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Selection of white oat genotypes for contrasting fungicide management conditions

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Abstract – The objective of this work was to select white oat (*Avena sativa*) genotypes for environments with and without fungicide application, as well as to identify relationships between meteorological variables and agronomic traits. Two experiments were carried out: one without and the other with the use of the tebuconazole fungicide. In each experiment, 26 genotypes were evaluated, conducted during ten years in the same experimental area; cultivation years were considered as one environment. The methodologies of genotype and of the genotypes x environments interaction were used to define the ideal genotype. 'URS Corona' is considered an ideal genotype due to its excellent responses in the environment with tebuconazole. The 'Brisasul', 'IPR Aphrodite', and 'URS Taura' genotypes respond better in the environment without the fungicide. However, based on multitraits, the 'URS Taura' and 'IPR Afrodite' genotypes can be positioned in environments with or without the use of tebuconazole. Genotypes with a rust incidence lower than 15% and a height higher than 93 cm in an environment with a relative humidity lower than 70.75% have a higher grain yield regardless of fungicide use. Greater magnitudes of air temperature and solar radiation result in a higher grain yield of white oat, regardless of fungicide use.

Index terms: genetic potential, genotype x environment interaction, ideotype, stability.

Seleção de genótipos de aveia-branca para condições contrastantes de manejo de fungicida

Resumo – O objetivo deste trabalho foi selecionar genótipos de aveia-branca (*Avena sativa*) para ambientes com e sem aplicação de fungicidas, bem como identificar relações entre variáveis meteorológicas e características agronômicas. Dois experimentos foram conduzidos: um sem e outro com o uso do fungicida tebuconazole. Em cada experimento, foram avaliados 26 genótipos, conduzidos durante dez anos na mesma área experimental; os anos de cultivo foram considerados como um ambiente. As metodologias de genótipos e da interação genótipos x ambientes foram utilizadas para definir o genótipo ideal. 'URS Corona' é considerado um genótipo ideal devida às suas ótimas respostas em ambiente com uso de tebuconazole. Já os genótipos 'Brisasul', 'IPR Afrodite' e 'URS Taura' respondem melhor em ambiente sem o fungicida. Contudo, com base em multicaracterísticas, os genótipos 'URS Taura' e 'IPR Afrodite' podem ser posicionados em ambientes com ou sem o uso de tebuconazole. Genótipos com incidência de ferrugem menor que 15% e altura maior que 93 cm, em ambiente com umidade relativa menor que 70,75%, apresentam maior produtividade de grãos independentemente do uso de fungicida. Maiores magnitudes de temperatura do ar e radiação solar resultam em maior produtividade de grãos de aveia-branca, independentemente do uso de fungicida.

Termos para indexação: potencial genético, interação genótipo x ambiente, ideótipo, estabilidade.

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Introduction

White oat (*Avena sativa* L.) is an annual grass belonging to the Poaceae family. Its cultivation is carried out mainly at latitudes from 30º to 65º in several countries and, according to FAO (2020) crop estimates, more than 9.4 million hectares of white oat were harvested worldwide, of which approximately 450,000 were in Brazilian territory. Conab (2022) estimates an increase in the area of white oat cultivation of 2.12% for the year 2022 in relation to the previous year, with an increase in grain production of 2.5%. In relation to the last five years, the area of cultivation and grain production of white oat increased by 66% and 85%, respectively.

This increase in the production of white oat grains is a reflection of its multiple functionality (Kim et al., 2021), in agriculture with a great diversity of crops, animal feed, as well as benefits attributed to the presence of beta glucan in the composition of its grains for human health (Zielke et al., 2017). However, the expansion of cultivated areas, driven by the needs of food consumption, promotes increase in the use of chemical management to ensure crop productivity. In turn, strategies should and can be implemented in order to minimize the indiscriminate use of chemical management through selection of genotypes that express superior performance, for example, in conditions without use of fungicides.

The meteorological conditions of the growing environment determine the performance of the genotypes (Howarth et al., 2021), as well as the incidence of diseases (Morkeliūnė et al., 2021). In white oats, leaf rust and leaf spots are the main diseases responsible for reducing grain yield of the crop (Nazareno et al., 2018). Currently, the main strategy for controlling these pathogens is the use of fungicides from the chemical groups of triazole and strobilurin. However, the application of fungicides, often excessive, in addition to the high economic cost, promotes negative effects on the environment.

Some research was carried out and identified promising white oat genotypes for cultivation with reduced use of fungicides (Silva et al., 2015; Oliveira Neto et al., 2019; Dornelles et al., 2021). Although the aforementioned studies were efficient in the selection of white oat genotypes, they did not infer the influence of meteorological variables on the performance of the genotypes over several years. In addition, there is limited information on the interaction considering environments with and without the use of fungicides over a large time series for variables related to disease tolerance.

The understanding of these relationships over a historical series is important in decision-making for the selection of genotypes. This is due to the fact that, in the evaluation of genotypes in a small series of years, unfavorable meteorological conditions for the development of pathogens in the crop may occur and, therefore, variability is not identified in the responses of genotypes in management with or without application of fungicide.

This reflects in the biased selection of genotypes and, consequently, in the positioning of the genotypes in unfavorable conditions for their maximum performance.

The objective of this work was to select white oat genotypes for environments with and without fungicide application, as well as to identify relationships between meteorological variables and agronomic traits.

Materials and Methods

The work was developed between the years 2008 and 2017 (10 years) at the Instituto Regional de Desenvolvimento Rural (IRDeR), which is linked to the Universidade Regional do Noroeste do Estado do Rio Grande do Sul (Unijuí) and located in the municipality of Augusto Pestana, in the state of Rio Grande do Sul (RS), Brazil. IRDeR’s geographic coordinates of latitude and longitude are 28º26'25'S and 54º00'07'W, respectively, and its altitude is 280 m. In this area, the climate, according to the Köppen-Geiger classification, is of the Cfa type, with wet and cold winters and hot and rainy summers. The relief is wavy; in addition, the soil is classified as a typical dystroferric Latossolo Vermelho (Oxisol), with high clay content (Santos et al., 2018).

Two experiments were carried out in the same experimental area. In one experiment, 26 white oat genotypes were evaluated without fungicide application. In the other experiment, the same 26 genotypes of white oats were evaluated, but with application of fungicide. Both experiments were conducted for 10 years (2008 to 2017) in the same experimental area, with the same genotypes. In addition, with the same conditions, being: without application of fungicide and with application of fungicide.

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Regarding the condition with fungicide, three applications were made: at the end of the stretching, in flowering and in grain filling. These conditions represent the most common application of fungicides in crops of oats in Brazil. A fungicide whose active ingredient is tebuconazole was used at a dose of 0.75 L ha^{-1}. The experiment without use of the fungicide was characterized by the absence of pesticides to control diseases.

The experimental design used in both experiments was randomized blocks, with three replications per treatment – thus, totaling 78 experimental units per experiment in each year. Therefore, in the experiment without fungicide application, each year of cultivation was considered as an environment. Likewise, in the experiment with fungicide application, each year of cultivation was considered an environment. Thus, each experiment (with and without fungicide) totaled 780 experimental units (26 genotypes × 3 replicates × 10 environments).

In this work, the 26 major white oat genotypes (cultivars) recommended for cultivation in Brazil were evaluated (according to their position): Barbarasul (1), Brisasul (2), Carlasul (3), Chiarasul (4), Dilmasul (5), Fapa 4 (6), Guapa (7), IAC 7 (8), IPR Afrodite (9), Louise (10), UPF 18 (11), Temprama (12), Gaudéria (13), Ouro (14), URS 21 (15), Charrua (16), URS Corona (17), Estampa (18), Fapa Slava (G19), Guará (20), Guria (21), Penca (22), Tarimba (23), URS Taura (24), Torena (25), and URS 22 (26).

The 780 experimental units of each experiment consisted of five seeding rows spaced 0.20 m apart, five meters long, totaling 5 m² per experimental unit. The sowings were carried out in a direct sowing system between April 15 and May 15, where the predecessor crop in all years was soybean. In the present study, 200 kg ha^{-1} of fertilizer N-P-K was used with the 03-15-10 (6 kg ha^{-1} N, 30 kg ha^{-1} P_2O_5, and 20 kg ha^{-1} K_2O) formula and 300 viable seeds per square meter, according to the technical instructions for the culture. As for fertilization cover, a urea source was adopted for the application of 60 kg ha^{1} N at the phenological stage of the fourth expanded leaf.

In each experimental unit, of the two experiments, the three central rows were harvested, disregarding two lateral rows, considered as borders. Thus, in each experiment, in the 10 previously characterized environments, 780 experimental units were collected. All harvests were carried out in the second half of October.

The variables analyzed were grain yield (GY, kg ha^{-1}), plant architecture (PA, cm), thousand grain weight (TGW, g), hectoliter weight (HW, g 250 cm^{-3}), leaf rust (LR, %), stem rust (SR, %), leaf spot (LS, %), and lodging (Log, %). The phenological variables were recorded in each genotype in all years of cultivation, as follows: days from emergence to flowering (DEF), days from flowering to maturation (DFM), and days from emergence to maturation (DEM).

Weather information such as medium temperature (Tmed, °C), minimum temperature (Tmin, °C) and maximum temperature (Tmax, °C) of air, precipitation (Prec, mm), relative humidity (RH, %) and incident radiation (Rad, MJ m^{-2} per day) were expressed in order to better understand the results obtained by Nasa Power (2022).

The data obtained were subjected to the assumptions of the statistical model of normality of errors by Shapiro Wilk test and homogeneity of residual variances by Bartlett. Analysis of variance at 5% probability was performed using F test to identify the interaction between white oat genotypes × environments individually for each experiment (without fungicide application and with fungicide application). With the presence of genotypes × environments interaction, the methodologies of genotypes and the interaction of genotypes × environments (GGE) were used to define the ideal genotype and adapted to certain environments (Yan et al., 2007; Woyann et al., 2017).

Subsequently, the variance and genetic components restricted by the maximum likelihood (REML) are estimated. They are genotypic variance (Gen_var), percentage of genotypic variance (Gen, %), residual variance (Res_var), percentage of residual variance (Res, %), phenotypic variance (Phen_var), heritability (H^2), average heritability of the genotype (H^2mg), accuracy, genotypic variation coefficient (CVg), residual variation coefficient (CVr) and the ratio between the genotypic coefficient of variation and the residual coefficient of variation (CVratio).

To select genotypes based on multitrait, the multitrait genotype-ideotype distance index (MGIDI), developed by Olivoto & Nardino (2021), was applied. In order to establish relationships, Pearson's linear correlation was applied at 5% probability using the t test. In order to express the best assertiveness in the yield of white oats, an artificial intelligence method with unsupervised learning called regression tree was used, defining the

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grain yield as the dependent variable and the other variables as independent. Statistical analyses were based on the use of packages metan (Olivoto & Lúcio, 2020) and ggplot2 (Wickham, 2016) using Software R (R Core Team, 2022).

Results and Discussion

The analysis of variance was performed individually for the two experiments – the first analysis for the experiment without use of fungicide, and the second analysis for the experiment with use of fungicide. Analysis of variance revealed a significant effect for genotype (G) × environments interaction for all variables by the F-test, at 5% probability, in both experiments (Table 1). The occurrence of significance of the G × E interaction, which is influenced by the complexity of environmental variations, indicates that the genotypes present different responses in the evaluated environments, which justifies the performance of stability and adaptability analyses. Rother et al. (2019) evaluated seven genotypes of white oats in six years of cultivation in the same location, with and without fungicide application, however, with different fungicides than that of the present study. The authors showed a significant effect for genotype × environment interaction for thousand-grain mass, hectoliter weight and grain yield. Dyulgerova & Savova (2020) also identified a significant effect of the genotype × environment interaction for the grain yield variable, where environments were characterized by years of cultivation in the same location.

Table 1. Analysis of variance (ANOVA) for thousand grain weight (TGW, g), hectoliter weight (HW, g 250 cm^{-3}), and grain yield (GY, kg ha^{-1}) of white oat (*Avena sativa*) in systems without and with the use of tebuconazole fungicide in 10 years of cultivation (2008 to 2017), performed in the municipality of Augusto Pestana, RS, Brazil[(1)].

Source of variation	DF	Mean square		
		TGW	HW	GY
With tebuconazole				
Env	9	406.09*	1,423.70*	24,883,039.90*
Rep (Env)	20	8.59*	8.31*	403,184.78*
Gen	25	110.01*	100.86*	3,244,286.03*
Gen x Env	225	23.45*	29.79*	547,455.44*
Residue	500	4.89	3.91	79,041.48
Total	779			
Without tebuconazole				
Env	9	618.39*	1,091.58*	30,000,000.00*
Rep (Env)	20	5.97	7.62*	318,296.00*
Gen	25	112.05*	50.16*	3,919,224.00*
Gen x Env	225	15.21*	13.70*	348,222.00*
Residue	500	4.05	3.60	101,105.00*
Total	779			

[(1)]DF, degrees of freedom; Env, environments; Rep, repetitions; Gen, genotypes. *Significant at 5% probability by F-test.

The REML is a method for estimating the components of variation and genetic parameters of a database and thus allows identification of variables that have significance. Heritability (H^2) for management without fungicide was classified as low for all variables analyzed (Table 2). This fact indicates that the variables are highly influenced by the environment (more than 80%) in the expression of their characteristics. The average heritability of the genotypes (H^2mg) represents the genetic contribution in the expression of the character regardless of the evaluation environment, which shows reduced values for lodging and hectoliter weight, while grain yield and thousand grain weight showed 34.2% and 38.3%, respectively, without fungicide.

Accuracy is used in genotype competition assays to determine experimental precision and to assess genotypic variation in the character – thus, 55% for leaf rust, 54.6% for stem rust, 51.1% for leaf spot, 58.5% for grain yield and 61.9% for thousand grain weight, without fungicide, classified as moderate according to Resende & Duarte (2007), and low for lodging (44.3%) and hectoliter weight (44.8%). Low and moderate estimates of accuracy can be explained by the great representation of the years of cultivation.

The genotypic coefficient of variance (CVg) is used to estimate the genetic variability of the trait available in the population, being of great value for genetic improvement programs of plants, aiming at the highest possible values (Carvalho et al., 2016). The variables leaf rust, stem rust, leaf spot and grain yield showed the highest values, while reduced values were verified for lodging, thousand grain weight and hectoliter weight.

The coefficient of residual variance (CVr) refers to the experimental error and, therefore, can be used to estimate the experimental precision. High values (greater than 30%) are seen for the variables lodging, leaf rust, stem rust, leaf spot and grain yield. As for the variables thousand grain weight and hectoliter weight, values lower than 15% were visualized, indicating average experimental precision. The coefficient of variation of the proportion between the genotypic coefficient of variation and residual coefficient of variation (CVratio) shows values between 28.5 and 45.5%, without fungicide, which indicates that the population used in this work is insufficient to select superior genotypes for the variables analyzed.

Different results were observed in management with the use of fungicide. By observing the heritability (H^2), an increase in lodging values, grain yield and thousand-grain weight was visualized, a fact that indicates less influence of the environments on these characters due to the contribution of the use of tebuconazole fungicide (Table 2), while leaf rust, stem rust, leaf spot and hectoliter weight had their coefficient reduced by the use of fungicide, suggesting greater interference of the environment in the expression of the character. When analyzing the average heritability of the genotypes (H^2mg) in a system with the use of fungicide, increases in lodging, grain yield and thousand grain weight and a reduction in leaf rust, stem rust, leaf spot and hectoliter weight were observed.

The accuracy for cultivation without fungicide use shows the same classifications as for cultivation without fungicides according to Resende & Duarte (2007); however, with use of tebuconazole, there is increase for the variables lodging, grain yield and weight of one thousand grains, and there is reduction of the values of leaf rust, stem rust, leaf spot and hectoliter weight. The genotypic coefficient of variance (CVg), when cultivated with fungicide use, showed an increase in its values for the variables lodging, leaf rust, stem rust and leaf spot. As for the variables grain yield, thousand grain weight and hectoliter weight, the values were reduced.

The residual coefficient of variance (CVr) for oat in cultivation with fungicide use was similar to the one for the system without fungicide, where the variables

Table 2. Estimates of variance components and genetic parameters by restricted maximum likelihood (REML) for the variables analyzed in white oats (*Avena sativa*) in cultivation without and with the use of tebuconazole fungicide in 10 years of cultivation (2008 to 2017), in the municipality of Augusto Pestana, RS, Brazil[(1)].

Parameter	LOD	LR	SR	LS	GY	TGW	HW
				Without tebuconazole			
Gen_var	52.418	80.095	14.349	19.690	90,719.876	3.159	2.405
Gen (%)	7.521	12.645	12.416	10.528	14.794	17.146	7.733
Res_var	644.558	553.329	101.224	167.345	522,519.983	15.263	28.699
Res (%)	92.479	87.355	87.584	89.472	85.206	82.854	92.267
Phen_var	696.976	633.423	115.573	187.036	613,239.859	18.422	31.104
H^2	0.075	0.126	0.124	0.105	0.148	0.171	0.077
h^2mg	0.196	0.303	0.298	0.261	0.342	0.383	0.201
Accuracy	0.443	0.550	0.546	0.511	0.585	0.619	0.448
CVg (%)	9.534	19.977	23.326	14.642	16.141	6.572	3.602
CVr (%)	33.432	52.507	61.953	42.686	38.737	14.447	12.444
CV ratio	0.285	0.380	0.377	0.343	0.417	0.455	0.289
				With tebuconazole			
Gen_var	118.632	14.021	2.858	5.577	112,282.900	3.244	1.017
Gen (%)	13.798	4.721	10.714	7.216	17.150	18.007	4.906
Res_var	741.119	282.986	23.818	71.715	542,431.449	14.771	19.703
Res (%)	86.202	95.279	89.286	92.784	82.850	81.993	95.094
Phen_var	859.751	297.007	26.676	77.292	654,714.349	18.015	20.719
H^2	0.138	0.047	0.107	0.072	0.171	0.180	0.049
h^2mg	0.324	0.129	0.265	0.189	0.383	0.397	0.134
Accuracy	0.570	0.360	0.514	0.435	0.619	0.630	0.366
CVg (%)	20.120	19.337	25.218	15.822	11.536	5.772	2.087
CVr (%)	50.290	86.874	72.799	56.735	25.356	12.316	9.186
CV ratio	0.400	0.223	0.346	0.279	0.455	0.469	0.227

[(1)]Gen_var, genotypic variance; Gen (%), percentage of genotypic variance; Res_var, residual variance; Res (%), residual variance percentage; Phen_var, phenotypic variance; H^2, heritability; H^2mg, average heritability of the genotype; CVg, genotypic coefficient of variation; CVr, residual coefficient of variation; CVratio, ratio between genotypic and residual coefficient of variation; Lod (%), lodging; LR (%), leaf rust; SR (%), stem rust; LS (%), leaf spot; GY (kg ha^{-1}), grain yield; TGW (g), thousand grain weight; HW (g 250 cm^{-3}), hectoliter weight.

lodging, leaf rust, stem rust, leaf spot and grain yield showed high values (greater than 30%), while the thousand grain weight and hectoliter weight showed reduced values (less than 15%). The coefficients of variation of the proportion between the genotypic coefficient and residual coefficient of variation (CVratio) found for the variables analyzed ranged from 22.3% to 46.9%, indicating that the population is insufficient to select superior genotypes for these traits.

The genotype and genotype by environment interaction (GGE) model, like the AMMI model, has the advantage of graphically representing its results, although the resulting BIPLOT graph is different (Figure 1). The green line, in the horizontal direction, indicates the behavior of the trait of agronomic interest and the arrow, present in this line, represents the value of the trait of the ideal genotype. The vertical green line indicates the stability of the crops, therefore, the closer the crop is to the line, the greater the stability. In addition, the crops that are above the line show a positive deviation and thus indicate favorable environments for the expression of the characteristic.

'URS Corona' and 'Guará' genotypes present characteristics that are close to those of the ideal genotype for a thousand grain weight, and 'Guará' genotype is responsible for the highest expression of this variable, which justifies its indication for cultivation in environments with no fungicides (Figure 1A). The 2010 and 2008 crop seasons presented the best conditions for development of genotypes, as they show a positive contribution to the genotype × environment interaction. For the hectoliter weight, 60.68% of the explanation of the data total variability is evidenced and, as well as for the thousand grain weight, characteristics close to those of the ideal genotype were verified for 'URS Corona' genotype, together with the 'URS 21' in environments with no fungicides (Figure 1 B). The most stable agricultural crops were those of 2008, 2013, 2016, and 2015. The two main components explained 65.79% of the data variability for grain yield, and 'URS Corona', 'Carlasul', and 'IPR Afrodite' genotypes were shown as the genotypes with the closest characteristics to the ideal (Figure 1 C). The 2017 agricultural harvest promoted greater stability to the productive performance of the genotypes.

Observing the GGE analyses for these same variables, conducted with fungicide application, similar trends are observed for 'URS Corona' genotype. In this scenario, for thousand grain weight, hectoliter weight and grain yield, 73.59, 56.02, and 70.13% of the total variability of the data, respectively, were explained by the first two principal components (Figure 1 D, E and F). Therefore, it is evident that for all characteristics, in environments with fungicide application, 'URS Corona' genotype can be characterized as an ideal genotype. Thus, it is a genotype that should be indicated for cultivation in the evaluation region, since, in ten years, it presented optimal responses that characterize it as the ideal genotype, according to GGE methodology.

In the selection of superior genotypes for genetic improvement programs, variables for which increase in their values is of interest are observed, such as grain yield, thousand grain weight and hectoliter weight (Table 3). However, there are others that it is interesting to suppress, such as leaf rust, stem rust, leaf spot and lodging. This occurs regardless of whether the crop is grown without or with the use of fungicide.

It is observed that the MGIDI index was able to select, in descending order, genotypes 'URS Taura', 'Brisasul', 'Charrua', and 'IPR Afrodite' in the environment without fungicide application (Figure 2 A). 'Brisasul' was selected with potentials described in the first factor, which shows a reduction in the levels of leaf rust, stem rust, lead spot, and an increase in thousand grain weight and hectoliter weight (Figure 2 B), while 'Charrua' has as a strong point the reduction of lodging (second factor). Thus, it can be inferred that these genotypes have great potential for cultivation in conditions in which the use of fungicides is not performed. For example, they can be potential parents in genetic improvement programs with the objective of developing genotypes for the organic system, as well as contributing to the reduction of management with fungicides in conventional production systems. This promotes great advances in sustainability, reduction of agricultural production costs and greater safety in cultivation of this grass.

In cultivation with use of fungicides, the MGDI index showed selection of genotypes 'Brisasul', 'URS Corona', 'IPR Afrodite', and 'URS Taura' in ascending order (Figure 2 C). It was observed that the same genotypes 'Brisasul', 'IPR Afrodite', and 'URS Taura' were selected in the environment without fungicide application, which allows understanding that the response of these genotypes is independent of the fungicide management used, validating the inferences about these genotypes.

Furthermore, it can be inferred that genotype 'URS Taura', selected by the MGDI index in the environment

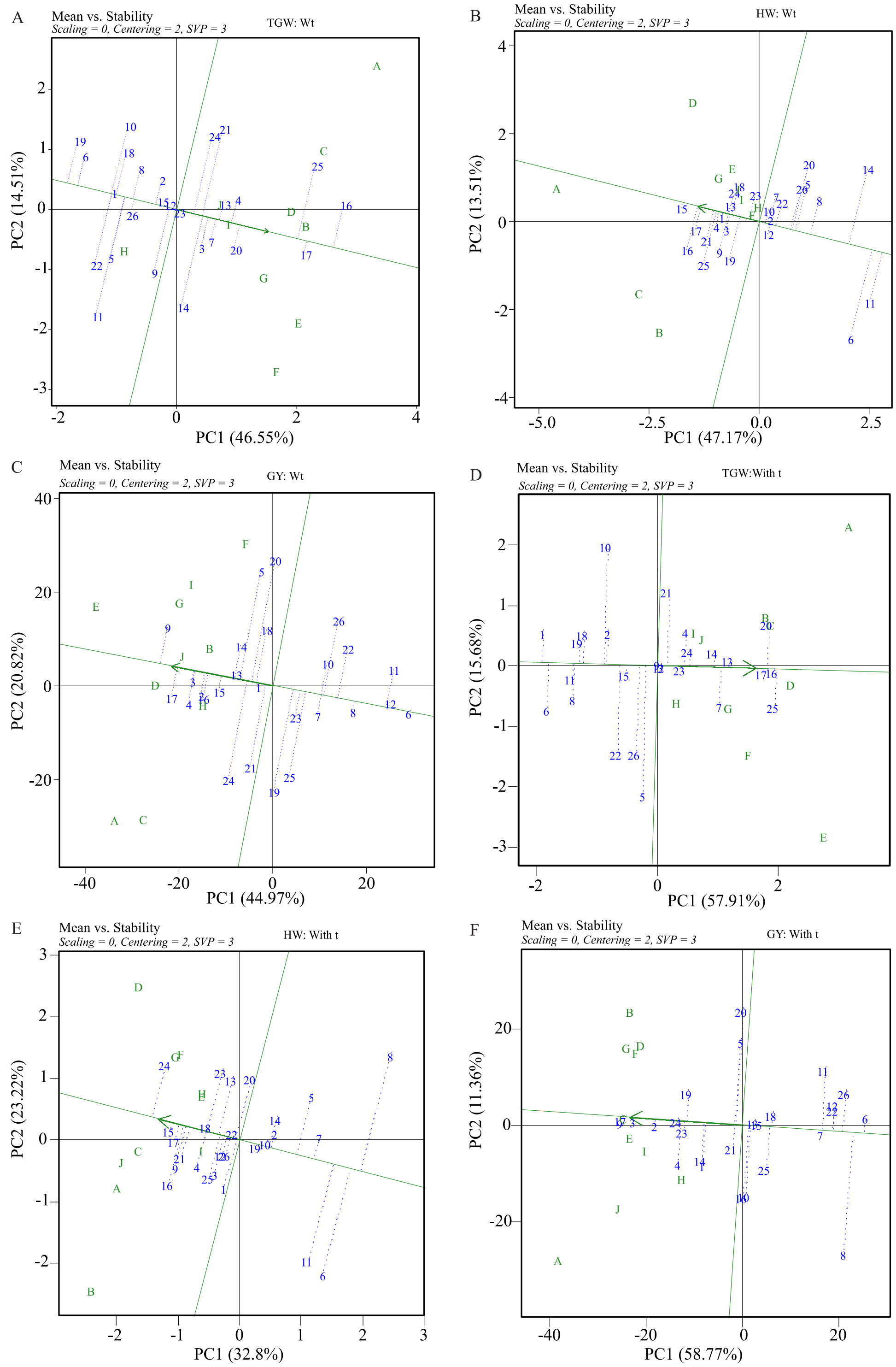

Figure 1. GGE biplot for thousand grain weight (TGW, g), hectoliter weight (HW, g 250 cm^{-3}) and grain yield (GY, kg ha^{-1}) of white oat (*Avena sativa*) in crops without and with the use of tebuconazole fungicide in 10 years of cultivation (2008 to 2017), performed in the municipality of Augusto Pestana, RS, Brazil, in relation to: TGW in management without fungicide (A); HW in management without fungicide (B); GY in management without fungicide (C); TGW in management with fungicide (D); HW in management with fungicide (E); and GY in management with fungicide (F). Biplot based on singular data decomposition standardized by genotypes. Environment: 2008 (A), 2009 (B), 2010 (C), 2011 (D), 2012 (E), 2013 (F), 2014 (G), 2015 (H), 2016 (I), 2017 (J). The name of the 26 genotypes (cultivars) is described in the material and methods

with fungicide application, has similar potential to the one regarding management without fungicide, with a greater contribution of the first factor (Figure 2D), while for genotypes 'IPR Afrodite' and 'URS Corona', there is a balance in the contribution of the first and second factor. Genotype 'URS Corona', however, was not selected in the environment without the use of fungicides, but showed positive responses when evaluated in environments with the use of fungicides. Thus, it can be inferred that the genotype presents specific adaptability for the use of fungicides, since it expresses positive potential in these environments.

Pearson's linear correlation is a way of analyzing the relationship between two variables, given by coefficients that indicate the direction and magnitude of the correlation that can vary from -1 to 1, and when the coefficient is closest to 1, that indicates maximum positive correlation between variables (Carvalho et al., 2018; Loro et al., 2021). The reduction of the minimum, average and maximum temperature allied to the increase of relative humidity of the air influences the increase of the plant lodging (Figure 3). Stem rust, leaf spot, days from flowering to maturation, days from emergence to flowering, days from emergence to maturation and plant height are positively correlated with lodging. The increase in minimum, medium, maximum temperature and radiation, combined with the reduction of leaf spot, stem rust and leaf rust, influence the increase in the thousand grain weight.

To increase the hectoliter weight, it is necessary to reduce stem rust and leaf rust and to increase the minimum, medium, maximum temperature, radiation, thousand grain weight, days from flowering to ripening, days from emergence to flowering, days from emergence to maturation and grain yield. The reduction of stem rust, leaf rust and leaf spot, together with the increase in minimum, medium, maximum temperature, radiation, thousand grain weight, days from flowering to ripening, days from emergence to flowering and days from emergence to ripening influence the increase in grain yield. Verdi et al. (2019) evidenced different results, where they identified negative relationships between emergence to flowering and flowering to maturity sub-periods with grain yield.

Leaf spot is directly influenced by the increase in relative air humidity and inversely influenced by the minimum, average, maximum temperature and radiation. The increase in leaf rust reduces the hectoliter weight, grain yield and thousand grain weight. In addition, the increase in minimum, medium, maximum

Table 3. Genetic gain predicted by multitrait genotype-ideotype distance index (MGIDI) analysis in white oat (*Avena sativa*) traits in crops with and without the use of tebuconazole fungicide in 10 years of cultivation (2008 to 2017), in the municipality of Augusto Pestana, RS, Brazil(1).

Traits	Factor	Xo	Xs	SD	Sdperc	H^2	SG	Sgperc	Sense	Goal
						Without tebuconazole				
LR (%)	FA 1	44.8	38.1	-6.68	-14.9	0.303	-2.02	-4.52	Reduce	100
SR (%)	FA 1	16.2	12.2	-4.05	-25	0.298	-1.21	-7.45	Reduce	100
LS (%)	FA 1	30.3	24.8	-5.52	-18.2	0.261	-1.44	-4.75	Reduce	100
GY (kg ha^{-1})	FA 1	1,866	2,081	215	11.5	0.342	73.7	3.95	Increase	100
TGW (g)	FA 1	27	28.6	1.54	5.68	0.383	0.588	2.17	Increase	100
HW (g 250 cm^{-3})	FA 1	43	43.6	0.583	1.35	0.201	0.117	0.272	Icrease	100
LOD (%)	FA 2	75.9	65	-10.9	-14.4	0.196	-2.14	-2.82	Reduce	100
						With tebuconazole				
LR (%)	FA 1	19.4	16.3	-3.09	-16	0.129	-0.4	-2.07	Reduce	100
SR (%)	FA 1	6.7	5.89	-0.812	-12.1	0.265	-0.215	-3.21	Reduce	100
LS (%)	FA 1	14.9	12.2	-2.71	-18.1	0.189	0.512	-3.43	Reduce	100
GY (kg ha^{-1})	FA 1	2,905	3,330	426	14.7	0.383	163	5.62	Increase	100
TGW (g)	FA 1	31.2	32.5	1.29	4.14	0.397	0.513	1.65	Increase	100
HW (g 250 cm^{-3})	FA 1	48.3	49.3	0.991	2.05	0.134	0.133	0.275	Increase	100
LOD (%)	FA 2	54.1	46.3	-7.86	-14.5	0.324	-2.55	-4.71	Reduce	100

(1)Xo, observed average; Xs, target average; SD, standard deviation; Sdperc, standard deviation percentage; H^2, heritability; SG, selection of genetic gain; Sgperc, percentage selection of genetic gain; LR, leaf rust; SR, stem rust; LS, leaf spot; GY, grain yield; TGW, thousand grain weight; HW, hectoliter weight; LOD, lodging.

temperature and radiation combined with the reduction of relative humidity influence the reduction of leaf rust.

The regression tree is used for solving problems of a quantitative nature in which it identifies patterns for creating groups. In this way, it is possible to identify the size and productivity of the group as well as the characteristics that gave rise to it. Therefore, the regression tree had 43 nodes and 23 population groups (Figure 4).

In conditions of leaf rust lower than 15%, followed by height greater than 93 cm, relative humidity greater

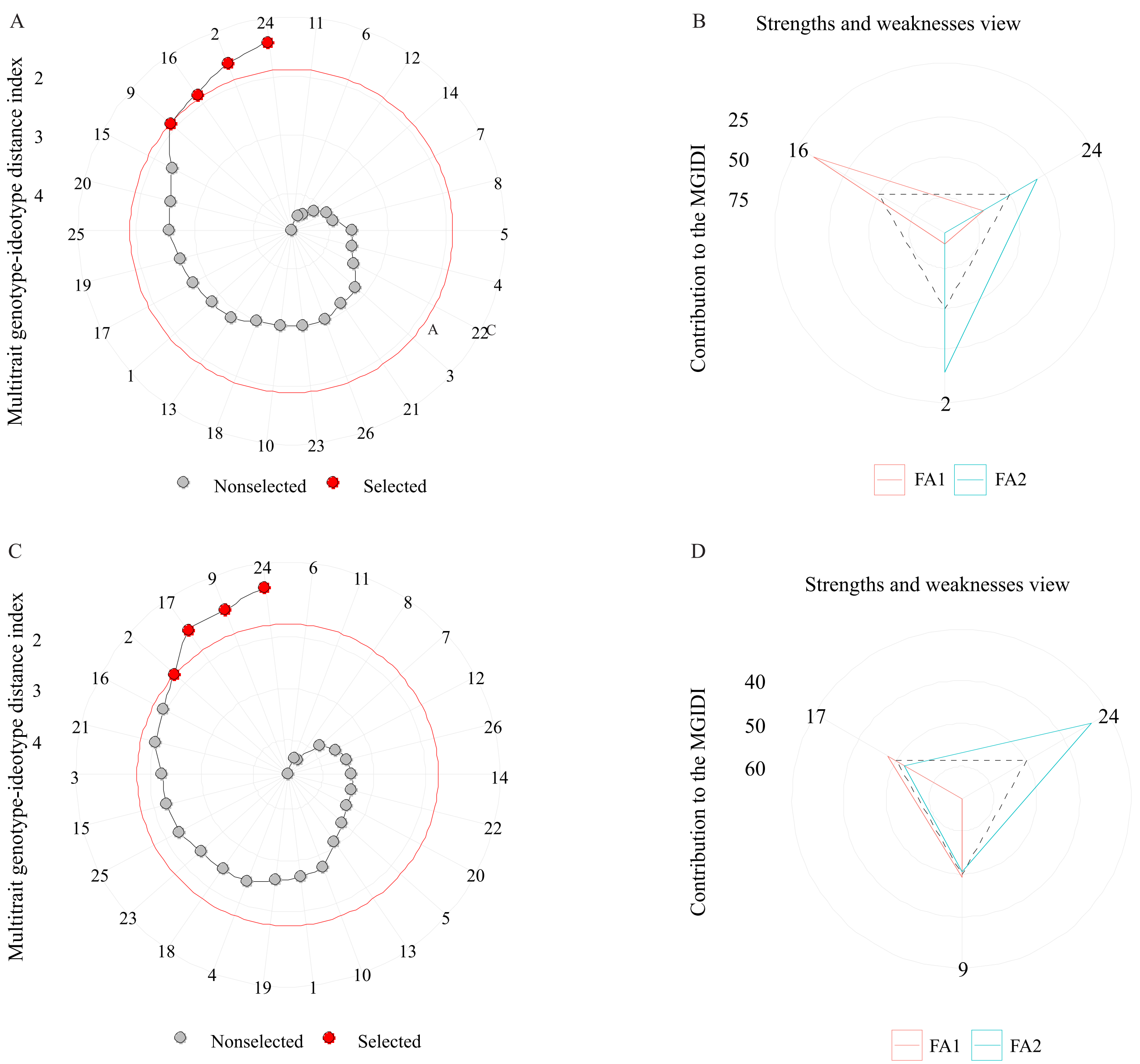

Figure 2. Multitrait selection of white oat (*Avena sativa*) genotypes by MGIDI (A) and visualization of strengths and weaknesses of genotypes (B) in management without tebuconazole fungicide in 10 years of cultivation (2008 to 2017) and multitrait selection of white oat genotypes by MGIDI (C) and visualization of the strengths and weaknesses of the genotypes (D) in the management with tebuconazole in 10 years of cultivation (2008 to 2017) – performed in the municipality of Augusto Pestana, RS, Brazil.Genotypes: Barbarasul (1), Brisasul (2), Carlasul (3), Chiarasul (4), Dilmasul (5), Fapa 4 (6), Guapa (7), IAC 7 (8), Afrodite (9), Louise (10), UPF 18 (11), Temprama (12), Gaudéria (13), Ouro (14), URS 21 (15), Charrua (16), Corona (17), Estampa (18), Fapa Slava (G19), Guará (20), Guria (21), Penca (22), Tarimba (23), Taura (24), Torena (25), URS 22 (26).

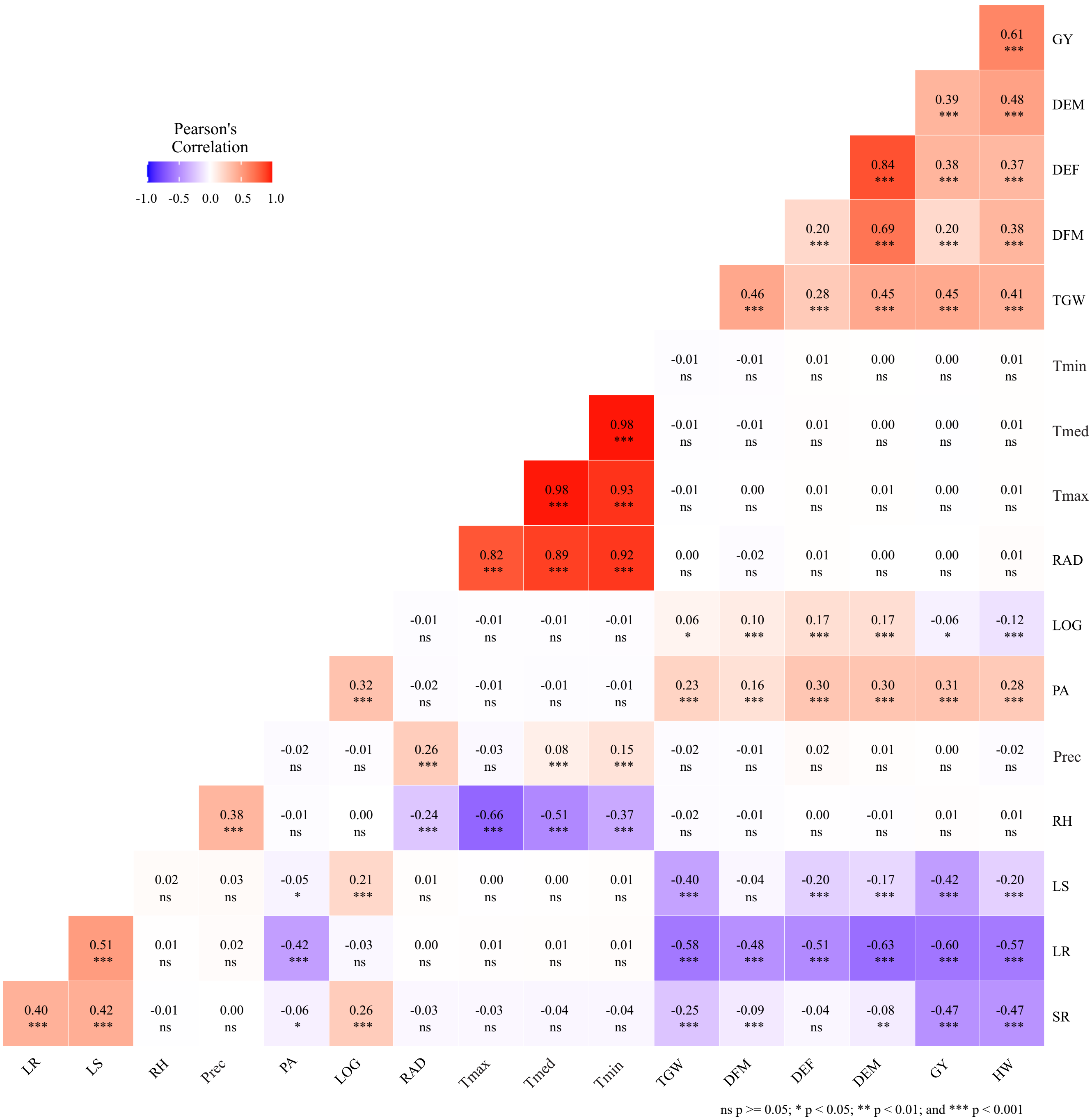

Figure 3. Pearson's linear correlation estimates between disease incidence variables, meteorological, phenological, morphological and productive variables of 26 white oat (*Avena sativa*) genotypes cultivated without and with the use of tebuconazole fungicide in 10 years of cultivation (2008 to 2017) – performed in the municipality of Augusto Pestana, in the state of Rio Grande do Sul, Brazil. Pearson's linear correlation coefficient (n = 1,560) significant at 5% probability by the T test; SR (%), stem rust; LR (%), leaf rust; LS (%), leaf spot; Tmax (°C), maximum temperature; Rad (MJ m^{-2} per day), solar radiation; Tmed (°C), medium temperature; Tmin (°C), minimum temperature; TGW (g), thousand grain weight; DFM, days from flowering to maturation; DEF, days from emergence to flowering; DEM, days from emergence to maturation; GY (kg ha^{-1}), grain yield; HW (g 250 cm^{-3}), hectoliter weight; Prec (mm), precipitation; RH (%), relative humidity air; PA (cm), plant architecture; LOG (%), lodging.

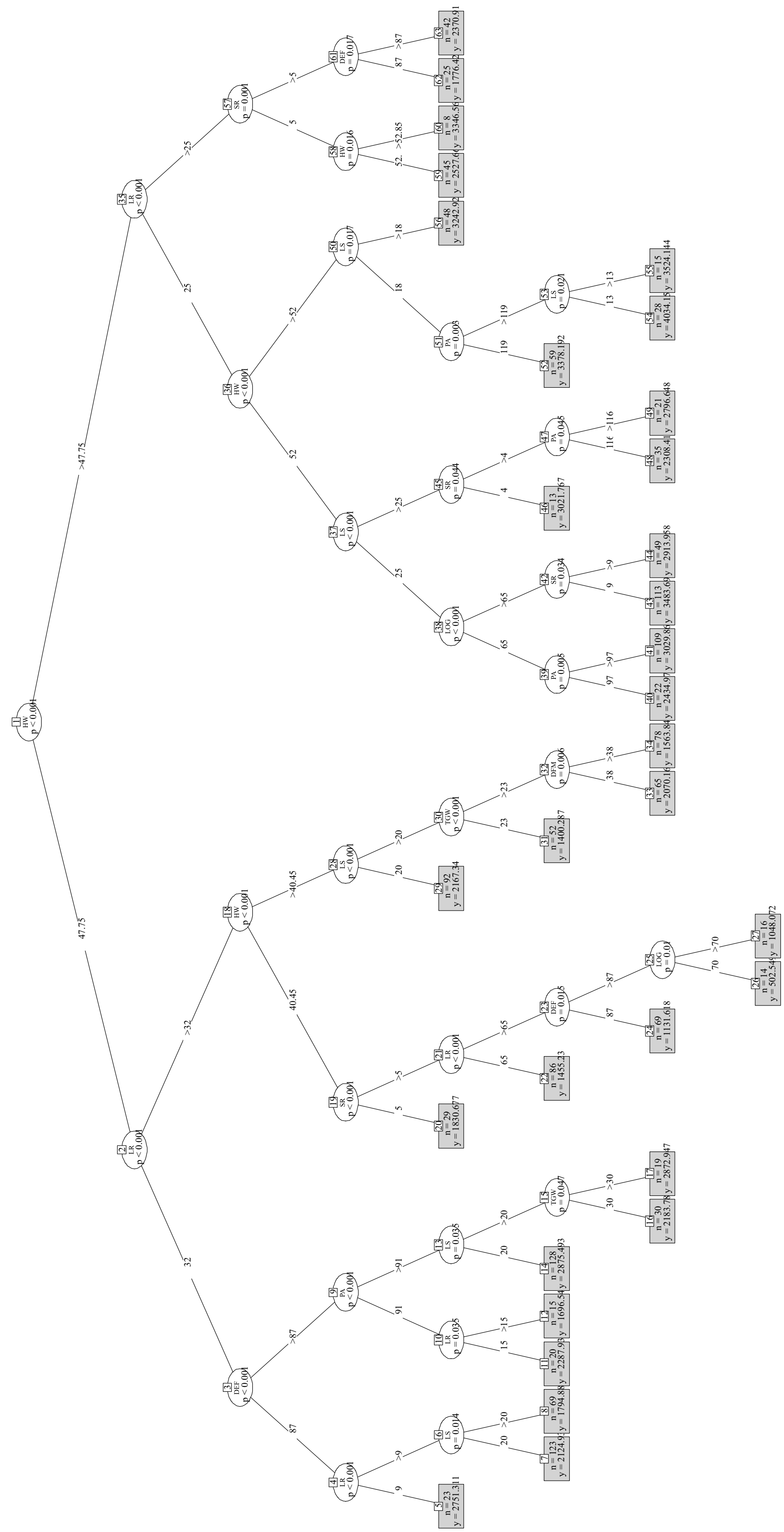

Figure 4. Regression tree for the dependent variable grain yield of white oat (*Avena sativa*) in environments with and without the use of tebuconazole fungicide in 10 years of cultivation (2008 to 2017). Branches indicate the independent variables leaf rust (LR, %), stem rust (SR, %), plant architecture (PA, cm), days from emergence to maturation (DEM), relative air humidity (RH, %), thousand grain weight (TGW, g), radiation (Rad, MJ m^{-2} per day), leaf spot (LS, %) and lodging (LOD, %) – performed in the municipality of Augusto Pestana, RS, Brazil.

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than 70.75%, stem rust lower than or equal to 9%, and days from emergence to maturation greater than 116 days, the largest population class (n) was identified – it had 302 experimental plots and its average grain yield (y) was 3,131 kg ha^{-1}.

The class with high grain yield (y) was observed in a contrasting condition in which leaf rust was greater than 32%, stem rust was less than or equal to 1%, and thousand grain weight was greater than 24.8 grams, and productivity of 3,030 kg ha^{-1} was obtained. The highest grain yield was observed in conditions with an incidence of lower leaf rust of 15%, height greater than 93 cm and relative humidity of less than 70.75%. In these conditions, 3,617 kg ha^{-1} of grain yield (y) was observed and those conditions were identified in 76 experimental units.

The results show the response of white oat genotypes in ten years of cultivation, which provides greater accuracy in the selection of the main genotypes. Thus, due to variations in meteorological conditions, genotypes with superiority and predictability for the variables studied can be evidenced and, therefore, used as parents in genetic improvement programs or cultivated in production units. Thus, it will be possible to develop genotypes that are predictable under current weather conditions, and therefore guarantee the progress of the development of plants capable of adapting to ensure productivity, mainly of grains. Thus, this study contributes to mitigating one of the main global concerns related to changes in meteorological variables and the guarantee of food production.

Conclusions

1. 'URS Corona' is a white oat (*Avena sativa*) genotype that should be indicated for cultivation in the environment with tebuconazole fungicide application, since, over ten years, it has presented excellent responses that characterize it as the ideal genotype – while the 'Brisasul', 'IPR Afrodite', and 'URS Taura' genotypes must be placed in environments without tebuconazole fungicide.

2. Based on multitraits, the 'URS Taura' and 'IPR Afrodite' genotypes can be placed in environments with or without use of tebuconazole.

3. Cultivation with the fungicide tebuconazole promotes superior heritability for thousand-grain mass and grain yield over ten years of cultivation.

4. Genotypes with an incidence of rust lower than 15%, height greater than 93 cm, in an environment with relative humidity lower than 70.75%, have a higher grain yield regardless of the use of fungicide.

5. Greater magnitudes of air temperature and solar radiation result in higher grain yield of white oats, regardless of the use of fungicide.

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References

CARVALHO, I.R.; NARDINO, M.; DEMARI, G.H.; BAHRY, C.A.; SZARESKI, V.J.; PELISSARI, G.; FERRARI, M.; PELEGRIN, A.J. de; OLIVEIRA, A.C. de; MAIA, L.C. da; SOUZA, V.Q. de. Bi-segmented regression, factor analysis and AMMI applied to the analysis of adaptability and stability of soybean. **Australian Journal of Crop Science**, v.10, p.1410-1416, 2016. DOI: https://doi.org/10.21475/ajcs.2016.10.10.pne63.

CARVALHO, I.R.; SZARESKI, V.J.; MAMBRIN, R.B.; FERRARI, M.; PELEGRIN, A.J.; ROSA, T.C. da; PETER, M.; SILVEIRA, D.C.; CONTE, G.G.; BARBOSA, M.H.; SOUZA, V.Q. de. Biometric models and maize genetic breeding: a review. **Australian Journal of Crop Science**, v.12, p.1796-1805, 2018. DOI: https://doi.org/10.21475/ajcs.18.12.11.p792.

CONAB. Companhia Nacional de Abastecimento. **Safra brasileira de grãos**. 2022. Available at: <https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de graos/item/download/28484_9a9ee12328baa359b3708d64e774e5d8>. Accessed on: Sept. 20 2021.

DORNELLES, E.F.; SILVA, J.A.G. da; COLET, C. de F.; FRAGA, D. da R.; PANSERA, V.; ALESSI, O.; CARVALHO, I.R.; LAUTENCHLEGER, F.; ROSA, J.A. da; WARMBIER, E.; JUNG, M.S.; POLANCZYK, A.K. The efficiency of Brazilian oat cultivars in reducing fungicide use for greater environmental quality and food safety. **Australian Journal of Crop Science**, v.15, p.1058-1065, 2021. DOI: https://doi.org/10.21475/ajcs.21.15.07.p3175.

DYULGEROVA, B.; SAVOVA, T. Genotype by environment interaction for grain yield in winter oat. **Bulgarian Journal of Agricultural Science**, v.26, p.992-997, 2020.

FAO. Food and Agriculture Organization of the United Nations. **Save and Grow**. 2020. Available at: <http://www.fao.org/ag/save-and-grow/MRW/index_en.html>. Accessed on: May 10 2023.

HOWARTH, C.J.; MARTINEZ-MARTIN, P.M.J.; COWAN, A.A.; GRIFFITHS, I.M.; SANDERSON, R.; LISTER, S.J.; LANGDON, T.; CLARKE, S.; FRADGLEY, N.; MARSHALL, A.H. Genotype and environment affect the grain quality and yield of winter oats (*Avena sativa* L.). **Foods**, v.10, art.2356, 2021. DOI: https://doi.org/10.3390/foods10102356.

KIM, I.-S.; HWANG, C.-W.; YANG, W.-S.; KIM, C.-H. Multiple antioxidative and bioactive molecules of oats (*Avena sativa* L.) in human health. **Antioxidants**, v.10, art.1454, 2021. DOI: https://doi.org/10.3390/antiox10091454.

LORO, M.V.; CARVALHO, I.R.; SILVA, J.A.G. da; MOURA, N.B.; HUTRA, D.J.; LAUTENCHLEGER, F. Artificial intelligence and multiple models applied to phytosanitary and nutritional aspects that interfer in the physiological potential of soybean seeds. **Brazilian Journal of Agriculture**, v.96, p.324-338, 2021. DOI: https://doi.org/10.37856/bja.v96i1.4258.

MORKELIŪNĖ, A.; RASIUKEVIČIŪTĖ, N.; VALIUŠKAITĖ, A. Meteorological conditions in a temperate climate for *Colletotrichum acutatum*, strawberry pathogen distribution and susceptibility of different cultivars to anthracnose. **Agriculture**, v.11, art.80, 2021. DOI: https://doi.org/10.3390/agriculture11010080.

NASA POWER. National Aeronautics and Space Administration. **NASA Prediction of Worldwide Energy Resources**. 2022. Available at: <https://power.larc.nasa.gov/>. Accessed on: May 10 2023.

NAZARENO, E.S.; LI, F.; SMITH, M.; PARK, R.F.; KIANIAN, S.F.; FIGUEROA, M. *Puccinia coronata* f. sp. *avenae*: a threat to global oat production. **Molecular Plant Pathology**, v.19, p.1047-1060, 2018. DOI: https://doi.org/10.1111/mpp.12608.

OLIVEIRA NETO, S.S. de; ZEFFA, D.M.; ARRUDA, K.M.A.; RIEDE, C.R. White oat agronomic performance and cultivar reactions to leaf rust and leaf spot. **Agronomy Science and Biotechnology**, v.5, p.24-31, 2019. DOI: https://doi.org/10.33158/ASB.2019v5i1p24.

OLIVOTO, T.; LÚCIO, A.D.C. metan: an R package for multi-environment trial analysis. **Methods in Ecology and Evolution**, v.11, p.783-789, 2020. DOI: http://doi.org/10.1111/2041-210X.13384.

OLIVOTO, T.; NARDINO, M. MGIDI: toward an effective multivariate selection in biological experiments. **Bioinformatics**, v.37, p.1383-1389, 2021. DOI: https://doi.org/10.1093/bioinformatics/btaa981.

R CORE TEAM. **R**: a language and environment for statistical computing. Viena: R Foundation for Statistical Computing, 2022. Available at: <https://www.R-project.org/>. Accessed on: May 10 2023.

RESENDE, M.D.V. de; DUARTE, J.B. Precisão e controle de qualidade em experimentos de avaliação de cultivares. **Pesquisa Agropecuária Tropical**, v.37, p.182-194, 2007. Available at: <https://www.revistas.ufg.br/pat/article/view/1867>. Accessed on: May 11 2023.

ROTHER, V.; VERDI, C.A.; THUROW, L.B.; CARVALHO, I.R.; OLIVEIRA, V.F. de; MAIA, L.C. da; VENSKE, E.; PEGORARO, C.; OLIVEIRA, A.C. de. Uni-and multivariate methods applied to the study of the adaptability and stability of white oat. **Pesquisa Agropecuária Brasileira**, v.54, e00656, 2019. DOI: https://doi.org/10.1590/S1678-3921.pab2019.v54.00656.

SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.Á. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; ARAÚJO FILHO, J.C. de; OLIVEIRA, J.B. de; CUNHA, T.J.F. **Sistema brasileiro de classificação de solos**. 5.ed. rev. e ampl. Brasília: Embrapa, 2018. 356p.

SILVA, J.A.G. da; WOHLENBERG, M.D.; ARENHARDT, E.G.; OLIVEIRA, A.C. de; MAZURKIEVICZ, G.; MÜLLER, M.; ARENHARDT, L.G.; BINELO, M.O.; ARNOLD, G.; PRETTO, R. Adaptability and stability of yield and industrial grain quality with and without fungicide in Brazilian oat cultivars. **American Journal of Plant Sciences**, v.6, p.1560-1569, 2015. DOI: https://doi.org/10.4236/ajps.2015.69155.

VERDI, C.; ROTHER, V.; CARVALHO, I.R.; THUROW, L.B.; NORNBERG, R.; OLIVEIRA, V.F. de; MAIA, L.C. da; OLIVEIRA, A.C. de. Path analysis on traits associated with oat milling yield. **Communications in Plant Sciences**, v.9, p.59-65, 2019. DOI: https://doi.org/10.26814/cps20190010.

WICKHAM, H. **ggplot2**: Elegant Graphics for Data Analysis. New York: Springer-Verlag, 2016. Available at: <https://ggplot2.tidyverse.org>. Accessed on: May 10 2023.

WOYANN, L.G.; BENIN, G.; STORCK, L.; TREVIZAN, D.M.; MENEGUZZI, C.; MARCHIORO, V.S.; TONATTO, M.; MADUREIRA, A. Estimation of missing values affects important aspects of gge biplot analysis. **Crop Science**, v.57, p.40-52, 2017. DOI: https://doi.org/10.2135/cropsci2016.02.0100.

YAN, W.; KANG, M.S.; MA, B.; WOODS, S.; CORNELIUS, P.L. GGE biplot vs. AMMI analysis of genotype-by-environment data. **Crop Science**, v.47, p.643-655, 2007. DOI: https://doi.org/10.2135/cropsci2006.06.0374.

ZIELKE, C.; KOSIK, O.; AINALEM, M.-L.; LOVEGROVE, A.; STRADNER, A.; NILSSON, L. Characterization of cereal β-glucan extracts from oat and barley and quantification of proteinaceous matter. **PLoS ONE**, v.12, e0172034, 2017. DOI: https://doi.org/10.1371/journal.pone.0172034.