Mexican Journal of Phytopathology
e-ISSN: 2007-8080

Crossref
Open access

Phytopathological Note

Strategies to reduce losses from *Fusarium graminearum* head blight in bread wheat

Víctor Manuel Arzola-Mora[1], Héctor Eduardo Villaseñor-Mir[2], Salvador Carranza-González[*3], Carlos Sánchez-Abarca[1], René Hortelano-Santa-Rosa[2], Julio Huerta-Espino[2], María Elsa Rodríguez-Contreras[2], Pawan Kumar Singh[4], Xinyao He[4]. [1]Universidad Autónoma Chapingo, Departamento de Fitotecnia. Carretera México-Texcoco km 38.5, Chapingo, Estado de México, C. P. 56230. [2]Campo Experimental Valle de México - INIFAP. Carretera Los Reyes-Texcoco 9, km 13.5, Coatlinchán, Texcoco, Estado de México, México. C. P. 56250. [3]Posgrado en Recursos Genéticos y Productividad-Producción de Semillas-Colegio de Postgraduados. Campus Montecillo, Carretera México-Texcoco km 36.5, Montecillo, Texcoco, Estado de México. C. P. 56230. [4]International Maize and Wheat Improvement Center (CIMMYT), Apdo, Postal 6-641, 06600 CDMX, México.

***Corresponding author:**
Salvador Carranza-González
carranza.salvador@colpos.mx

Section:
Periodical issue

Received:
October 14, 2025
Accepted:
February 13, 2026
Published:
March 02, 2026

Citation:
Arzola-Mora VM, Villaseñor-Mir HE, Carranza-González S, Sánchez-Abarca C, Hortelano-Santa-Rosa R, *et al*. 2026. Strategies to reduce losses from *Fusarium graminearum* head blight in bread wheat. Mexican Journal of Phytopathology 44(2): 116. https://doi.org/10.18781/R.MEX.FIT.2510-3

ABSTRACT

Background/Objective. Head blight (fusarium), caused by *Fusarium graminearum* in bread wheat, reduces crop yield and contaminates the grain with mycotoxins such as deoxynivalenol (DON), which affects the quality and safety of the product. Its severity increases in warm and humid areas during flowering, which highlights the need for integrated management strategies. The present study aimed to evaluate the interaction between three wheat genotypes (Heilo, Falcin and Ocoroni F86) and three fungicides Tilt® 250 EC (25% propiconazole), Nativo® 300 SC [trifloxistrobin (20%) + tebuconazole (10%)); and Folicur® 250 EW (tebuconazole (25%)], in order to reduce the severity of *F. graminearum* and improve yield under field conditions during two production cycles.

Experimental development. The experiment was carried out at the INIFAP Valley of Mexico Experimental Field during the spring-summer 2022 and 2023 cycles, a split plot design with three replications was used. Agronomic variables such as days to flowering (DF), days to maturity (DM), plant height (ALT), grain yield (REND) and severity of *F. graminearum* in the head (FEsp) were recorded. Statistical analysis was carried out using ANOVA, Duncan´s test ($p<0.05$) and Pearson´s correlations.

Results. The Heilo variety, when propiconazole (25%) or trifloxistrobin (20%) + tebuconazole (10%) was applied, showed the highest yield (>4 000 kg ha^{-1}) and the lowest severity of fusarium head scab (FEsp ≤1.5). In contrast, Ocoroni F86 was susceptible, even under chemical treatment. Climatic conditions had a significant effect on the severity of the disease.

Conclusion. The combines use of varieties with genetic resistance and triazole fungicides is a feasible agronomic strategy to mitigate fusarium head scab. It is recommended to validate these results in different environments to expand their applicability.

Keywords: Fusarium head scab, Triazoles, Yield, Resistant varieties, Diseases

INTRODUCTION

Bread wheat (*Triticum aestivum*) is one of the world's main crops due to its nutritional and economic importance, as well as its strategic role in global food security. However, its production is threatened by fungal diseases, among which head blight or fusariosis, caused by *Fusarium graminearum*, is particularly significant. This disease reduces crop yield, deteriorates grain quality, and contaminates it with mycotoxins such as deoxynivalenol (DON), which pose a risk to human and animal health (Alisaac y Mahlein, 2023; Haile *et al*., 2019). Fusariosis has increased in severity in various regions of the world, including Mexico, as a result of intensive agricultural practices and warm, humid climatic conditions during the flowering stage (Beres *et al*., 2018). In this context, integrated crop management combines genetic resistance, appropriate agronomic practices, and the responsible use of fungicides is essential for disease management. Several studies have shown that triazole fungicides such as propiconazole and tebuconazole can reduce fusariosis severity and DON concentrations in grain (Klix *et al*., 2007; Wegulo *et al*., 2011), an effect that is enhanced in varieties with some level of genetic resistance (He *et al*., 2013).

Despite the above, the effectiveness of fungicides can be influenced by environmental conditions in the production region, the timing of application, and their interaction with the genotype. Therefore, it is necessary to generate information under local conditions to optimize fusariosis management strategies. In this study, the hypothesis was that the combined use of resistant varieties and fungicides reduces fusariosis severity and prevents yield losses in wheat. Accordingly, the objective was to evaluate the effect of three fungicides on three bread wheat genotypes (Heilo, Falcin, and Ocoroni F86) over two production cycles, in order to identify effective interactions for fusariosis control.

EXPERIMENTAL DEVELOPMENT

Experimental Setup. The study was conducted at the Campo Experimental Valle de México (CEVAMEX) of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), located in Texcoco, State of Mexico, during the 2022 and 2023 spring–summer cropping cycles. The site is situated at an altitude of 2 250 m, at geographic coordinates 19°26′40.86″N and 98°53′19.49″W. The regional climate is classified as temperate subhumid with summer rainfall, with a mean annual temperature of 16 °C.

Two bread wheat varieties were used: Heilo, a variety with 60 days to flowering (DF), 110 days to maturity (DM), and intermediate plant height; Ocoroni F86, a variety with 55 DF, 105 DM, and short stature; and the advanced line Falcin, with 55 DF, 105 DM, and tall stature. These genotypes were selected for their variability in response to head blight.

Treatments consisted of the foliar application of three fungicides readily available in the region: Tilt® 250 EC (propiconazole 25%; rate of 0.5 L ha^{-1}), Nativo® 300 SC (trifloxystrobin (20%) + tebuconazole (10%); rate of 0.2 kg ha^{-1}), and Folicur® 250 EW (tebuconazole (25%); rate of 0.6 L ha^{-1}), plus an untreated control. A single application was made at the anthesis growth stage, a critical period for infection by *F. graminearum*. The pathogen was inoculated at the tillering stage by spreading infected maize seed in the experimental plots, obtained according to the methodology of Lozano (2020). The strain was provided by the phytopathology programs of the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), following the protocols of He *et al*. (2013).

Conventional agronomic practices for wheat cultivation were implemented. Fertilization was applied using the 80-40-00 N-P-K formula at sowing and at the tillering stage. Irrigation was provided after sowing and weed control and phytosanitary monitoring were conducted according to the recommendations of the INIFAP-CEVAMEX wheat program.

Experimental design and statistical analysis. The experiment was conducted under a randomized complete block design with three replications in a split-plot treatment arrangement, where fungicide was considered the main plot and variety the subplot. Each experimental unit consisted of four rows, 5 m in length and spaced 0.3 m apart.

The following agronomic variables were evaluated: days to flowering (DF), days to physiological maturity (DM), plant height (ALT in cm), grain yield (REND in kg ha^{-1}), and severity of *F. graminearum* on the spike (FEsp) (Figure 1), which was determined by modifying the scale proposed by Stack and McMullen (1998). In this case, the scale considered each infected spikelet to represent 7%; accordingly, categories 1–4 corresponded to one spikelet up to one-third of the spikelets affected, categories 5–7 corresponded to approximately half of the spike infected, and categories 8–9 corresponded to two-thirds or more of the spike affected. Data was analyzed using analysis of variance (ANOVA) under a split-plot model. Mean comparisons were performed using Duncan's test ($p \leq 0.05$), and Pearson correlation coefficients were calculated among the evaluated variables. All analyses were conducted using SAS® software version 9.4 (SAS Institute Inc., 2009).

The analysis of variance showed significant differences between years for ALT, REND, and FEsp, and a stronger statistical effect for DF. For fungicides, significant differences were detected for DM and highly significant differences for REND and FEsp. For varieties, highly significant differences were detected for all variables.

Highly significant interactions were observed for REND in the years × fungicides and years × variety combinations (Table 1). The year factor significantly influenced days to flowering (DF), plant height (ALT), and yield (REND), suggesting that environmental conditions between cropping cycles affected the phenological development and productivity of the crop.

Figure 1. Modified visual scale by Stack and McMullen (1998), used to assess the severity of *F. graminearum* in spikes, modified. **A)** Low severity: similar heads obtained values on the scale of 1-4; **B**) Medium severity: similar heads obtained values on the scale of 5-7; **C**) High severity: similar heads obtained a scale of 8-9.

Table 1. Analysis of variance (ANOVA) and statistical significance between the interactions of three varieties of bread wheat and three fungicides in two production cycles.

SV	df	DF	DM	ALT	REND	FEsp
Years	1	147 **	13.4 ns	501.3 *	31 574 755 *	2.7 *
Rep (Years)	4	1 ns	4.3 **	78.4 ns	497 154 ns	0.1 ns
Fungicide	3	0.4 ns	18.5 *	34.8 ns	2 178 090 **	7.1 **
Years x Fungicide	3	0.1 ns	2.7 ns	9.4 ns	480 944 **	0.2 ns
Rep x Fungicide (Years)	12	0.9 ns	0.8 ns	53.3 ns	22 124 ns	0.2 ns
Var	2	392 **	243.8 **	4344.6 **	10 982 662 **	160.6 **
Years x Var	2	5 **	976 **	30.1 ns	2 299 417 **	11.1 **
Fungicide x Variety	6	0.1 ns	0.2 ns	23.1 ns	114 461 ns	0.6 *
Years x Fung x Var	6	0.4 ns	1.9 *	29.6 ns	172 587 *	0.3 ns
Error	39	0.5	0.6	37.9	189 515	0.1
Total	71					
R^2		0.98	0.97	0.90	0.92	0.99
CV (%)		1.30	0.74	7.17	11.33	8.72
Mean		58.0	109.9	85.9	3842	4.1

SV= source of variation, df= degrees of freedom, DF= days to flowering, DM= days to maturity, ALT= plant height in cm, REND= yield in kg ha^{-1}, FEsp= *F. graminearum* in the head, Rep= repetitions within each year, Fung= fungicide, Var= variety, R^2= coefficient of determination, CV= coefficient of variation, **= statistical significance at $p \leq 0.001$, *= statistical significance at $p \leq 0.05$, ns= not significant.

Table 2 shows the mean comparisons for the agronomic variables DF, ALT, and REND over two production cycles. In year 1, the average DF values were higher (59.5 days) than in year 2 (56.6 days). For DM, no significant differences were observed between years, indicating similar maturity. For ALT, values were also higher in year 1 (88.6 cm) compared to year 2 (83.3 cm).

In contrast, grain yield (REND) was lower in year 2 (3 179 kg ha^{-1}) than in year 1 (4 504 kg ha^{-1}). In the first year, FEsp showed higher values (4.4) compared to year 2 (3.0), indicating greater pathogen severity during that cycle.

Table 2. Comparison of means of the variables evaluated in three wheat varieties in two production cycles.

Year	DF	DM	ALT	REND	FEsp
1	59.5 a	109.9 a	88.6 a	4504 a	4.4 a
2	56.6 b	110.5 a	83.3 b	3179 b	3.0 b

DF= days to flowering, DM= days to maturity, ALT= plant height in cm, REND= yield in kg ha^{-1}, FEsp= *F. graminearum* in the ear. Values with the same letter do not differ from each other (Duncan, 0.05).

Table 3 shows that treatments with the fungicides propiconazole (25%), trifloxystrobin (20%) + tebuconazole (10%), and tebuconazole (25%) exhibited similar DM values among them and higher than the untreated control (110.3 to 110.6 vs. 108.4 days), suggesting that fungicide use was associated with an extension of the crop maturity cycle, attributable to reduced stress caused by fusariosis.

Treatments with trifloxystrobin (20%) + tebuconazole (10%) and tebuconazole (25%) showed the highest yields (4 092 and 3 998 kg ha^{-1}, respectively), followed by propiconazole (25%) (3 949 kg ha^{-1}). In contrast, the untreated control showed the lowest yield (3 327 kg ha^{-1}), confirming the negative effect of the disease when fungicides were not applied. With propiconazole (25%), trifloxystrobin (20%) + tebuconazole (10%), and tebuconazole (25%), significantly lower fusariosis severity levels (3.8) were observed compared to the untreated control (5.1).

Table 3. Comparison of means of the variables evaluated for three fungicides and three varieties of bread wheat during two production cycles.

Fungicide	DM	REND	FEsp
Tilt®	110.6 a	3 949 a	3.8 b
Nativo®	110.4 a	4 092 a	3.8 b
Folicur®	110.3 a	3 998 a	3.8 b
Control	108.4 b	3 327 b	5.1 a

DM= days to maturity, REND= yield in kg ha^{-1}, FEsp= *F. graminearum* in the ear. Values with the same letter do not differ from each other (Duncan, 0.05).

Table 4 presents the mean values for each of the evaluated varieties. The variety Heilo showed the highest value for REND (4 241 kg ha^{-1}), followed by Falcin, whereas Ocoroni F86 recorded the lowest yield.

Similarly, Heilo exhibited the lowest FEsp value, indicating lower disease severity in this genotype. In contrast, Ocoroni F86 showed the lowest values for all evaluated variables except FEsp, for which it had the highest value, indicating that the disease had a greater impact on this genotype compared to the others.

The Falcin line, with a yield of 4,223 kg ha^{-1} and low fusariosis severity (4.0), presented an acceptable combination of yield and disease tolerance, making it a viable alternative in environments where the incidence and severity of *F. graminearum* are low. Likewise, the variety Heilo would be an alternative for environments with high disease incidence.

Table 4. Comparison of means of the variables evaluated in two production cycles in three varieties of bread wheat.

Variety	DF	DM	ALT	REND	FEsp
Heilo	62.7 a	113.1 a	87.1 b	4 241 a	1.6 c
Falcin	55.7 b	109.9 b	98.7 a	4 223 a	4.0 b
Ocoroni F86	55.7 b	106.7 c	71.9 c	3 061 b	6.8 a

DF= days to flowering, DM= days to maturity, ALT = plant height in cm, REND= yield in kg ha^{-1}, FEsp= *Fusarium* in the head. Values with the same letter do not differ from each other (Duncan, 0.05).

Comparison of treatments among varieties. The combinations Heilo + propiconazole (25%) and Heilo + trifloxystrobin (20%) + tebuconazole (10%) achieved the highest yields (>4 300 kg ha^{-1}) and the lowest fusariosis severity (FEsp = 1.5). In contrast, Ocoroni F86, even with fungicide application, did not exceed 3 232 kg ha^{-1} in yield and showed high infection levels (FEsp > 6.1).

Figure 2 shows the variation in wheat yield according to the combination of three fungicides [propiconazole (25%), trifloxystrobin (20%) + tebuconazole (10%), and tebuconazole (25%)] and three bread wheat varieties (Falcin, Heilo, and Ocoroni), compared with an untreated control (no fungicide).

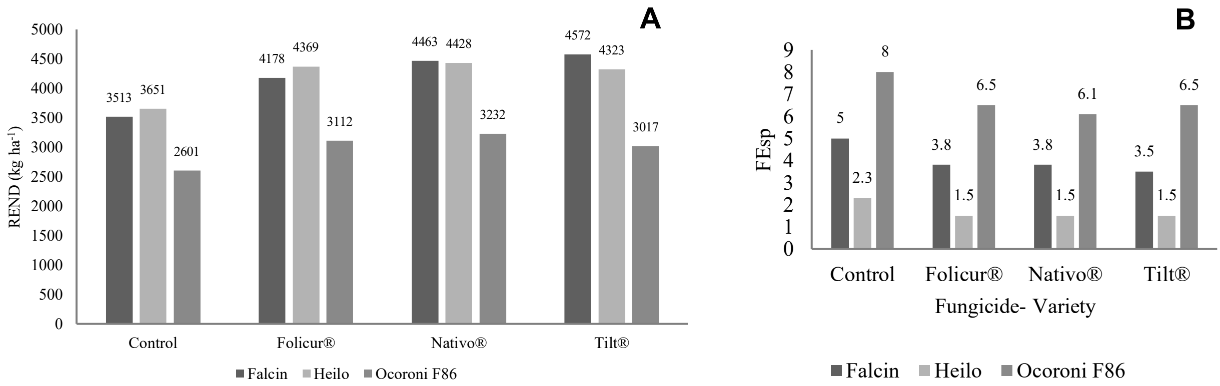

Figure 2. Mean yield **(A)** and severity of *F. graminearum* **(B)** in the head (FEsp) for the interaction of three varieties of bread wheat and three fungicides.

The results in Figure 2 show a correlation between *F. graminearum* severity on the spike and wheat yield. The most effective combinations [Heilo with propiconazole (25%) or trifloxystrobin (20%) + tebuconazole (10%)] reduced *F. graminearum* severity. Heilo showed the highest yield and level of resistance; the disease reduced its productivity by approximately 15%. The correlation coefficients obtained for DM and FEsp showed a highly significant negative relationship (−0.856), indicating an inverse association between these variables, where genotypes with a longer maturity period exhibited lower fusariosis severity.

Comparison between cropping cycles. Environmental conditions may have influenced disease severity during year 1, as documented in previous studies (Paul *et al*., 2007; Wegulo *et al*., 2015). The higher fusariosis severity observed in year 1 could be associated with climatic conditions more favorable for pathogen development, such as high humidity and warm temperatures during flowering, as reported by Beres *et al*. (2018). The lower severity in year 2 suggests that conditions were less conducive to disease development. During year 1, the greater fusariosis severity may also have been related to flowering and maturity timing, as shorter cycles may limit the plant's ability to respond to biotic stress (Vaughan *et al*., 2016).

Effect of fungicide on yield and fusariosis severity. The present study is consistent with reports demonstrating that triazoles are effective for fusariosis control and crop productivity. Klix *et al*. (2007) reported the effect of propiconazole (25%) (Tilt®) and trifloxystrobin (20%) + tebuconazole (10%) (Nativo®) in reducing *F. graminearum* severity by inhibiting ergosterol synthesis in fungal cell membranes, thereby preventing fungal growth and reproduction. Likewise, according to Lux *et al*. (2023), triazole-based fungicides such as propiconazole and tebuconazole have been shown to be effective in reducing fusariosis severity and lowering DON (deoxynivalenol) accumulation.

In this study, Heilo stood out for presenting higher yield (4,241 kg ha^{-1}) and lower disease severity, which is consistent with previous research reporting the genetic resistance of Heilo to *F. graminearum* (He *et al*., 2013). The results of the present study confirm the importance of genetic resistance in minimizing the impact of fusariosis on wheat yield (Mesterházy *et al*., 2003). As mentioned previously, the variety Heilo, with its superior yield and lower fusariosis severity, stands out as a preferred option for regions with high disease severity.

Varieties with longer phenological cycles, such as Heilo, often exhibit greater tolerance to biotic stress, as noted by Wu *et al*. (2022). This may be related to greater reserve accumulation and more uniform development under adverse conditions.

Performance of varieties and fungicide use. The combination of the variety Heilo + propiconazole (25%) and Heilo + trifloxystrobin (20%) + tebuconazole (10%) showed the highest yields and the lowest fusariosis severity, consistent with the findings of He *et al*. (2013), who reported that genetically resistant varieties such as Heilo can optimize fungicide efficacy by reducing disease severity and improving yield stability. In addition, Wegulo *et al*. (2011) emphasize that genetic resistance, when combined with appropriate chemical treatment, results in lower yield losses.

The negative association between DM and FEsp suggests that long-cycle varieties may partially hinder the establishment of *F. graminearum* (Ponte *et al*., 2007). The variety Ocoroni F86, which showed high susceptibility to *F. graminearum*, with FEsp values ranging from 6.5 to 8.0 even with the use of fungicides such as propiconazole (25%) and trifloxystrobin (20%) + tebuconazole (10%), highlights the importance of avoiding the cultivation of susceptible varieties in areas with high fusariosis severity. This disease not only reduces yield but also increases the risk of mycotoxin accumulation. These results are consistent with those reported by Mesterházy *et al*. (2003), who emphasized that susceptible varieties make less effective use of fungicides and exhibit lower grain quality.

The lower disease severity observed in the variety Heilo suggests that resistant and/or tolerant varieties not only limit pathogen spread but also optimize the efficacy of chemical treatments (Shude *et al*., 2020). This aligns with the objective of developing management strategies that integrate genetic resistance with chemical control, as proposed for this variety by He *et al*. (2013). The longer phenological cycle of Heilo, characterized by more days to flowering and maturity, may be associated with a greater capacity to tolerate biotic stress and maximize grain filling, thereby increasing yield.

Overall, the results of the present study highlight the importance of planting resistant varieties to achieve more effective integrated management of *F. graminearum*. In addition, the selection of specific fungicides such as propiconazole (25%) or trifloxystrobin (20%) + tebuconazole (10%), which proved to be the most effective in this research, ensures adequate chemical control when used in combination with resistant varieties. This combined strategy not only reduces *F. graminearum* severity but also contributes to the sustainability of wheat production systems in regions vulnerable to this disease, as well as to the reduction of the pathogen’s seasonal inoculum.

CONCLUSIONS

The results showed that the variety Heilo, in combination with propiconazole (25%) or trifloxystrobin (20%) + tebuconazole (10%), exhibited favorable performance in terms of yield (>4,000 kg ha^{-1}) and lower pathogen severity (FEsp $\leq$ 1.5), highlighting the importance of implementing integrated strategies to reduce losses caused by fusariosis in environments with optimal conditions for its development.

Limitations. Although relevant, this study presents certain limitations that should be considered when interpreting the results. The research was conducted under the conditions of the Campo Experimental Valle de México; therefore, its findings can be extrapolated only to similar production environments. A limited number of varieties and fungicides were evaluated, which restricts generalization to other genotypes or active ingredients. Fusariosis severity was estimated through visual assessment, which, although validated, may introduce some degree of subjective bias. In addition, the pathogen was artificially dispersed, which does not fully represent the natural dynamics of field infection. Finally, as the study was based on two production cycles, it is recommended to replicate this approach across more environments and years to validate the stability of the results.

Conflict of interest. None of the authors has any conflict of interest related to this work.

Funding. This research was funded by the project "Understanding and Managing *Fusarium* Head Blight in Mexico" (CIMMYT/INIFAP).

Acknowledgments. To the INIFAP project "Programa Nacional de Mejoramiento Genético para generar variedades resistentes a royas, de alto rendimiento y alta calidad para una producción sustentable de trigo en México." To the CIMMYT Wheat Pathology Program.

Author Contributions. Experiment establishment, management, and data recording: Víctor Manuel Arzola Mora, Héctor Eduardo Villaseñor Mir, Salvador Carranza González, and René Hortelano Santa Rosa. Data analysis: Carlos Sánchez Abarca and René Hortelano. Interpretation and editing: Julio Huerta Espino and María Elsa Rodríguez Contreras. Funding acquisition and conceptualization: Pawan K. Singh, Xinyao He, and Héctor Eduardo Villaseñor Mir. All authors have read and approved the content of the manuscript.

REFERENCES

Alisaac E and Mahlein AK. 2023. *Fusarium* head blight on wheat: biology, modern detection and diagnosis and integrated disease management. Toxins 15(3): 192. https://doi.org/10.3390/toxins15030192

Beres BL, Brûlé-Babel AL, Ye Z, Graf RJ, Turkington TK, *et al.* 2018. Exploring genotype × environment × management synergies to manage Fusarium head blight in wheat. Canadian Journal of Plant Pathology 40(2): 179–188. https://doi.org/10.1080/07060661.2018.1445661

Haile JK, N'diaye A, Walkowiak S, Nilsen KT, Clarke JM, *et al*. 2019. *Fusarium* head blight in durum wheat: recent status, breeding directions, and future research prospects. Phytopathology 109(10): 1664–1676. https://doi.org/10.1094/PHYTO-03-19-0095-RVW

He X, Singh PK, Duveiller E, Schlang N, Dreisigacker S and Singh RP. 2013. Identification and characterization of international Fusarium head blight screening nurseries of wheat at CIMMYT, Mexico. European Journal of Plant Pathology 136(1): 123–134. https://doi.org/10.1007/s10658-012-0146-7

Klix MB, Verreet JA and Beyer M. 2007. Comparison of the declining triazole sensitivity of *Gibberella zea* and increased sensitivity achieved by advances in triazole fungicide development. Crop Protection 26(4): 683–690. https://doi.org/10.1016/j.cropro.2006.06.006

Lozano N. 2020. CIMMYT/PR-WP-20: Increasing *Fusarium* on corn for FHB nursery inoculum. CIMMYT. México. https://repository.cimmyt.org/

Lux LA, Halvorson J, Hansen B, Meyer S, Carruth D, *et al.* 2023. Effects of metconazole + prothioconazole, pydiflumetofen + propiconazole, and variety resistance on Fusarium head blight and yield in hard red spring wheat. Plant Health Progress 24(2): 155–161. https://doi.org/10.1094/PHP-08-22-0070-RS

Mesterházy Á, Bartók T and Lamper C. 2003. Influence of wheat cultivar, species of *Fusarium*, and isolate aggressiveness on the efficacy of fungicides for control of Fusarium head blight. Plant Disease 87(9): 1107–1115. https://doi.org/10.1094/PDIS.2003.87.9.1107

Paul PA, Lipps PE, Hershman DE, McMullen MP, Draper MA, *et al*. 2007. A quantitative review of tebuconazole effect on Fusarium head blight and deoxynivalenol content in wheat. Phytopathology 97(2): 211–220. https://doi.org/10.1094/PHYTO-97-2-0211

Ponte EM, Fernandes JMC and Bergstrom GC. 2007. Influence of growth stage on *Fusarium* head blight and deoxynivalenol production in wheat. Journal of Phytopathology 155(10): 577–581. https://doi.org/10.1111/j.1439-0434.2007.01281.x

SAS Institute Inc. 2009. SAS® 9.4. Statistical Analysis System. SAS Institute Inc. Cary, NC, USA. https://www.sas.com

Shude SPN, Yobo KS and Mbili NC. 2020. Progress in the management of Fusarium head blight of wheat: an overview. South African Journal of Science 116(11/12): Art. #7854. https://doi.org/10.17159/sajs.2020/7854

Stack RW and McMullen M. 1998. A visual scale to estimate severity of *Fusarium* head blight in wheat. North Dakota State University Extension Circular. Fargo, ND, USA. https://scabusa.org/pdfs/StackMcMullen_2011_pp1095.pdf

Vaughan M, Backhouse D and Del Ponte EM. 2016. Climate change impacts on the ecology of *Fusarium graminearum* species complex and susceptibility of wheat to Fusarium head blight: a review. World Mycotoxin Journal 9(5): 685–700. https://doi.org/10.3920/WMJ2016.2053

Wegulo SN, Baenziger PS, Hernandez Nopsa J, Bockus WW and Hallen-Adams H. 2015. Management of Fusarium head blight of wheat and barley. Crop Protection 73: 100–107. https://doi.org/10.1016/j.cropro.2015.02.025

Wegulo SN, Bockus WW, Hernandez Nopsa J, De Wolf ED, Eskridge KM, *et al.* 2011. Effects of integrating cultivar resistance and fungicide application on Fusarium head blight and deoxynivalenol in winter wheat. Plant Disease 95(5): 554–560. https://doi.org/10.1094/PDIS-07-10-0495

Wu L, He X, He Y, Jiang P, Xu K, *et al.* 2022. Genetic sources and loci for *Fusarium* head blight resistance in bread wheat. Frontiers in Genetics 13: 988264. https://doi.org/10.3389/fgene.2022.988264