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Management alternatives for winter cereals: effects on the agronomic components of white oats and wheat

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Abstract

This study was developed in order to propose and validate alternative management strategies to increase the productivity of white oat and wheat through the evaluation of agronomic components. Field experiments were carried out during the 2022 and 2023 fall/winter seasons in a randomized block design with three replicates, structured in four phases. Phases 1 and 2 compared the performance of white oat genotypes (URS Brava, IDR Artemis, URS Corona, and URS Taura). Phase 3 evaluated 15 treatments in white oat, combining fungal control agents, plant growth-promoting bacteria (e.g., *Bacillus* spp., *Azospirillum brasilense*, *Pseudomonas fluorescens*), phytohormones (e.g., indoleacetic acid), and fungicides. Phase 4 tested eight similar treatments in wheat. Standard sowing density, fertilization, and crop management practices were followed. Phytosanitary treatments were applied with a CO_2-pressurized backpack sprayer. Each phase was analyzed separately using ANOVA, with significance assessed via the F test (5 % level), and means compared using Duncan's test. In Phases 1 and 2, genotype significantly affected most variables, except grains per panicle (2022–2023) and panicle insertion height (2023). In Phases 3 and 4, fungal and growth promoter treatments significantly affected all evaluated variables in both species. Among the oat cultivars, IDR Artemis reached the highest yield in years with low lodging probability, while URS Corona exhibited lower lodging and high grain mass under lodging-prone conditions. Management alternatives influenced agronomic traits in both crops, though no significant effects were observed on final grain yield. These findings highlight the potential of genotype selection and integrated management to optimize oat and wheat performance.

Keywords: Genotype performance evaluation. Growth-promoting treatments. Fungal disease control. Crop management.

Introduction

Cereals play a fundamental role in the economy, due to their nutritional value, wide use, and contribution to the quality of agricultural systems. Among them, wheat (*Triticum aestivum* L.) stands out historically for its suitability for breadmaking, long post-harvest durability and high environmental adaptability (INNES *et al.*, 2015; RADDATZ *et al.*, 2023). White oats (*Avena sativa* L.), in turn, are the winter cereal with the best nutritional quality, being rich in soluble fibers, such as β-glucan, and in oleic and linoleic fatty acids (HAWERROTH *et al.*, 2015; CRESTANI *et al.*, 2010). In addition, these crops contribute with significant amount of straw with a high carbon/nitrogen ratio, which provides biological benefits and soil cover for long periods after harvest (MANTAI *et al.*, 2016).

These factors highlight the importance of these cereals as contributors to sustainable agricultural practices. Sustainable agriculture is necessary to maintain farmers' livelihoods and to sustain long-term food and nutritional security (PAWLAK, KOLODZIEJCZAK, 2020). Therefore, to maximize grain productivity potential, adjustments and management techniques are necessary, such as genotype selection, adequate soil nutrient supply, and product positioning for phytosanitary applications, considering the economic cost of production. In this context, the addition of biological and non-synthetic products that act synergistically and reduce the use of chemicals already used in the production system is a way to increase production efficiency (DERESA, DIRIBA, 2023).

Low levels of nitrogen fertilization, poor weed management, thermal and water stresses, as well as losses due to lodging and incidence of phytopathogens are the main causes of reduced productive efficiency of autumn/winter cereals (HOCHMAN, HORAN, 2018; BELACHEW *et al.*, 2022). Among these factors, lodging directly compromises the harvest by affecting both grain yield and quality, caused by stem breakage or bending (HAWERROTH *et al.*, 2015; MULSANTI *et al.*, 2018). Similarly, phytopathogens cause serious problems for cereals, affecting various parts of the plant, in addition to secreting several types of mycotoxins, such as aflatoxin and deoxynivalenol, resulting in post-harvest losses (SHABANA *et al.*, 2017; JIMÉNEZ-REYES *et al.*, 2019). In this scenario, chemical fungicides are widely used to control phytopathogens, but the repeated use of the same molecule without association with multi-site fungicides can favor the selection of resistant isolates, making disease control difficult and increasing production costs (DERESA, DIRIBA, 2023).

An economically and environmentally viable possibility to overcome these problems is the association of plant growth-promoting rhizobacteria (PGPR) and non-synthetic products in production systems. PGPR (e.g., *Bacillus*, *Azospirillum*, *Pseudomonas*) have gained prominence as an alternative to reduce the use of chemical fertilizers, especially nitrogen and phosphate fertilizers, meeting the demands of agricultural and environmental development (MITRA *et al.*, 2021; IGIEHON, BABALOLA, 2017). Their recommendation alone or in conjunction with phytohormones, as long as accompanied by growth regulators to prevent lodging, may be a viable practice to increase grain yield. Furthermore, specific strains of these bacteria and non-synthetic products (e.g., ethoxylated alcohol and calcium polysulfide), if they demonstrate fungicidal aptitude, may be applied via foliar as a complement to chemical fungicides, being useful in managing fungal resistance as they normally present multisite action (LI *et al.*, 2018; ZEISLER-DIEHL *et al.*, 2022).

Given the above, this study was developed in order to propose and validate alternative management strategies that contribute to increasing the productivity of white oats and wheat, based on the evaluation of agronomic components.

Material and methods

The experiments were carried out in 2022 and 2023, during the fall/winter growing season, at Escola Fazenda of Regional University of Northwestern Rio Grande do Sul, located in the municipality of Augusto Pestana-RS (28º26’20.4” S, 54º00’22.7” W, altitude of 286 m). The soil in the area is classified as typical dystrophic red latosol (SANTOS *et al.*, 2018), while the climate is characterized as Cfa - humid subtropical (ALVARES *et al.*, 2014). The trials on wheat and white oat crops were performed in four distinct phases, all using a randomized block design with treatments arranged in three replicates. For both crops, the experimental units consisted of 34 seeding rows spaced at 0.17 m, totaling 23.12 m^2.

Phases 1 and 2 of the study consisted of a performance comparison of white oat genotypes. In 2022, four white oat genotypes were evaluated (URS Brava, IDR Artemis, URS Corona and URS Taura), while in 2023 only the first three genotypes were used. The white oat crop was sown in the second half of May of the respective years, with a sowing density of 50 seeds per linear meter. The base fertilization was carried out with 150 kg ha^{-1} of the formulated fertilizer 10-20-20 and a topdressing application of urea, carried out at stage 21 of the scale of Zadoks *et al.* (1974).

In *Phase 3*, regarding the evaluation of fungal treatments and growth promoters in the white oat crop in the 2023 harvest, the following treatments were applied (Table 1).

In *Phase 4*, of the evaluation of fungal treatments and growth promoters in wheat crops in the 2023 harvest, the following treatments were applied (Table 2).

To evaluate fungal treatments and growth promoters in white oat crops, the URS Taura cultivar was sown in the second half of 2023, with a seeding density of 50 seeds per linear

Table 1. Composition, concentration, and dosage of treatments evaluated in white oat.

Treatment	Composition/Strain	Concentration	Dosage[1]
T1	Ethoxylated fatty alcohol	11 % v v^{-1}	1000
T2	*Bacillus aryabhattai* (CBMAI1120)	2.1×10^{12} viable endospores L^{-1}	200
	Bacillus haynesii (CCT7926)	8.8×10^{11} viable endospores L^{-1}	200
	Bacillus circulans (CCT0026)	3.0×10^{11} viable endospores L^{-1}	200
T3	*Azospirillum brasilense* (Ab-V6) + *Pseudomonas fluorescens* (CCTB03)	1×10^{8} CFU mL^{-1}	200
T4	*Bacillus subtilis* (BV02)	3×10^{9} CFU mL^{-1}	2000
T5	*Bacillus subtilis* (BV02) + Hydrogen peroxide	3×10^{9} CFU mL^{-1} + H_2O_2 30 % v v^{-1}	2000 + 200
T6	*Bacillus amyloliquefaciens* (CNPSo3202)	2.1×10^{11} viable endospores L^{-1}	1000
	Bacillus velezensis (CNPSo3602)	1.2×10^{11} viable endospores L^{-1}	1000
	Bacillus thuringiensis (CNPSo3915)	1.9×10^{11} viable endospores L^{-1}	1000
T7	*Bacillus licheniformis* (CCTB07)	1×10^{8} CFU mL^{-1}	1000
T8	*Bacillus pumilus* (CCTB05) + *B. subtilis* (CCTB04) + *B. amyloliquefaciens* (CCTB09)	1×10^{8} CFU mL^{-1}	200
T9	*B. subtilis* (CCTB04)	1.5×10^{11} viable endospores L^{-1}	400
	B. velezensis (CCTB09)	1.2×10^{11} viable endospores L^{-1}	400
	B. pumilus (CCTB05) + Indoleacetic acid ($C_{10}H_9NO_2$)	1.9×10^{11} viable endospores L^{-1} + IAA	400 + 400
	Picoxystrobin ($C_{18}H_{16}F_3NO_4$) + Cyproconazole ($C_{15}H_{18}ClN_3O$)	200 g L^{-1} + 80 g L^{-1}	400
T10	Similar to T9 without indoleacetic acid	–	400
T11	Calcium polysulfide	50 % S, 5 % Ca v v^{-1}	1000
T12	Hydrogen peroxide	30 % v v^{-1}	200
T13	Picoxystrobin + Cyproconazole	200 g L^{-1} + 80 g L^{-1}	400
T14	Absolute control (no fungal treatments)	–	–
T15	Indoleacetic acid ($C_{10}H_9NO_2$)	–	400

[1] mL ha^{-1}; CFU: colony forming unit; H_2O_2: hydrogen peroxide; IAA: indolacetic acid; S: sulfur; Ca: calcium.
Source: authors (2025).

Table 2. Composition, concentration, and dosage of treatments evaluated in white oat.

Treatment	Composition/Strain	Concentration	Dosage[1]
TI	*Bacillus amyloliquefaciens* (CNPSo3202)	2.1×10^{11} viable endospores L^{-1}	1000
	Bacillus velezensis (CNPSo3602)	1.2×10^{11} viable endospores L^{-1}	1000
	Bacillus thuringiensis (CNPSo3915)	1.9×10^{11} viable endospores L^{-1}	1000
TII	*Bacillus licheniformis* (CCTB07)	1×10^{8} CFU mL^{-1}	1000
TIII	*Bacillus pumilus* (CCTB05) + *Bacillus subtilis* (CCTB04) + *Bacillus amyloliquefaciens* (CCTB09)	1×10^{8} CFU mL^{-1}	200
TIV	*Bacillus subtilis* (CCTB04)	1.5×10^{11} viable endospores L^{-1}	400
	Bacillus velezensis (CCTB09)	1.2×10^{11} viable endospores L^{-1}	400
	Bacillus pumilus (CCTB05)	1.9×10^{11} viable endospores L^{-1}	400
TV	*Bacillus subtilis* (CCTB04)	1.5×10^{11} viable endospores L^{-1}	400
	Bacillus velezensis (CCTB09)	1.2×10^{11} viable endospores L^{-1}	400
	Bacillus pumilus (CCTB05) + Indoleacetic acid ($C_{10}H_9NO_2$) + Picoxystrobin ($C_{18}H_{16}F_3NO_4$) + Cyproconazole ($C_{15}H_{18}ClN_9O$)	1.9×10^{11} viable endospores L^{-1}; 200 g L^{-1} + 80 g L^{-1}	400 + 400 + 400
TVI	Picoxystrobin + Cyproconazole (control with fungicide application)	200 g L^{-1} + 80 g L^{-1}	400
TVII	Absolute control (no fungal treatments)	–	–
TVIII	Indoleacetic acid ($C_{10}H_9NO_2$)	–	400

[1] mL ha^{-1}; CFU: colony forming unit; IAA: indolacetic acid.
Source: authors (2025).

meter. Base fertilization consisted of 150 kg ha^{-1} of 10-20-20 formulated fertilizer and one application of urea as topdressing, carried out at stage 21 on the Zadoks *et al.* (1974) scale. Wheat sowing was carried out in the first half of June 2023, applying 200 kg ha^{-1} of 10-20-20 formulated fertilizer at the seeding base and 150 kg ha^{-1} of urea (45 % N) in two applications (beginning of tillering and beginning of elongation), respectively at stages 21 and 31 on the Zadoks *et al.* (1974) scale. The wheat cultivar mix XBIO Fusão (TBIO Audaz + TBIO Sagaz) was used, with a density of 80 seeds per linear meter. The applications of phytosanitary products and growth promoters were carried out with a CO_2-pressurized backpack sprayer, with a spray volume of 100 L ha^{-1} and constant pressure, with three applications of fungal treatments and one application of indoleacetic acid at stage 21 (ZADOKS *et al.*, 1974).

In order to aid in understanding the results obtained, the meteorological variables minimum, mean and maximum air temperature (in ºC) and precipitation (in mm) were extracted for the duration of the crop cycle in each year (INMET, 2025). Evaluations of plant height (PH, cm), panicle insertion height (PIH, cm), and lodging (LOD, %) were performed only in the white oat crop. The PH and PIH variables were obtained with a graduated ruler, while the lodging percentage was determined visually. The variables analyzed for both crops in the experiment were the number of grains per plant (NGP, units), grain weight per plant (GWP, g), thousand grain weight (TGW, g) and grain yield (GY, kg ha^{-1}). The TGW variable was determined based on 200 grains per experimental unit, while GY was measured through the total harvest of the plot, with the exception of the two end rows, with grain moisture corrected to 13 %.

The data obtained were subjected to the assumptions of normality of errors, homogeneity of variances and independence of errors by the Shapiro-Wilk, Bartlett and Durbin-Watson tests, respectively. Once the assumptions were met, individual variance analysis was performed for each experimental phase, with the results supported by the F test at 5 % probability. The variables that presented a significant effect of the treatments were subjected to the Duncan mean comparison test, at 5 % probability. All analyses were performed with the AgroR package (SHIMIZU *et al.*, 2024), using R software (R CORE TEAM, 2025).

Results and discussion

Meteorological covariates

The meteorological conditions for the years 2022 and 2023 (Figure 1) had mean air temperature below 20 °C during the months of August and September. Innes *et al.* (2015) reported that the optimal temperatures for wheat during the reproductive stages (terminal spikelet, anthesis and grain filling) are approximately 12, 23 and 21 °C. The minimum, optimum and maximum temperatures that efficiently promote oat development are, respectively, 4 °C, 22 °C and 30 °C from emergence to anthesis, and 15 °C, 25 °C and 35 °C from anthesis to maturity (MANTAI *et al.*, 2017).

In 2022, the average daily precipitation during the grain filling and maturation months – September and October – ranged from 2 to 4 mm, which may have resulted in fewer periods of leaf wetness and a lower incidence of pathogens (Figure 1). In contrast, a daily average of 26 mm was observed in the same period in 2023. These conditions favor the manifestation of diseases, representing a significant potential for reducing productivity (ROZEWICZ *et al.*, 2021), in addition to increasing the probability of lodging.

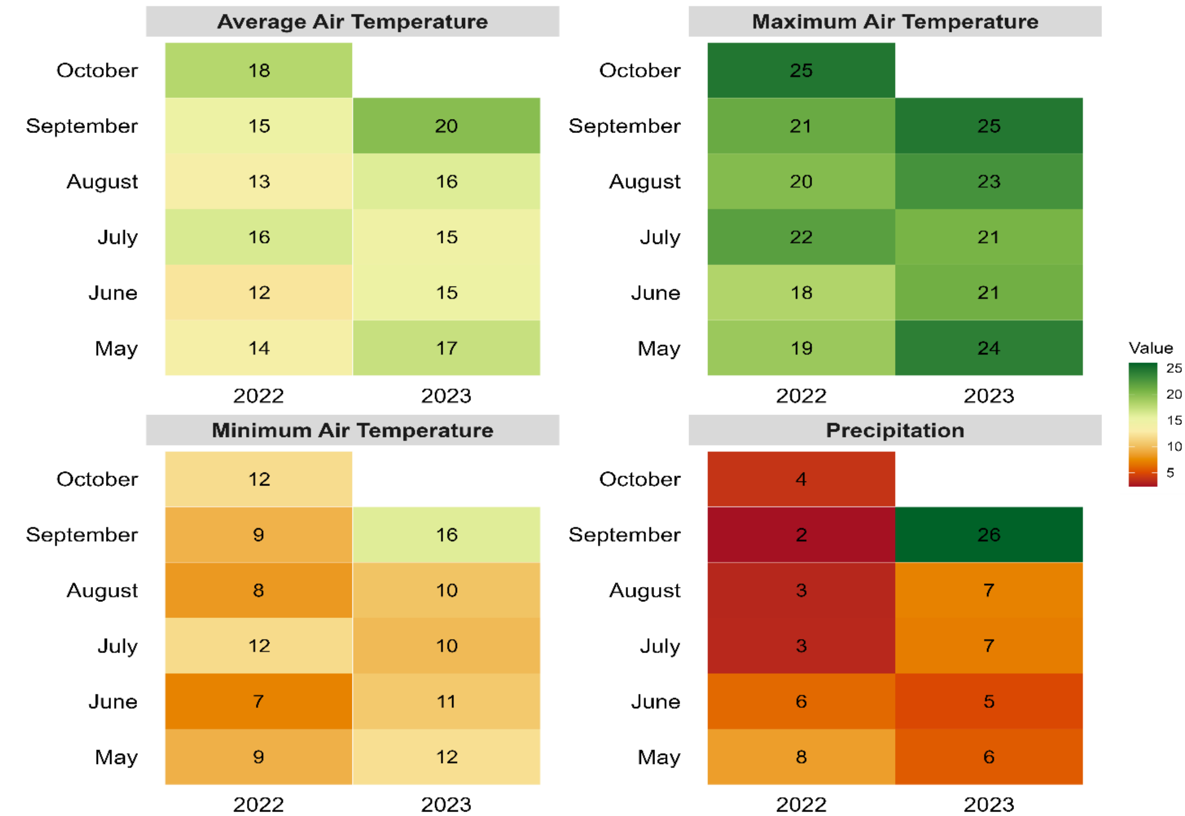
Phase 1 and 2 – White oat cultivar trial (2022 and 2023)

Analysis of variance (ANOVA) revealed a significant effect of white oat genotypes on all variables evaluated at the 5 % probability level, except for the number of grains per panicle in 2022 and 2023, as well as for panicle insertion height in 2023 (Table 3).

In 2022, a lodging percentage of 65 % was observed for the URS Corona cultivar, statistically higher than the others, even though the URS Brava cultivar presented the highest averages for plant height and panicle insertion height (Table 4). Lodging reduces the photosynthetic capacity and biomass production of plants (WU, MA, 2019), a situation in which the use of growth regulators may be necessary to avoid productivity losses (MAROLLI *et al.*, 2017). The IDR Artemis cultivar obtained the best performance for grain weight per plant and grain yield, with 36 g and 3543 kg ha^{-1}, respectively. Grain yield varied between 1536 and 1829 kg ha^{-1} for the other cultivars, with no significant differences. There was no significant difference between the averages for the thousand grain weight (Table 4).

The averages for lodging were higher in 2023, where there was no significant difference between IDR Artemis and URS Brava, with percentages of 72.8 and 67.8 %, respectively (Table 4). Therefore, URS Corona cultivar expressed lower lodging potential even without differences in plant height values between genotypes. Thus, this cultivar revealed the highest averages for grain weight per plant and thousand grain weight, with values of 59 grains and 2.0 g, respectively. For grain yield, there was no significant difference between URS Corona and URS Brava, respectively at

Figure 1. Average monthly values of mean air temperature (ºC), maximum air temperature (ºC), minimum air temperature (ºC) and precipitation (mm) for the wheat and white oat cultivation cycle in the years 2022 and 2023, in Augusto Pestana-RS.



Source: authors (2025).

Table 3. Analysis of variance (ANOVA) for the effect of cultivars (Phases 1 and 2) on the variables analyzed in the white oat crop in the years 2022 and 2023.

White Oat Cultivar Trial - 2022								
SV	DF	LOD	PH	PIH	NGP	GWP	GY	TGW
		Mean Square						
Genotypes	3	126.49*	628.91*	612.15*	247.57	1.56*	16781842*	844.68*
Block	2	0.00*	9.04	5.3	107.97	0.16	235246.6	46.68
Residual	66	9.12	74.54	53.98	236.15	0.18	1225890.3	73.41
White Oat Cultivar Trial - 2023								
SV	DF	LOD	PH	PIH	NGP	GWP	GY	TGW
		Mean Square						
Genotypes	3	4049.42*	154.12*	75.75	1200.37*	1.94*	6594769.20*	52.76*
Block	2	27.84	48.8	21.56	19.54	0.03	7973.95	3.02
Residual	75	315.26	53.09	35.11	83.91	0.15	831670.36	24.82

SV: source of variation; DF: degrees of freedom; LOD: lodging (%); PH: plant height (cm); PIH: panicle insertion height (cm); NGP: number of grains per plant (units); GWP: grain weight per plant (g); GY: grain yield (kg ha^{-1}); TGW: thousand grain weight (g); *: significant at 5 % probability by F test.

Source: authors (2025).

Table 4. Comparison test of means for the effect of genotype in the white oat cultivar trial, in the years 2022 and 2023.

White Oat Cultivar Trial - 2022						
Genotype	LOD	PH	PIH	GWP	GY	TGW
IDR Artêmis	35 b	99 b	82 b	36 a	3543 a	36 a
URS Brava	32 b	106 a	90 a	21 b	1829 b	33 a
URS Corona	65 a	98 b	80 b	25 b	1532 b	28 a
URS Taura	29 b	92 c	77 b	22 b	1536 b	28 a
White Oat Cultivar Trial - 2023						
Genotype	LOD	PH	NGP	GWP	GY	TGW
IDR Artêmis	73 a	112 a	38 c	1.3 b	2513 b	33 b
URS Brava	68 a	112 a	48 b	1.5 b	3516 a	32 b
URS Corona	47 b	113 a	59 a	2.0 a	4016 a	35 ab

LOD: lodging (%); PH: plant height (cm); PIH: panicle insertion height (cm); NGP: number of grains per plant (units); GWP: grain weight per plant (g); GY: grain yield (kg ha^{-1}); TGW: thousand grain weight (g). Means followed by the same letter do not differ statistically from each other by Duncan's test, at 5 % probability.

Source: authors (2025).

4016 and 3516 kg ha^{-1}. However, URS Brava cultivar maintained good production potential even with a high lodging percentage, unlike IDR Artemis, where lodging was the direct cause of the reduction in grain yield. These grain yield values were higher than the general average of 3469 kg ha^{-1} verified in three different years by Marolli *et al.* (2017).

Phase 3 and 4 – Testing of fungal treatments and growth promoters in white oat and wheat crops

The results of the analysis of variance (ANOVA) indicated that the fungal and growth promoter treatments had a significant effect on all variables evaluated in the white oat crop, as evidenced by the rejection of the null hypothesis of equality between means (Table 5). Similarly, in the wheat crop, the treatments also had a statistically significant effect on all variables analyzed.

From the comparison test of means for the trial of fungal treatments and growth promoters in white oat crops (Table 6), a lodging percentage of 85 % was observed for treatments T_6 (*Bacillus amyloliquefaciens* + *Bacillus velezensis* + *Bacillus thuringiensis*) and T_{15} (indoleacetic acid), being statistically higher than the other treatments. This shows that these treatments should be used with caution in white oat crops. Treatment T_1 (ethoxylated fatty alcohol) resulted in a lodging percentage of 47 %, lower only than T_{14} (no application). In addition to being positive for lodging, the use of ethoxylated fatty alcohol increases the cuticular absorption of lipophilic products and increases the bioactivity of fungal products against pathogens, in addition to reducing cuticular transpiration rates (LI *et al.*, 2018; ZEISLER-DIEHL *et al.*, 2022).

From the mean comparison test for the fungal and growth promoter treatments assay in white oat crops (Table 6), a lodging percentage of 85 % was observed for treatments T_6 (*Bacillus amyloliquefaciens* + *Bacillus velezensis* + *Bacillus thuringiensis*) and T_{15} (indoleacetic acid), being statistically higher than the other treatments. These treatments should be used with caution in white oat crops. Treatment T_1 (ethoxylated fatty alcohol) resulted in a lodging percentage of 47 %, lower only than T_{14} (no

Table 5. Analysis of variance for the effect of fungal treatments and growth promoters on the variables analyzed in the white oat and wheat crops (phases 3 and 4) in 2023.

Trial of Fungal Treatments and Growth Promoters in White Oats								
SV	DF	LOD	PH	PIH	NGP	GWP	GY	TGW
		Mean Square						
Treatments	14	1200.51*	110.20*	101.27*	155.20*	0.46*	1200880.7*	81.37*
Block	2	27.84	48.80	21.56	19.54	0.03	7973.9	3.02
Residual	64	296.65	45.33	22.54	120.65	0.17	1021051	13.76

Trial of Fungal Treatments and Growth Promoters in wheat					
SV	DF	NGP	GWP	GY	TGW
		Mean Square			
Treatments	7	23.76*	0.13*	1896608.3*	90.90*
Block	2	28.53	0.20	437324.4	20.51
Residual	14	17.00	0.07	568882.7	21.84

SV: source of variation; DF: degrees of freedom; LOD: lodging (%); PH: plant height (cm); PIH: panicle insertion height (cm); NGP: number of grains per plant (units); GWP: grain weight per plant (g); GY: grain yield (kg ha^{-1}); TGW: thousand grain weight (g); *: significant at 5 % probability by F test.

Source: authors (2025).

Table 6. Comparison test of means for the effect of fungal treatments and growth promoters on white oat crops (phase 3) in 2023.

Treatment	LOD	PH	PIH	NGP	GWP	GY	TGW
T_1	47 bc	112 abcd	95 cde	56 a	2.0 a	4141 a	36 ab
T_2	70 ab	112 abcd	96 abcde	41 a	1.2 bc	2977 a	30 cdef
T_3	75 ab	121 a	103 a	45 a	1.5 abc	2797 a	32 bcde
T_4	66 ab	109 bcd	90 e	52 a	1.8 ab	3468 a	35 abc
T_5	68 ab	107 d	91 e	42 a	1.4 abc	3426 a	33 abc
T_6	85 a	119 ab	99 abcd	51 a	1.4 abc	3109 a	27 def
T_7	75 ab	119 abc	103 ab	57 a	1.6 abc	3059 a	27 def
T_8	70 ab	117 abcd	100 abc	41 a	1.1 c	2731 a	27 def
T_9	75 ab	115 abcd	100 abc	45 a	1.1 c	2838 a	25 f
T_{10}	70 ab	118 abcd	100 abc	41 a	1.3 bc	3110 a	31 bcdef
T_{11}	75 ab	109 bcd	92 de	49 a	1.7 abc	3989 a	35 abc
T_{12}	65 ab	108 cd	92 de	46 a	1.5 abc	2934 a	33 abcd
T_{13}	70 ab	118 abcd	100 abc	44 a	1.6 abc	3798 a	36 ab
T_{14}	33 c	111 abcd	95 bcde	53 a	2.0 a	3835 a	38 a
T_{15}	85 a	119 ab	102 abc	55 a	1.4 abc	3521 a	28 ef

LOD: lodging (%); PH: plant height (cm); PIH: panicle insertion height (cm); NGP: number of grains per plant (units); GWP: grain weight per plant (g); GY: grain yield (kg ha^{-1}); TGW: thousand grain weight (g). Means followed by the same letter do not differ statistically from each other by Duncan's test, at 5 % probability.

Source: authors (2025).

application). In addition to being positive for lodging, the use of ethoxylated fatty alcohol increases the cuticular absorption of lipophilic products and increases the bioactivity of fungal products against pathogens, in addition to reducing cuticular transpiration rates (LI *et al.*, 2018; ZEISLER-DIEHL *et al.*, 2022).

There was no statistical difference between treatments for the number of grains per plant and grain yield (Table 7). Treatments T_1 and T_{14} also obtained the best performance for grain weight per plant, with no statistical difference for T_3, T_4 (*Bacillus subtilis*), T_5 (*Bacillus subtilis* + hydrogen peroxide), T_6, T_{11} (calcium polysulfide), T_{12} (hydrogen peroxide), T_{13} (picoxystrobin + cyproconazole) and T_{15}. The lowest average thousand grain weight was attributed to treatment T_9 (*Bacillus subtilis* + *Bacillus velezensis* + *Bacillus pumilus* + indoleacetic acid + picoxystrobin + cyproconazole), a fact that suggests the existence of antagonism due to the large number of inputs applied. Although increased microbial diversity in natural environments is undoubtedly positive, the intensity of antagonism between many strains and species isolated in biological products can lead to a passive effect on plant growth, lead to inconsistent performances and, in some cases, lead to decreases in grain yield (WANG *et al.*, 2022).

The test for comparison of means for the trial of fungal treatments and growth promoters in wheat crops (Table 7) revealed that treatment T_V (*Bacillus subtilis* + *Bacillus velezensis* + *Bacillus pumilus* + indoleacetic acid + picoxystrobin + cyproconazole) had the best performance for the number of grains per plant. Regarding the variable thousand grain weight, treatments T_{VII} (no application) and T_{VIII} (indoleacetic acid) had the best performance, with no difference for T_I (*Bacillus amyloliquefaciens* + *Bacillus velezensis* + *Bacillus thuringiensis*), T_{II} (*Bacillus licheniformis*) and T_{III} (*Bacillus pumilus* + *Bacillus subtilis* + *Bacillus amyloliquefaciens*). Superiority was attributed to treatments T_{III}, T_{VII} (absence of application) and TV_{III} for grain yield, with averages of 3903, 4361 and 3562 kg ha^{-1}, respectively, demonstrating little effectiveness.

Thus, a high effect of lodging on the performance of white oat genotypes was

Table 7. Comparison test of means for the effect of fungal treatments and growth promoters on wheat crops (phase 4) in 2023.

Treatment	NGP	GWP	GY	TGW
T_I	28 ab	1.4 ab	3352 bcd	28 abc
T_{II}	30 ab	1.4 ab	3476 bcd	27 abcd
T_{III}	31 ab	1.5 ab	3903 abc	27 abcd
T_{IV}	29 ab	1.0 b	2342 d	20 cd
T_V	36 a	1.3 ab	3229 bcd	21 bcd
T_{VI}	31 ab	1.0 b	2515 cd	18 d
T_{VII}	26 b	1.5 ab	4361 ab	31 a
T_{VIII}	27 b	1.5 ab	3562 abcd	32 a

NGP: number of grains per plant (units); GWP: grain weight per plant (g); GY: grain yield (kg ha^{-1}); TGW: thousand grain weight (g). Means followed by the same letter do not differ statistically from each other by Duncan's test, at 5 % probability.

Source: authors (2025).

identified, in addition to little effectiveness of alternative management on the grain yield of white oats and wheat. Future studies are needed to demonstrate the possible causes of the observed facts.

Conclusions

Among the white oat cultivars evaluated, the IDR Artemis genotype has the highest grain yield potential in years with low probability of lodging.

The white oat cultivar URS Corona presents less lodging in conditions favorable to the occurrence of the problem, maintaining high values of grain weight per plant and a thousand grains weight.

Management alternatives influence the agronomic characteristics of wheat and oats, but without significant impact on grain yield.

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