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ALTERNATIVES OF CHEMICAL AND BIOLOGICAL MANAGEMENT TO ENHANCE GRAIN YIELD FROM WHEAT CROPS

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Abstract

This study aims to evaluate chemical and biological management alternatives to enhance the grain yield of wheat crops, based on the evaluation of the crop's productivity components. The experiment was conducted in 2022, under field conditions, at Escola Fazenda of UNIJUÍ (Regional University of Northwestern Rio Grande do Sul), located in the municipality of Augusto Pestana, Brazil. The experimental design used was randomized blocks with an 8 x 9 factorial scheme, with eight wheat cultivars (TBIO Audaz, TBIO Ponteiro, TBIO Trunfo, TBIO Toruk, TBIO Astro, ORS Madrepérola, ORS Agile and BRS Belajoia) and nine management protocols, arranged in two repetitions. At full physiological maturity, the following agronomic traits were measured: number of grains on the cob; cob grain weight; thousand grain weight; and grain yield. Analysis of variance took place to detect the effects of cultivar, management protocols and their interaction on the analyzed variables. The Duncan test was used to compare treatment means, at 5% probability. The use of BOMBARDEIRO as a reinforcement to the chemical fungicide promoted an increase in the thousand grain weight. The highest values for grain yield were obtained with the protocols BIOASIS+BIOEQUILÍBRIO+BIOFREE, BIOTRIO and ORKESTRA SC, for the genotypes TBIO Toruk, TBIO Ponteiro and TBIO Trunfo. The use of biological management in wheat crops enhances nutrient absorption and acts synergistically with chemical fungicides, contributing to increased productivity and sustainable management.

Keywords: *Triticum aestivum*; microorganisms; sustainable agriculture.

ALTERNATIVAS DE MANEJO QUÍMICO E BIOLÓGICO PARA AUMENTAR O RENDIMENTO DE GRÃOS DA CULTURA DE TRIGO

Resumo

Este estudo teve como objetivo avaliar alternativas de manejo químico e biológico para aumentar a produtividade de grãos da cultura do trigo, a partir da avaliação dos componentes de produtividade da cultura. O experimento foi conduzido em 2022, em condições de campo, na Escola Fazenda da UNIJUÍ (Universidade Regional do Noroeste do Rio Grande do Sul), localizada no município de Augusto Pestana, Brasil. O delineamento experimental utilizado foi o de blocos casualizados em esquema fatorial 8 x 9, com oito cultivares de trigo (TBIO Audaz, TBIO Ponteiro, TBIO Trunfo, TBIO Toruk, TBIO Astro, ORS Madrepérola, ORS Agile e BRS Belajoia) e nove protocolos de manejo, dispostos em duas repetições. Na maturidade fisiológica completa, foram mensurados os seguintes caracteres agronômicos: número de grãos na espiga; peso de grãos da espiga; peso de mil grãos; e produtividade de grãos. Foi realizada análise de variância para detectar os efeitos da cultivar, dos protocolos de manejo e de sua interação sobre as variáveis analisadas. O teste de Duncan foi utilizado para comparar médias de tratamentos, a 5% de probabilidade. A utilização do BOMBARDEIRO como reforço ao fungicida químico promoveu aumento na massa de mil grãos. Os maiores valores de produtividade de grãos foram obtidos com os protocolos BIOASIS+BIOEQUILÍBRIO+BIOFREE, BIOTRIO e ORKESTRA SC, para os genótipos TBIO Toruk, TBIO Ponteiro e TBIO Trunfo. O uso do manejo biológico nas lavouras de trigo aumenta a absorção de nutrientes e atua em sinergia com os fungicidas químicos, contribuindo para o aumento da produtividade e o manejo sustentável.

Palavras-Chave: *Triticum aestivum;* microrganismos; agricultura sustentável.

Introduction

Several factors such as climatic conditions, insect pests and diseases are involved in reducing the productive potential of crops (Skendzic *et al.*, 2021). Diseases that affect wheat crops can result in significant losses, responsible for 10 to 50% (on average) of wheat productivity losses worldwide (Ristaino *et al*., 2021). The crop has widespread global importance (Khalid *et al.*, 2023), having a high yield potential, so that the expression of this potential has often not been achieved in the production systems in which the crop participates.

The diseases affect the structure of the leaves, reducing the effectiveness of uptake and use of solar radiation in the affected areas (Ristaino *et al*., 2021). In this context, a wide complex of pathogens can affect wheat crops, with emphasis on the fungi: *Puccinia triticina* (leaf rust) (Bolton *et al*., 2008), *Blumeria graminis* f.sp. *tritici* (powdery mildew) (Zeng *et al*., 2010), *Bipolaris sorokiniana* (helmintosporiosis) (Gupta *et al.*, 2017), *Pyrenophora tritici-repentis* (yellow spot) (Kariyawasam *et al.*, 2021), and *Fusarium graminearum* (telomorph *Gibberela zeae*), which causes wheat head blight (Moonjely *et al*., 2023).

Currently, there are several management strategies to control diseases in wheat, based on the use of tolerant cultivars, application of fungicides and biological control (Khan *et al*., 2023). Due to the rapid evolution of pathogens, the genetic tolerance of wheat cultivars ends up losing efficiency over the years (Santos *et al*., 2017; Wulff; Krattinger, 2022), where the use of chemical control has become the most rapid and efficient control (May *et al*., 2020).

Integrated disease management (IDM) can be used (Ons *et al*., 2020), being defined as a mix of strategies for disease control, taking into account the productivity, profitability and health of the crop (FAO, 2020). Biological control consists of the use of living organisms that act against a specific pathogen via parasitism, antibiosis or competition for nutrients (Stenberg *et al*., 2021), inducing systemic resistance that strengthens the mechanical and physical vigor of the cell wall, in addition to altering the biochemical and physiological activity of the host (Naeem *et al*., 2015). This study aims to evaluate chemical and biological management alternatives to enhance the grain yield of wheat crops, based on the evaluation of the crop's productivity components.

Material And Methods

The experiment was conducted in 2022, under field conditions, at Escola Fazenda of UNIJUÍ (Regional University of Northwestern Rio Grande do Sul), located in the municipality of Augusto Pestana – Rio Grande do Sul – RS (28º31’01”S, 53º59’32”W, 390 meters above sea level). The soil in the experimental area is classified as a Typical Dystroferric Red Oxisol. The region's climate is type *Cfa* (humid subtropical), according to the Köeppen climate classification, with rainfall well distributed throughout the year.

The experimental design used was randomized blocks with an 8 x 9 factorial scheme, with eight wheat cultivars (TBIO Audaz, TBIO Ponteiro, TBIO Trunfo, TBIO Toruk, TBIO Astro, ORS Madrepérola, ORS Agile and BRS Belajoia) and nine management protocols (Table 1), arranged in two repetitions.

Table 1. Management protocols, commercial name, concentration, dose and technical name of the products used in the study.

Protocol	Commercial product	Concentration	Dose (mL ha^{-1})
P1	BIOASIS$^{(1)}$	S.I.	S.I.
P2	BIOEQUILÍBRIO$^{(2)}$	S.I.	S.I.
P3	BIOFREE$^{(3)}$	$1x10^8$ CFU mL^{-1}	500
P4	BIOASIS + BIOEQUILÍBRIO + BIOFREE	-	-
P5	BIOTRIO$^{(4)}$	$1x10^8$ CFU mL^{-1}	200
P6	ORKESTRA SC$^{(5)}$	167 g L^{-1} + 333 g L^{-1}	350
P7	ORKESTRA SC + BOMBARDEIRO$^{(6)}$	$^{(5)}$ + [$1.5x10^{11}$ VE L^{-1} + $1.2x10^{11}$ L^{-1} + $1.9x10^{11}$VE L^{-1}]	350 + 300
P8	ORKESTRA SC + BOMBARDEIRO + STIMUTROP$^{(7)}$	$^{(5)}$ + $^{(6)}$ + 0.003% g L^{-1}	350 + 300 + 200
P9	Check$^{(8)}$	-	-

P1: Protocol 1; P2: Protocol 2; P3: Protocol 3; P4: Protocol 4; P5: Protocol 5; P6: Protocol 6; P7: Protocol 7; P8: Protocol 8; P9: Protocol 9; CFU: colony forming units; VE: viable endospores; $^{(1)}$S. I.; $^{(2)}$S. I.; $^{(3)}$*Pseudomonas fluorescens* (CCTB03) + *Azospirillum brasilense (AbV6)*; $^{(4)}$*B. plumilus* (CCTBO5) + *B. subtilis* (CCTB04) + *B. amyloliquefaciens* (CCTB09); $^{(5)}$Fluxapyroxad+Pyraclostrobin; $^{(6)}$*B. subtilis* (CCTB04) + *B. velezensis* (CCTB09) + *B. plumilus* (CCTB05); $^{(7)}$Indoleacetic Acid; $^{(8)}$Check without application.

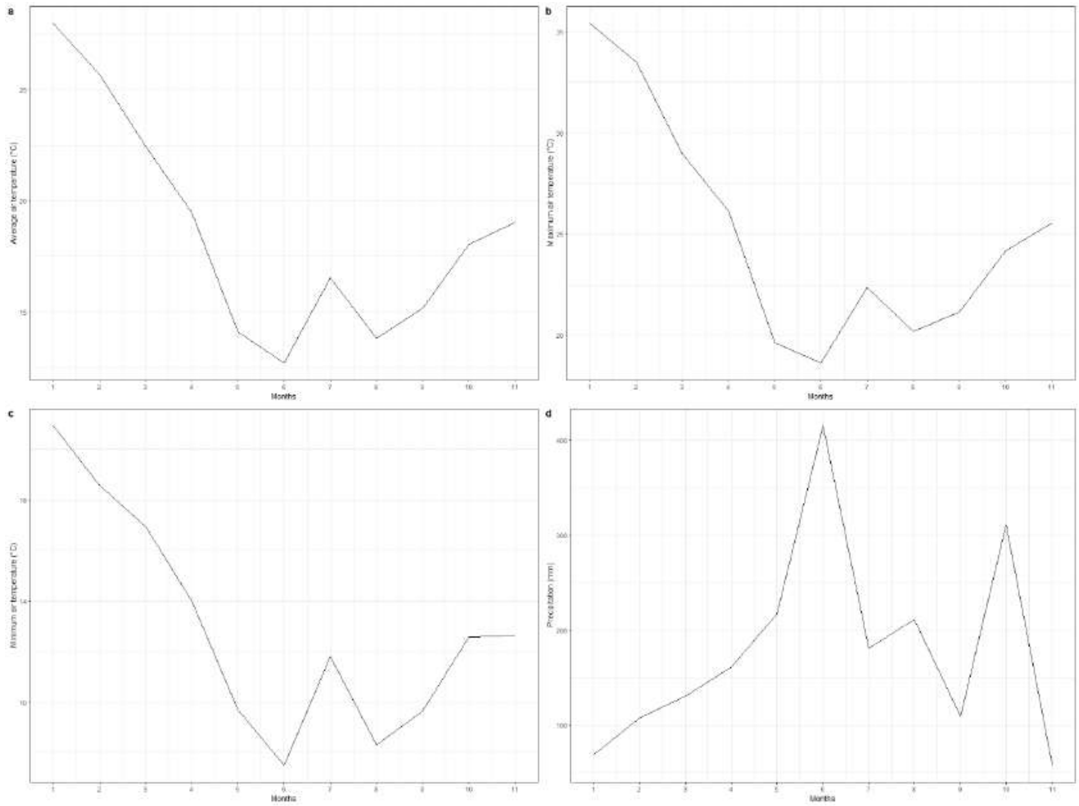
The experimental units were composed of five lines 1.5 m wide and 3 m long, totaling 4.5 m^2. Sowing was performed in the first half of June, using a sowing density of 400 seeds m^{-2}, with a spacing of 0.18 cm between rows. The base fertilizer used was 250 kg ha^{-1} of the formula 10-20-20 (N- nitrogen; P- phosphorus; K- potassium). The applications of the management protocols took place with a diaphragm backpack sprayer, pressurized with CO_2, with a maximum pressure of 70 psi (4.8 bar) and an opening of 2.1 liters min^{-1}, using an application bar with four nozzles equipped with spraying suitable for fungicide application. The control of invasive plants and insect pests took place preventively. The harvest took place when the plants reached the stage of physiological maturity, with 10 plants being collected per experimental unit, which were taken to a forced air greenhouse to correct humidity. The variables measured were: cob length (CL, cm); cob weight (CW, g); number of grains on the cob (NGC, no.); cob grain weight (CGW, g); thousand grain weight (TGW, g) and; grain yield (GY, kg ha^{-1}). To assist in understanding the results found, data on mean air temperature (Tmean, ºC), maximum air temperature (Tmax, ºC), minimum air temperature (Tmin, ºC) and precipitation (Prec, mm) were obtained for the wheat cultivation cycle (Nasa Power, 2022).

The data obtained were subjected to the assumptions of the statistical model, where the values of additivity, independence of errors, homogeneity and normality of residual variances were verified, using the Shapiro-Wilk and Bartlett tests. Analysis of variance took place to detect the effects of cultivar, management protocols and their interaction on the analyzed variables. The Duncan test was used to compare treatment means, at 5% probability. The analyzes were performed using the R software (R Core Team, 2022).

Results And Discussion

Climate information for the year 2022 is represented in the meteorological figure (Figure 1), where it is possible to identify the natural decline in temperature as the year passes from the hot season to the cold season. Considering the wheat cultivation cycle, which comprised the months of June to October, the lowest temperatures are observed in the months of June and August, with average temperatures close to 12.37ºC in June and 13.47ºC in August. The highest mean temperatures occurred in the months of October (24.68ºC) and July (22.07ºC). According to Silva et al. (2018), the ideal temperature for adequate growth and development of wheat is 20ºC, varying between 15 and 20ºC during tillering, and may vary between 20 and 25ºC for the other stages of the crop.

Figure 1. Mean air temperature (ºC), maximum air temperature (ºC), minimum air temperature (ºC) and precipitation (mm) for the wheat growing cycle, Augusto Pestana – RS, 2022.



Sowing and crop establishment coincided with the period of highest precipitation volumes, with an accumulation of more than 400 mm during the month of June. The water requirement during the crop cycle is around 430 mm (Zheng *et al.*, 2022). For the month of September, which coincided with the sprouting and anthesis stages, the volume of precipitation was low, close to 100 mm, only increasing again in October, which ended up promoting few conditions for the emergence and progression of cob disease-causing pathogens. Studies by Reis *et al*. (2023), show that the temperature range between 20ºC and 30ºC resulted in the highest intensities of fusarium head blight, with the peak at 25ºC in interaction with a wetness period of 50 h. The pressure from cob diseases increases mainly during anthesis, when the anthers, the preferred structures for infection, are exposed.

The results of the analysis of variance (Table 2) show that the effects of cultivars, application protocols and the interaction between these factors significantly changed the variables studied. The values found for the coefficients of variation had a range between 5.87 and 11.29%, being considered of low to medium magnitude according to the classification of Gomez (2000), a situation in which the average of the observations can be used to better explain the data set. This suggests differences in the way in which wheat genotypes express their agronomic traits through changes in management.

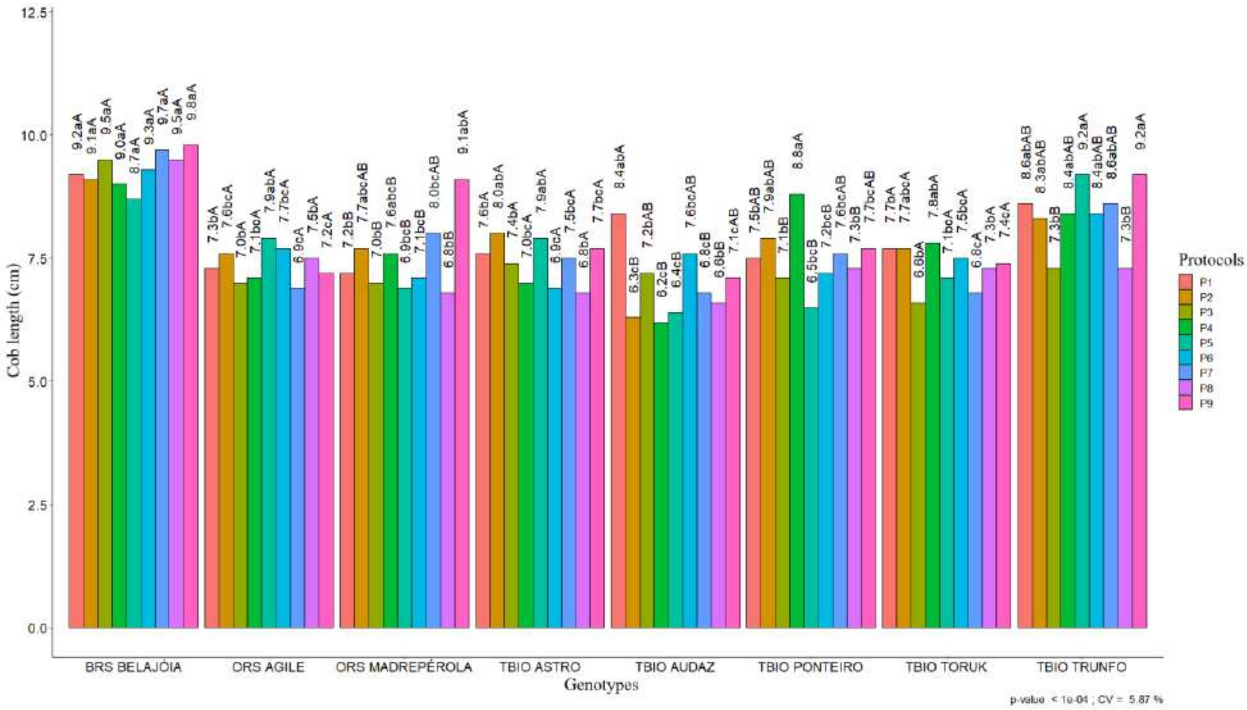
Table 2. Analysis of variance (ANOVA) considering eight wheat cultivars (C) and nine management protocols (P).

SV	DF	MS					
		CL	**CW**	**CGW**	**NGC**	**TGW**	**GY**
Block	7	2.777	0.584	0.085	155.417	2.298	1222372.7
Protocol	8	0.971*	0.063*	0.030*	77.957*	15.247*	479537.2*
C x P Bioasis	7	1.016*	0.137*	0.037*	56.257*	6.601*	733590.3*
C x P Bioequilíbrio	7	1.227*	0.308*	0.099*	53.958*	22.647*	1154278.1*
C x P Biofree	7	1.573*	0.172*	0.057*	41.028*	17.414*	1435350.2*
C x P Biofree + Biotrio + Bioasis	7	1.856*	0.187*	0.064*	49.891*	27.604*	1953518.9*
C x P Biotrio	7	2.095*	0.156*	0.050*	51.342*	12.795*	1827344.6*
C x P Orkestra	7	1.242*	0.146*	0.053*	60.960*	5.159*	1140842.2*
C x P Orkestra + Bombardeiro	7	2.056*	0.234*	0.054*	44.965*	11.174*	715216.9*
C x P Orkestra + Bombardeiro + Stimutrop	7	1.659*	0.061*	0.024*	11.130*	7.610*	905584.0*
C x P Check	7	2.200*	0.236*	0.073*	37.039*	10.106*	1125601.8*
Residue	71	0.205	0.041	0.013	12.215	5.172	218394.1
TOTAL	143	0.906	0.108	0.034	31.415	9.365	681845.7
CV (%)	-	5.87	10.61	11.14	9.07	8.4	11.29

SV: source of variation; MS: mean square; CL: cob length; CW: cob weight; CGW: cob grain weight; NGC: number of grains on the cob; TGW: thousand grain weight; GY: grain yield; CV: coefficient of variation; *: significant at 5% probability using the F test.

Considering the influence of the interaction between wheat cultivars and management protocols on the cob length variable, the BRS Belajoia genotype fell into the superiority group for all management protocols used in the experiment (Figure 2). On the other hand, the TBIO Audaz genotype presented the lowest cob length values, with the exception of the protocols with application of BIOASIS, BIOFREE and ORKESTRA SC. This suggests that this genotype is highly dependent on phytosanitary management. When using the application of BIOASIS (P1) and BIOEQUILÍBRIO (P2), separately, the cultivar TBIO Trunfo did not differ statistically from the best genotype, while the genotypes ORS Agile and ORS Madrepérola presented the lowest cob length values, considering the P1 protocol. For the management protocol with application of BIOFREE (P3), all genotypes were statistically different from the BRS Belajoia genotype.

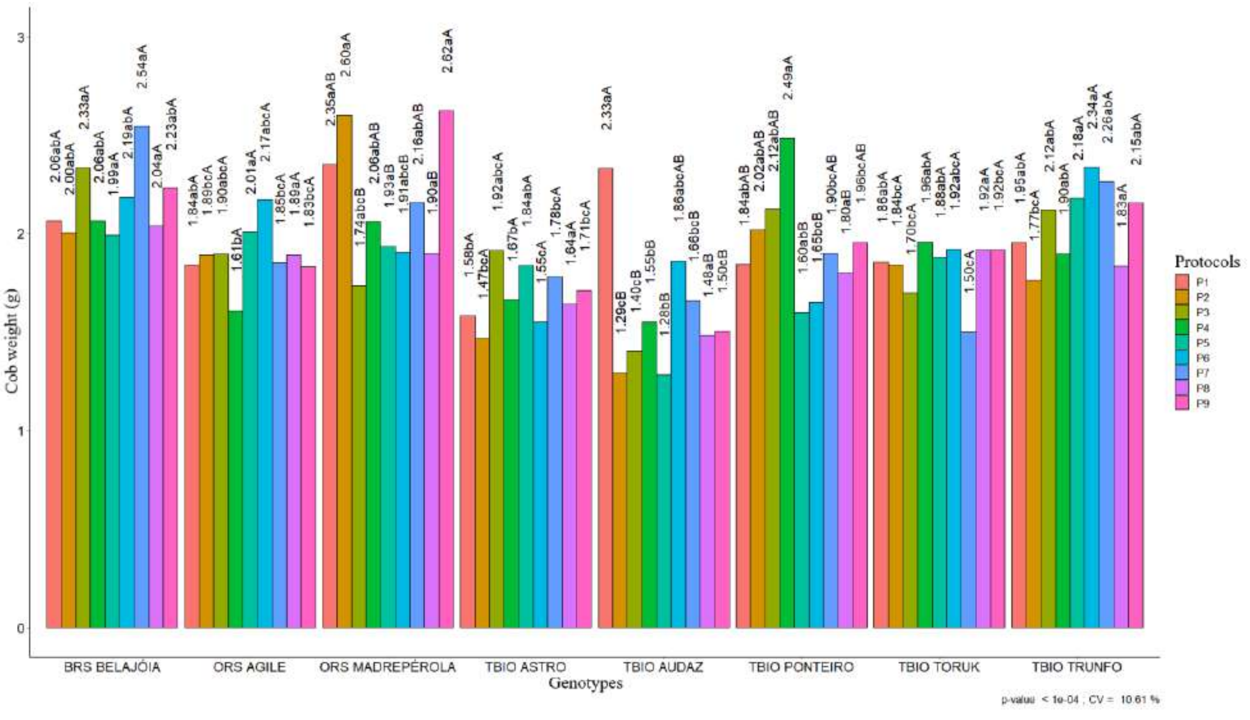
Figure 2. Averages for the variable cob length (CL, cm) considering eight cultivars and nine management protocols. P1: BIOASIS; P2: BIOEQUILÍBRIO; P3: BIOFREE; P4: BIOASIS+BIOEQUILÍBRIO+BIOFREE; P5: BIOTRIO; P6: ORKESTRA SC; P7: ORKESTRA SC+BOMBARDEIRO; P8: ORKESTRA SC+BOMBARDEIRO+STIMUTROP; P9: Check.



For the application of BIOFREE+BIOTRIO+BIOASIS (P4), TBIO Ponteiro and TBIO Trunfo also fell into the superiority group. Considering the isolated application of BIOTRIO (P5), the TBIO Trunfo genotype had a higher cob length than BRS Belajoia. Some biological antagonists can survive in plant leaves, allowing foliar applications against pathogens (Ons *et al.,* 2020). In this case, *B. subtilis* is a rhizobacteria that has been widely tested for its production of antibiotics that affect the cell wall of pathogens (Olmedo *et al*., 2022), being tested in foliar applications together with tebuconazole to promote synergy in disease control (Gu *et al*., 2023). Similar behavior was observed for the application of ORKESTRA SC (P6), application of ORKESTRA SC+BOMBARDEIRO (P7) and application of ORKESTRA SC+BOMBARDEIRO+STIMUTROP (P8), with the exception of the control without application (P9), where the cultivar ORS Modrepérola fell into the superiority group.

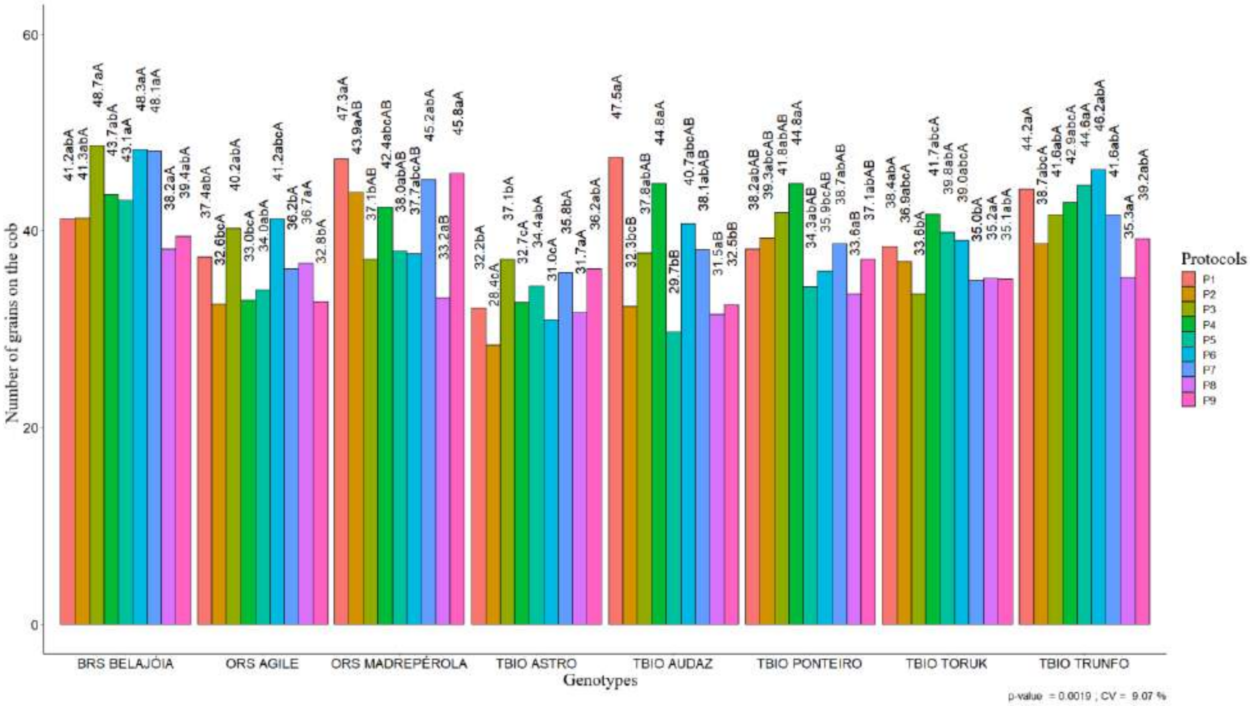
For the variable cob weight (Figure 3), when using the P1 protocol, the genotypes ORS Madrepérola and TBIO Audaz fell into the superiority group, but did not differ statistically from the genotypes BRS Belajoia and TBIO Trunfo. Considering the P2 protocol, again the ORS Madrepérola genotype showed superior performance, with TBIO Audaz and TBIO Astro obtaining the lowest cob weight values. When using protocol P3, only TBIO Audaz performed worse than the others, with the same scenario for protocols P4 and P5, where the genotypes with superior performance were TBIO Ponteiro and TBIO Trunfo, respectively. When co-inoculated, bacteria from different genera or species can communicate via chemical mediators and promote synergism for traits of agronomic interest in plants (Fagotti *et al.*, 2019). The highest values of cob weight were found when using protocols P6 (ORKESTRA SC) and P7 (ORKESTRA SC+BOMBARDEIRO), where the genotypes that showed superiority were TBIO Trunfo and BRS Belajoia. Considering the control without application (P9), the highest values for the variable were obtained for ORS Madrepérola and BRS Belajoia.

Figure 3. Averages for the variable cob weight (CW, g) considering eight cultivars and nine management protocols. P1: BIOASIS; P2: BIOEQUILÍBRIO; P3: BIOFREE; P4: BIOASIS+BIOEQUILÍBRIO+BIOFREE; P5: BIOTRIO; P6: ORKESTRA SC; P7: ORKESTRA SC+BOMBARDEIRO; P8: ORKESTRA SC+BOMBARDEIRO+STIMUTROP; P9: Check.



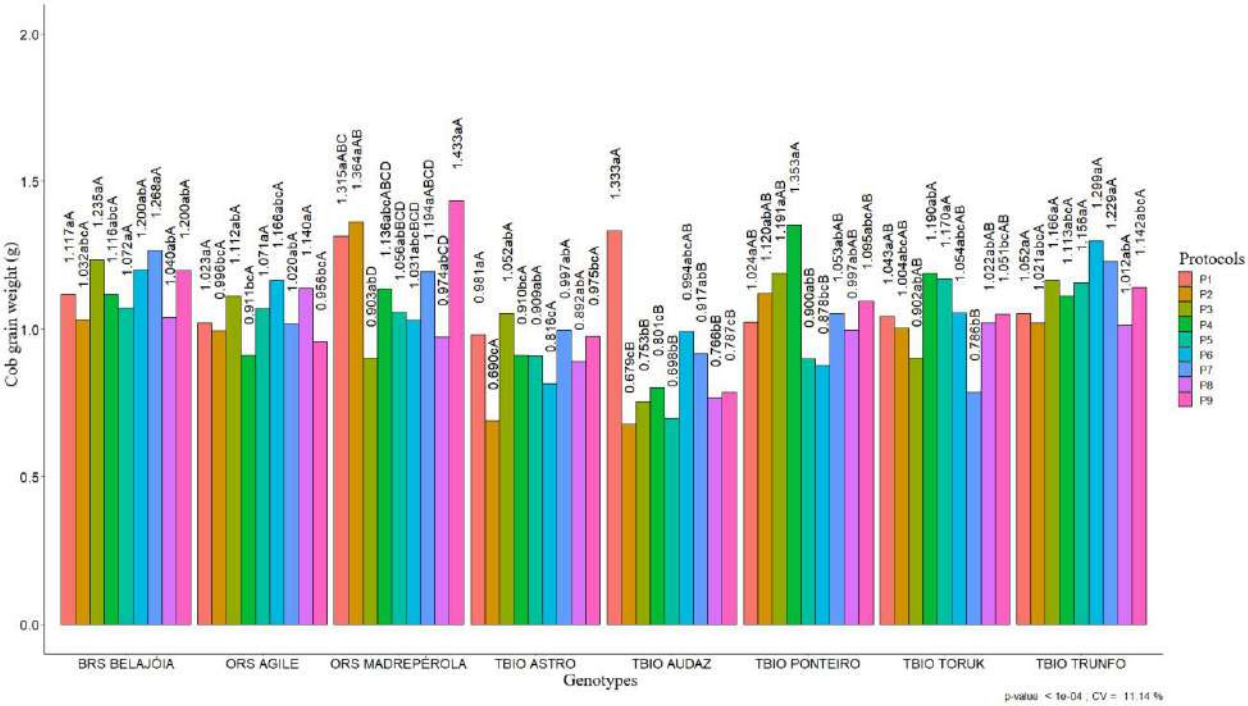
When evaluating the results for the number of grains on the cob (Figure 4), in general, the TBIO Astro genotype demonstrated below average performance in comparison to the other genotypes used. The increase in nutrients can promote an increase in wheat grain productivity, presenting positive changes in the wheat production components, particularly in the number of fertile tillers and grains on the cob (Yan *et al*., 2020). In this context, bacteria of the genus *Azospirillum* affect the rate and length of root hairs, increasing the development of lateral roots that increase the area of the root system (Fukami *et al*., 2018), resulting in a greater supply of nutrients to plants. TBIO Audaz and ORS Madrepérola were superior when applying the P1 protocol, not statistically different from TBIO Trunfo and BRS Belajoia. For protocol P2, a grouping of genotypes that do not statistically differ from each other is observed, where ORS Madrepérola and BRS Belajoia obtained superiority, and it can be inferred that the use of BIOEQUILÍBRIO has synergistic potential in the management of fungal diseases. The BRS Belajoia genotype fell into the superiority group when all remaining protocols were used, together with TBIO Trunfo and ORS Madrepérola.

Figure 4. Averages for the variable number of grains on the cob (NGC, no.) considering eight cultivars and nine management protocols. P1: BIOASIS; P2: BIOEQUILÍBRIO; P3: BIOFREE; P4: BIOASIS+BIOEQUILÍBRIO+BIOFREE; P5: BIOTRIO; P6: ORKESTRA SC; P7: ORKESTRA SC+BOMBARDEIRO; P8: ORKESTRA SC+BOMBARDEIRO+STIMUTROP; P9: Check.



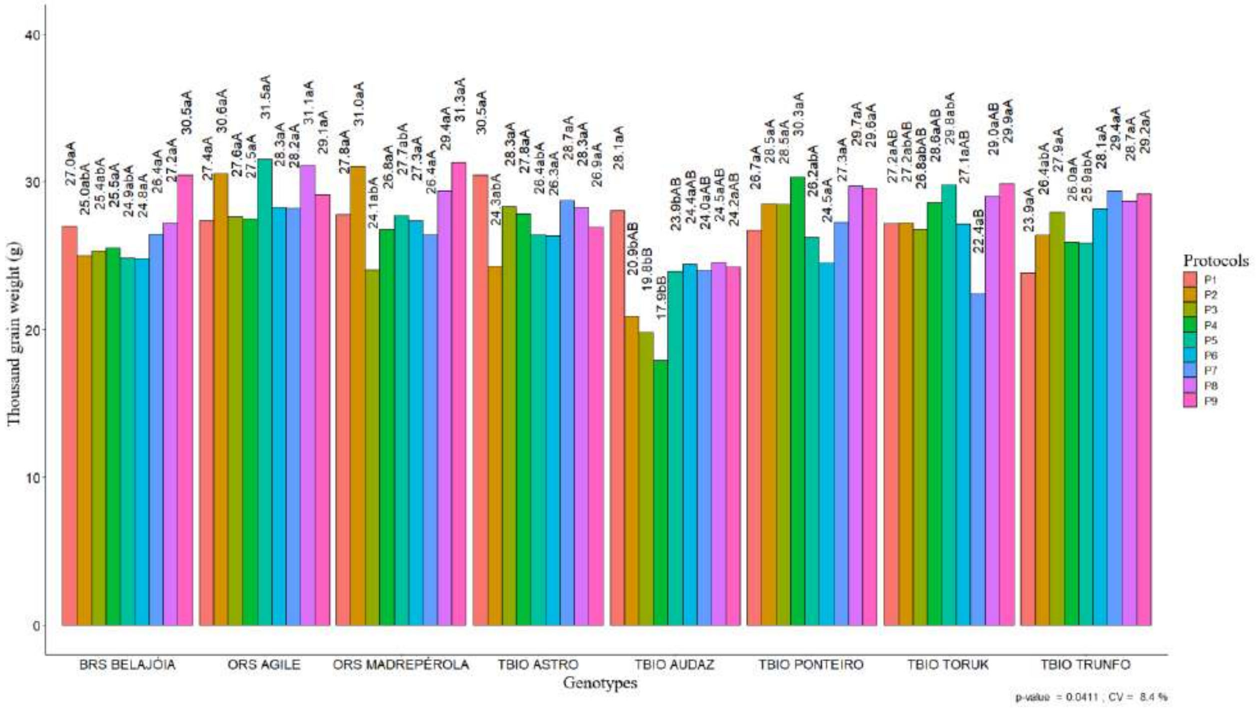
The results obtained for cob grain weight (Figure 5) were in line with the values for number of grains on the cob, where the same genotypes that showed superior performance for NGC were also superior for CGW. An exception identified was the TBIO Toruk genotype, which showed superiority when using protocols P4 (BIOFREE+BIOTRIO+BIOASIS), P5 (BIOTRIO) and P6 (ORKESTRA SC). BRS Belajoia was again the genotype with the greatest superiority for most treatments.

Figure 5. Averages for the variable cob grain weight (CGW, g) considering eight cultivars and nine management protocols. P1: BIOASIS; P2: BIOEQUILÍBRIO; P3: BIOFREE; P4: BIOASIS+BIOEQUILÍBRIO+BIOFREE; P5: BIOTRIO; P6: ORKESTRA SC; P7: ORKESTRA SC+BOMBARDEIRO; P8: ORKESTRA SC+BOMBARDEIRO+STIMUTROP; P9: Check.



Considering the influence of management protocols on the thousand-grain weight (Figure 6), one of the primary components of wheat crop yield, it is identified that the averages found for protocols P1 (BIOASIS), P6 (ORKESTRA SC), P8 (ORKESTRA SC+BOMBARDEIRO+STIMUTROP) and P8 (control without application) were statistically equal. For protocol P2, the ORS Madrepérola and ORS Agile genotypes demonstrated superiority, not statistically different from TBIO Ponteiro, TBIO Toruk and TBIO Trunfo. The use of fungicides can modify the abundance of native microbiological communities (Meena *et al*., 2020), a situation in which the application of *B. subtilis* together with the fungicide, which can act in different modes of action, results in the reduction of foliar diseases, increasing productivity and maintaining the quantities of microorganisms in the soil (Guimarães *et al*., 2021).

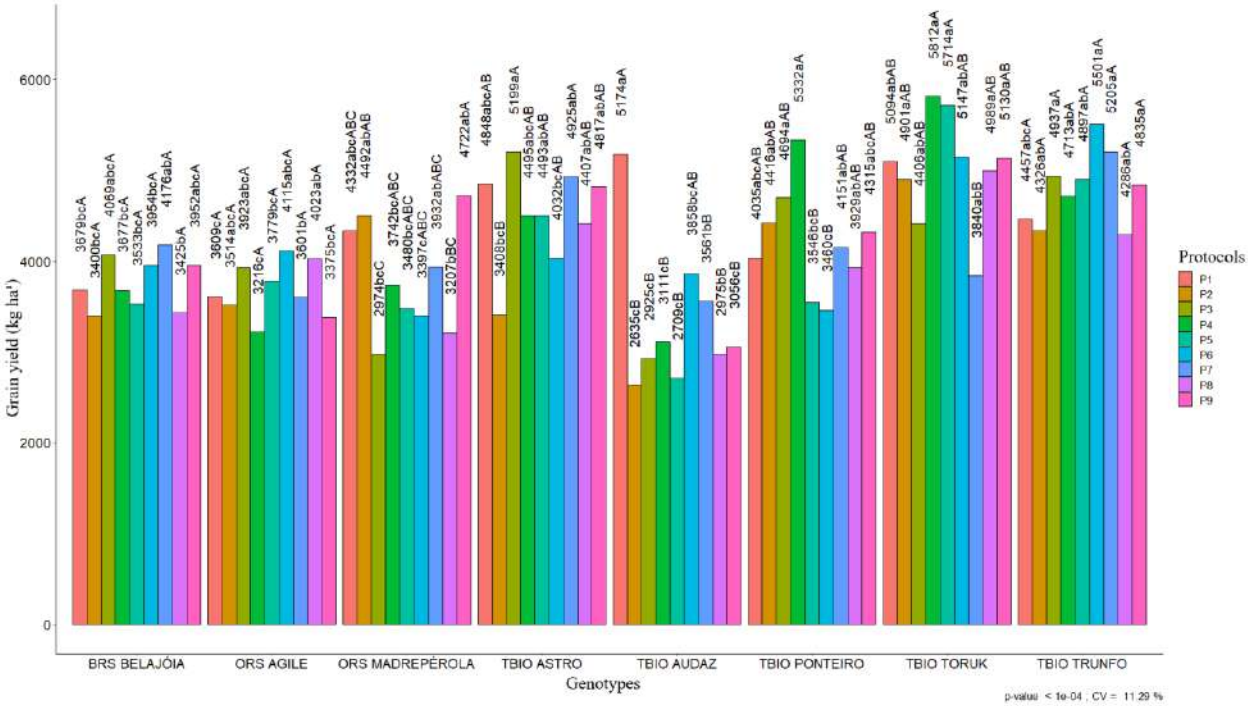
Figure 6. Averages for the variable thousand grain weight (TGW, g) considering eight cultivars and nine management protocols. P1: BIOASIS; P2: BIOEQUILÍBRIO; P3: BIOFREE; P4: BIOASIS+BIOEQUILÍBRIO+BIOFREE; P5: BIOTRIO; P6: ORKESTRA SC; P7: ORKESTRA SC+BOMBARDEIRO; P8: ORKESTRA SC+BOMBARDEIRO+STIMUTROP; P9: Check.



For protocol P3, only TBIO Audaz performed worse than the others did, as it is a genotype with wide use in areas destined for wheat farming, becoming dependent on applications of chemical fungicides. Considering the P4 protocol, the ORS Agile genotype again demonstrated superiority, together with TBIO Toruk, where only TBIO Audaz performed worse than the average of the other genotypes. When applied BOMBARDEIRO as a reinforcement to the chemical fungicide (P7), the group of superior genotypes was formed by TBIO Trunfo, TBIO Astro and ORS Agile.

For the grain yield variable (Figure 7), considering the interaction between cultivars and management protocols, it is observed that, despite obtaining superior performance for the variables discussed previously, the genotypes BRS Belajoia and ORS Madrepérola did not fit into the group of superiority. The TBIO Audaz genotype presented the lowest grain yield potential. When using the P1 protocol, TBIO Toruk obtained a higher grain yield than the others, with the lowest values being found for ORS Agile. For protocol P2, the TBIO Astro genotype was superior, not statistically different from TBIO Trunfo, TBIO Ponteiro and TBIO Toruk. Considering the P3 management protocol, the TBIO Astro genotype obtained the highest grain yield, followed by TBIO Trunfo, TBIO Ponteiro and TBIO Toruk, with the latter genotype also falling into the group of superior genotypes for the P4 protocols, together with TBIO Ponteiro, P5, together with TBIO Trunfo, P6, P8 and P9. For protocol P7 (ORKESTRA SC+BOMBARDEIRO), the genotypes TBIO Trunfo and TBIO Astro were superior.

Figure 7. Averages for the grain yield variable (GY, kg ha^{-1}) considering eight cultivars and nine management protocols. P1: BIOASIS; P2: BIOEQUILÍBRIO; P3: BIOFREE; P4: BIOASIS+BIOEQUILÍBRIO+BIOFREE; P5: BIOTRIO; P6: ORKESTRA SC; P7: ORKESTRA SC+BOMBARDEIRO; P8: ORKESTRA SC+BOMBARDEIRO+STIMUTROP; P9: Check.



When the genotypes are evaluated separately for grain yield, it is observed that TBIO Toruk was superior to all the others, obtaining a grain yield greater than 5000 kg ha^{-1}, followed by TBIO Trunfo, TBIO Astro and TBIO Ponteiro. TBIO Audaz was the genotype with the lowest grain yield. The genotypes BRS Belajoia, ORS Agile and ORS Madrepérola were intermediate to the others, with grain yields close to 3900 kg ha^{-1}.

Conclusions

The management protocols changed the variables cob length, cob weight, number of grains on the cob and cob grain weight to a greater extent.

The use of BOMBARDEIRO as a reinforcement to the chemical fungicide promoted an increase in the thousand grain weight.

The highest values for grain yield were obtained with the protocols BIOASIS+BIOEQUILÍBRIO+BIOFREE, BIOTRIO and ORKESTRA SC, for the genotypes TBIO Toruk, TBIO Ponteiro and TBIO Trunfo.

The use of biological management in wheat crops enhances nutrient absorption and acts synergistically with chemical fungicides, contributing to increased productivity and sustainable management. Further studies to clarify the potential of these associations in crops sown at the same time as wheat, such as white oats and barley, are important.

References

BOLTON, M. D.; KOLMER, J. A.; GARVIN, D. F. Wheat leaf rust caused by *Puccinia triticina*. **Molecular Plant Pathology**, v. 9, n. 5, p. 563-575, 2008. DOI: https://doi.org/10.1111/j.1364-3703.2008.00487.x

FAGOTTI, S. L.; ABRANTES, J. L. F.; CEREZINI, P.; FUKAMI, J.; NOGUEIRA, M. A.; DEL CERRO, P.; VALDERRAMA-FERNANEZ, R.; OLLERO, F. J.; MEGÍAS, M.; HUNGRIA, M. Quorum sensing communication: *Bradyrhizobium-Azospirillum* interaction via N-acyl-homoserine lactones in the promotion of soybean symbiosis. **Journal of Basic Microbiology**, v. 59, p. 38-53, 2019. DOI: https://doi.org/10.1002/jobm.201800324

FAO. **NSP – Integrated Pest Management**. 2020. Disponível em: https://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/en/. Acesso em: 30 ago. 2023.

FUKAMI, J.; CEREZINI, P.; HUNGRIA, M. *Azospirillum*: benefits that go far beyond biological nitrogen fixation. **AMB Express**, v. 8, n. 73, p. 1-12, 2018. DOI: https://doi.org/10.1186/s13568-018-0608-1

GOMES, F. P. **Curso de Estatística Experimental**. 14. ed. Piracicaba: Degaspari, 2000.

GU, Z-W.; YIN, J-H.; WU, H.; LIANG, Y-Q.; WU, W-H.; LU, Y.; LI, R.; TAN, S-B.; HE, C-P.; YI, K-X. Synergistic mechanism of *Bacillus subtilis* Czk1 combined with propiconazole and tebuconazole mixtures against *Pyrrhoderma noxium*. **Chemical and Biological Technologies in Agriculture**, v. 10, n. 113, p. 1-14, 2023. DOI: https://doi.org/10.1186/s40538-023-00487-4

GUIMARÃES, R. A.; ZANOTTO, E.; PERRONY, P. E. P.; ZANOTTO, L. A. S. Integrating a Chemical fungicide and *Bacillus subtilis* BIOUFLA2 ensures leaf protection and reduces ear rot (*Fusarium verticillioides*) and fumonisin contente in maize. **Journal of Phytopathology**, v. 169, p. 139-148, 2021. DOI: https://doi.org/10.1111/jph.12968

GUPTA, P. K.; CHAND, R.; VASISTHA, N. K.; PANDEY, S. P. Spot blotch disease of wheat: the current status of research on genetics and breeding. **Plant Pathology,** v. 67, n. 3, p. 508-531, 2017. DOI: https://doi.org/10.1111/ppa.12781

KARIYAWASAM, G. K.; WYATT N, S. H. I. G.; LIU, S.; YAN, C.; MA, Y.; ZHONG, S.; RASMUSSEN, J. B.; MOOLHUIJZEN, P.; MOFFAT, C. S.; FRIESEN, T. L.; LIU, Z. A genome-wide genetic linkage map and reference quality genome sequence for a new race in the wheat pathogen *Pyrenophora tritici-repentis*. **Fungal Genetics and Biology**, v. 152, p. 1-10, 2021. DOI: https://doi.org/10.1016/j.fgb.2021.103571

KHALID, A.; HAMEED, A.; TAHIR, M. F. Wheat quality: a review on chemical composition, nutritional attributes, grain anatomy, types, classification, and function of seed storage proteins in bread making quality. **Frontiers in Nutrition**, v. 10, 1053196, 2023. DOI: https://doi.org/10.3389/fnut.2023.1053196

KHAN, M. A.; RAHEEL, M.; KHAN, S. A.; ABID, A.; SHAZAD, S.; SIDDIQUI, H. Z.; ATIF, M.; HANIF, A. Eco-friendly management of wheat stripe rust trough application of *Bacillus subtilis* in a combination with plant defense activators. **Journal of King Saud University,** v. 35, n. 4, 102587, 2023. DOI: https://doi.org/10.1016/j.jksus.2023.102587

MAY, W. E.; BRANDT, S.; HUTT-TAYLOR, K. Response of oat grain yield and quality to nitrogen fertilizer and fungicides. **Agronomy Journal**, v. 122, n. 2, p. 1021-1034, 2020. DOI: https://doi.org/10.1002/agj2.20081

MEENA, R. S.; KUMAR, S.; DATTA, R.; LAL, R.; VIJAYAKUMAR, V.; BRTNICKY, M.; SHARMA, M. P.; YADAV, G. S.; JHARIYA, M. K.; JANGIR, C. K.; PATHAN, S. I.; DOKULILOVA, T.; PECINA, V.; MARFO, T. D. Impact of agrochemicals on soil microbiota and management: a review. **Land**, v. 9, n. 2, p. 1-22, 2020. DOI: https://doi.org/10.3390/land9020034

MOONJELY, S.; EBERT, M.; PATON-GLASSBROOK, D.; NOEL, Z.A.; ROZE, L.; SHAY, R.; WATKINS, T.; TRAIL, F. Update on the state of research to manage *Fusarium* head blight. **Fungal Genetics and Biology**, v. 169, 103829, p. 1-15, 2023. DOI: https://doi.org/10.1016/j.fgb.2023.103829

NASA POWER. **Prediction of Worldwide Energy Resource Applied Science Program**. 2022. Disponível em: https://power.larc.nasa.gov/docs/. Acesso em: 4 jul. 2023.

OLMEDO, C.; KOCH, A.; SARMIENTO, B.; IZQUIERDO, A. Antifungal potential of biosurfactants produced by strains of *Bacillus* spp. (Bacilalles: Bacillaceae) selected by molecular screening. **Revista de Biologia Tropical**, v. 7, p. 636-646, 2022. DOI: https://doi.org/10.15517/rev.biol.trop.2022.49716

ONS, L.; BYLEMANS, D.; THEVISSEN, K.; CAMMUE, B. P. A. Combining biocontrol agents with chemical fungicides for integrated plant fungal disease control. **Microorganisms**, v. 8, p. 1-19, 2020. DOI: https://doi.org/10.3390/microorganisms8121930

R CORE TEAM. **R:** a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2022.

REIS, E. M.; ZOLDAN, S. M.; ZANATA, M. Interactions between temperature and wheat head wetting duration on fusarium head blight intensity. **Summa Phytopathology**, v. 49, p. 1-5, 2023. DOI: https://doi.org/10.1590/0100-5405/268908

RISTAINO, J. B.; ANDERSON, P. K.; BEBBER, D. P.; BRAUMAN, K. A.; CUNNIFFE, N. J.; FEDOROFF, N. V.; FINEGOLD, C.; GARRETT, K. A.; GILLIGAN, C. A.; JONES, C. M.; MARTIN, M. D.; MACDONALD, G. K.; NEENAN, P.; RECORDS, A.; SCHMALE, D. G.; TATEOSIAN, L.; WEI, Q. The persistent threat of emerging plant disease pandemics to global food security. **Proceedings of the National Academy of Sciences of the United States of America**, v. 118, n. 23, e2022239118, 2021. DOI: https://doi.org/10.1073/pnas.2022239118

SANTOS, P. H. D.; SILVEIRA, S. F.; VIVAS, M.; CARVALHO, B. M.; PEREIRA, M. G. Alternative control to black spot disease in papaya genotypes. **Summa Phytopathology**, v. 43, n. 1, p. 60-62, 2017. DOI: https://doi.org/10.1590/0100-5405/2208

SILVA, E. R.; OLIVEIRA, J. N.; RUBIO, C. P.; DE LYRA, G. A.; RUBIO, C. P.; LYRA, G. A.; STEINER, F. Wheat sowing times for the central-south region of Mato Grosso. **Journal of Neotropical Agriculture**, v. 5, n. 1, p. 23-27, 2018.

SKENDZIC, S.; ZOVKO, M.; ZIVKOVIC, I. P.; LESIC, V.; LEMIC, D. The impact of climate change on agricultural insect pests. **Insects**, v. 12, n. 5, p. 1-31, 2021. DOI: https://doi.org/10.3390/insects12050440

STENBERG, J. A.; SUNDH, I.; BECHER, P. G.; BJORKMAN, C.; DUBEY, M.; EGAN, P. A.; FRIBERG, H.; GIL, J. F.; JENSEN, D. F.; JONSSON, M.; KARLSSON, M.; KHALIL, S.; NINKOVIC, V.; REHERMANN, G.; VETUKURI, R. R.; VIKETOFT, M. When is it biological control? A framework of definitions, mechanisms, and classifications. **Journal of Pest Science**, v. 91, p. 665-676, 2021. DOI: https://doi.org/10.1007/s10340-021-01354-7

WULFF, B. B. H.; KRATTINGER, S. G. The long road to engineering durable disease resistance in wheat. **Current Opinion in Biotechnology**, v. 73, p. 270-275, 2022. DOI: https://doi.org/10.1016/j.copbio.2021.09.002

YAN, S.; WU, Y.; FAN, J.; ZHANG, F.; ZHENG, J.; QIANG, S.; GUO, J.; XIANG, Y.; ZOU, H.; WU, L. Dynamic change and accumulation grain macronutrient (N, P and K) concentrations in winter wheat under different drip fertigation regimes. **Field Crops Research**, v. 250, p. 1-13, 2020. DOI: https://doi.org/10.1016/j.fcr.2020.107767

ZENG, X.; LUO, Y.; ZHENG, Y.; DUAN, X.; ZHOU, Y. Detection of laten infection of wheat leaves caused by *Blumeria graminis* f.sp. *tritici* using nested PCR. **Journal of Phytopathology**, v. 158, n. 4, p. 227-235, 2010. DOI: https://doi.org/10.1111/j.1439-0434.2009.01594.x

ZHENG, X.; YU, Z.; SHI, Y.; LIANG, P. Differences in water consumption of wheat varieties are affected by root morphology characteristics and post-anthesis root senescence. **Frontiers in Plant Science**, v. 12, p. 1-11, 2021. DOI: https://doi.org/10.3389/fpls.2021.814658