits measured

In estimating grain yield (GY), the three central lines of each plot were considered, harvested manually when the grains had moisture around 15%. The plants were threshed with a stationary harvester and the grains were sent to the laboratory to correct the humidity to 13% and to determine the productivity in kg ha^{-1}. At the 105 days after plant emergence, three plants were randomly collected from each plot. From each plant, three upper leaves were removed and scanned to read the necrotic leaf area with the WinDIAS Software (Copyright 2012, Delta-T Devices Limited) (data not shown).

Statistical analysis

The data were submitted to analysis of variance to detect the main and interaction effects between cultivars and fungicide use conditions. After a comparison test was carried out by Scott & Knott to analyze the performance of the cultivars in each condition of fungicide use. Under these conditions, the cultivars were classified as superior (S) and inferior (I) considering the mean plus or minus one standard deviation. Afterwards, a linear regression analysis ($y = b_0 \pm b_1x$), was carried out, in the dimensioning of the efficiency of the cultivars to the reduction of the pesticide, by the value of the linear coefficient = intercept (b_0), which indicates the starting point of the variable in the regression and the angular coefficient (b_1), which determines the growth rate of the variable y by the number of applications. Following with the analysis of the regression parameters by the average plus or minus one standard deviation, in the indication of superiority or inferiority of the parameters that they describe in the different handling conditions. The analyzes were performed using the GENES software (Quantitative Genetics and Experimental Statistics, version 2015.5.0).

Conclusion

In oat cultivation, the early and sequential application of fungicide at 60, 75 and 90 days after emergence guarantees satisfactory productivity with a long interval from the last application to harvest for greater food security.

The cultivars URS Altiva and IPR Artemis show resilience in the presence of foliar diseases in the absence and reduced use of fungicide, facilitating the transition between conventional and agroecological agriculture in oat cultivation.

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Conflicts of interest

The authors declare no conflict of interest.

References

Baibakova EV, Nefedjeva EE, Suska-Malawska M, Wilk M, Sevriukova GA, Zheltobriukhov VF (2019) Modern fungicides: mechanisms of action, fungal resistance and phytotoxic effects. Annu Res Rev Biol. 32(3): 1-16.

Cameron KC, Di HJ, Moir JL (2013) Nitrogen losses from the soil/plant system: a review. Ann of Appl Biol. 162: 145-173.

Carvalho NL (2012) Resistência genética induzida em plantas cultivadas. Rev Eletrônica Gest Educ Tecnol Ambient. 7(7): 1379-1390.

Chaplin-Kramer R, Sharp RP, Mandle L, Sim S, Johnson J, Butnar I, Canais LM, Eichelberger BA, Ramler I, Mueller C, McLachlan N, Youssefi A, King H, Kareiva PM (2015) Spatial patterns of agricultural expansion determine impacts on biodiversity and carbon storage. Proc Natl Acad Sci USA. 112(24): 7402–7407.

Corcino CO, Teles RBDA, Almeida JRGDS, Lirani LDS, Araújo CRM, Gonsalves ADA, Maia GLDA (2019) Avaliação do efeito do uso de agrotóxicos sobre a saúde de trabalhadores rurais da fruticultura irrigada. Ciênc Saúde Colet. 24: 3117-3128.

Cruz RP, Federizzi LC, Milach SCK (2001) Genética da resisténcia à ferrugem-da-folha em aveia. Pesq Agropec Bras. 36(9): 1127–1132.

Dias LCP, Pimenta FM, Santos AB, Costa MH, Ladle RJ (2016) Patterns of land use, extensification, and intensification of Brazilian agriculture. Glob Chang biol, 22(8): 2887–2903.

Dornelles EF, Silva JAG, Colet CF, Fraga DR, Pansera V, Alessi O, Carvalho IR, Lautenchleger F, Rosa JA, Warmbier E, Sostmeyer MJ, Polanczyk AK. (2021) The efficiency of Brazilian oat cultivars in reducing fungicide use for greater environmental quality and food safety. Univers J Plant Sci. 15(7): 1835-2707.

Frota MTBA, Siqueira CE (2021) Agrotóxicos: os venenos ocultos em nossa mesa. Cad Saude Publica. 37(2).

Hikishima M, Canteri MG, Godoy CV (2010) Quantificação de danos e relações entre severidade, medidas de refletância e produtividade no patossistema ferrugem asiática da soja. Trop Plant Pathol. 35: 96–103.

Kiran K, Rawal HC, Dubey H, Jaswal R, Devanna BN, Gupta DK, Bhardwaj SC, Prasad P, Pal D, Chhuneja P, Balasubramanian P, Kumar J, Swami M, Solanke AU, Gaikwad K, Singh NK, Sharma TR (2016) Draft genome of the wheat rust pathogen (*Puccinia triticina*) unravels genome-wide structural variations during evolution. Genome Biol Evol. 8(9): 2702–2721.

Kraisig AR, Silva JAG, Carvalho IR, Lautenchleger F, Mamann ÂTW, Fachinetto JM, Pereira LM, Basso NCF, Argenta CV, Norbert L, Berlezi JD (2020) Time of nitrogen supply in

yield and industrial quality of oat grains by agricultural condition. J Agric Stud. 8(4): 128-141.
Li Q, Wang B, Yu J, Dou D (2020) Melhoramento com informações de patógenos para resistência a doenças de cultivo. J Integr Plant Biol, 63(2): 305-311.
Lopes RA, Sales NIS (2020) Utilização de agrotóxicos em pastagens e monoculturas e morte súbita de abelhas em Porangatu-GO. Cader Agroec. 15(2).
López-González C, Juárez-Colunga S, Trachsel S, Marsch-Martínez N, Gillmor CS, Tiessen A (2022) Analysis of global gene expression in maize (*Zea mays*) vegetative and reproductive tissues that differ in accumulation of starch and sucrose. Plants. 11(3): 1-16.
Malalgoda M, Simsek S (2020) Pesticide residue in grain-based food: Effects on health, grain quality, and chemical properties of biomacromolecules. Cereal Chem. 98: 8–16.
Mamann ÂTW, Silva JAG, Scremin OB, Trautmann AP, Argenta CV, Matter EM (2020) Diffuse system simulating wheat productivity by nitrogen and temperature in the use of biopolymers. Rev Bras Eng Agríc Amb. 24(5): 289-297.
Manasa RL, Mehta A (2020) Wastewater: sources of pollutants and its remediation. Environ Biotechnol. 2: 197-219.
Mantai RD, Silva JAG, Carvalho IR, Lautenchleger F, Carbonera R, Rasia LA, Kraisig AR, Pansera V, Alessi O, Rosa JA, Warmbier E, Basso NCF, Matter EM (2021) Contribution of nitrogen on industrial quality of oat grain components and the dynamics of relations with yield. Aust J Crop Sci. 15(3): 334-342.
Mariyono J, Kuntariningsih A, Kompas T (2018) Pesticide use in Indonesian vegetable farming and its determinants. Manag Environ Qual. 29(2): 305-323.
Marolli A, Silva JAG, Romitti MV, Mantai RD, Hawerroth MC, Scremin OB (2017) Biomass and grain yield of oats by growth regulator. Rev Bras Eng Agríc Amb. 21(3): 163-168.
Mel R, Malalgoda M (2022) Oat protein as a novel protein ingredient: Structure, functionality, and factors impacting utilization. Cereal Chem. 99: 21–36.
Montagner SED, Colet CF, Maldaner KL, Silva JAG, Fell APW, Carbonera R, Stumm EMF (2021) Caracterização de indivíduos com câncer, residentes no meio rural, práticas no uso de agrotóxicos e níveis de acetilcolinesterase eritrocitárias. Res Soc Dev. 10(5): 1-18.
Nerbass Junior JM, Casa RT, Kuhnem Júnior PR, Gava F, Bogo A (2010) Modelos de pontos críticos para relacionar o rendimento de grãos de aveia branca com a intensidade de doença no patossistema múltiplo ferrugem da folha: helmintosporiose. Cienc Rural. 40(1): 1–6.
Novais CM, Queiroz TM, Seabra Júnior S (2021) Panorama da contaminação ambiental por agrotóxicos no estado do mato grosso: risco para o abastecimento urbano. Res Soc Dev. 10(1): 1-14.
Ranzi C, Forcelini CA (2013) Aplicação curativa de fungicidas e seu efeito sobre a expansão de lesão da mancha-amarela do trigo. Ciênc Rural. 43(9): 1576–1581.
Rosa JM, Arioli CJ, Nunes-Silva P, Garcia FRM (2019) Desaparecimento de abelhas polinizadoras nos sistemas naturais e agrícolas: Existe uma explicação? Rev Ciênc Agrovet. 18(1).
Scremin OB, Silva JAG, Carvalho IR, Mamann ÂTW, Alessi O, Pansera V, Lautenchleger F, Carbonera R, Norbert L, Basso NCF (2020) Fuzzy logic simulation of oat yield after using hydrogel and nitrogen biopolymer management. Aust J Crop Sci. 14(8): 1319-1327.
Silva JAG, De Mamann AT W, Scremin OB, Carvalho IR, Pereira LM, Lima ARC, Lautenchleger F, Basso NCF, Argenta CV, Berlezi JD, Porazzi FU, Matter EM, Norbert L (2020) Biostimullants in the indicators of yield and industrial and chemical quality of oat grains. J Agric Stud. 8: 68-87.
Silva JAG, Wohlenberg MD, Arenhardt EG, Oliveira AC, Mazurkievicz G, Müller M, Arenhardt LG, Binelo MO, Arnold G, Pretto R (2015) Adaptability and stability of yield and industrial grain quality with and without fungicide in Brazilian oat cultivars. Am J Plant Sci. 6(9): 1560-1569.
Silva V, Mol HGJ, Zomer P, Tienstra M, Ritsema CJ, Geissen V (2019) Pesticide residues in European agricultural soils – A hidden reality unfolded. Sci Total Environ. 653: 1532–1545.
Souza LP, Faroni LRDA, Heleno FF, Pinto FG, Queiroz MELR, Prates LHF (2019) Difenoconazole and linuron dissipation kinetics in carrots under open-field conditions. Ecotoxicol Environ Saf. 168: 479-485.
Spasova D, Spasov D, Atanasova B, Ilievski M, Kukutanov R, Georgieva T (2013) Impact of the system of cultivation on the vegetative growth and reproductive development of oats. Bulg J Agric Sci 19(5): 1047-1055.
Trautmann APB, Silva JAG, Binelo MO, Valdiero AC, Henrichsen L, Basso NCF (2020) Simulação da produção de trigo por nitrogênio e não linearidade das condições ambientais. Rev Bras Eng Agri Amb. 24(1): 44-51.
Tsalidis GA (2022) Human health and ecosystem quality benefits with life cycle assessment due to fungicides elimination in agriculture. Sustain. 14(2): 1-12, 2022.
Weitzman JN, Brooks JR, Compton JE, Faulkner BR, Mayer PM, Peachey RE, Rugh WD, Coulombe RA, Hatteberg B, Hutchins SR (2022) Deep soil nitrogen storage slows nitrate leaching through the vadose zone. Agric Ecosyst Environ. 332: 1-13.