USDA-ARS | U.S. Wheat and Barley Scab Initiative

FY21 FINAL Performance Progress Report

Due date: July 26, 2023

Cover Page

USDA-ARS Agreement ID:	59-0206-0-131
USDA-ARS Agreement Title:	Fusarium Head Blight Risk Assessment, Management, and Education
Principle Investigator (PI):	Pierce Paul
Institution:	Ohio State University
Institution UEI:	DLWBSLWAJWR1
Fiscal Year:	2021
FY21 USDA-ARS Award Amount:	$84,704
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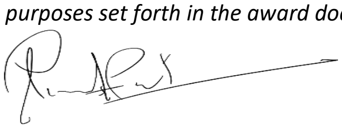
Period of Performance:	5/13/21 - 5/12/23
Reporting Period End Date:	5/12/2023

USWBSI Individual Project(s)

USWBSI Research Category[ǂ]	Project Title	ARS Award Amount
MGMT-IM	Efficacy of Miravis Ace in Combination with Resistance for FHB and DON Management	$72,738
MGMT	Application of Model Ensembles and Machine Learning to the Prediction of Fusarium Head Blight	$11,966
	FY21 Total ARS Award Amount	$84,704

I am submitting this report as a: ☒ FINAL Report

I certify to the best of my knowledge and belief that this report is correct and complete for performance of activities for the purposes set forth in the award documents.



07/26/2023

Principal Investigator Signature   Date Report Submitted

[ǂ] BAR-CP – Barley Coordinated Project
DUR-CP – Durum Coordinated Project
EC-HQ – Executive Committee-Headquarters
FST-R – Food Safety & Toxicology (Research)
FST-S – Food Safety & Toxicology (Service)
GDER – Gene Discovery & Engineering Resistance
HWW-CP – Hard Winter Wheat Coordinated Project
MGMT – FHB Management
MGMT-IM – FHB Management – Integrated Management Coordinated Project
PBG – Pathogen Biology & Genetics
TSCI – Transformational Science
VDHR – Variety Development & Uniform Nurseries
NWW –Northern Soft Winter Wheat Region
SPR – Spring Wheat Region
SWW – Southern Soft Red Winter Wheat Region

Project 1: Efficacy of Miravis Ace in Combination with Resistance for FHB and DON Management

1. **What are the major goals and objectives of the research project?**
   The overall goal of this project (as part of the FHB Integrated Management Coordinated Project [**IM_CP**]) was to develop best-management practices for FHB and mycotoxins in wheat that are robust to conditions experienced in production fields. The specific objectives were to:
   1) Evaluate the integrated effects of fungicide treatment and genetic resistance on FHB and DON, with emphasis on the new fungicide, Miravis Ace.
   2) Compare the efficacy of Miravis Ace when applied at early heading (Feekes 10.3) or at early anthesis (Feekes 10.5.1) to that of standard Feekes 10.5.1 applications of Prosaro and Caramba.
   3) Compare the efficacy of single and sequential applications of Miravis Ace, Prosaro, Caramba, and tebuconazole against FHB and DON.
   4) Determine the effects of rainfall timing, amount, and duration on the efficacy and residual life of Miravis Ace, Prosaro, and Caramba on wheat spikes.

2. **What was accomplished under these goals or objectives?** *(For each major goal/objective, address these three items below.)*

   a) What were the major activities?

   Obj 1 (**Wheat IM Coordinated Project; IM_CP - Ohio):** Inoculated field experiments were conducted in Ohio during the 2018, 2019, 2020, and 2021 growing seasons following the IM-CP standard protocol. Six fungicide treatments (**1-** nontreated, inoculated check; **2-** Prosaro at Feekes 10.5.1; **3-** Miravis Ace at Feekes 10.5.1; **4-** Miravis Ace at Feekes 10.3; **5-** Prosaro at Feekes 10.5.1, non-inoculated; **6-** Miravis Ace at anthesis followed by Folicur at 4 DAA; amd **7-** nontreated, non-inoculated check) were assigned to plots of wheat cultivars with different levels of resistance to FHB.

   Obj 2 and 3 (Wheat Uniform Fungicide Trial: UFT - Ohio): During the 2018-2021growing seasons, separate plots of a susceptible wheat cultivar were subjected to eleven fungicide treatments: **1)** a nontreated check; **2)** Prosaro at Feekes 10.5.1; **3)** Caramba at Feekes 10.5.1; **4)** Miravis Ace at Feekes 10.3; **5)** Miravis Ace at Feekes 10.5.1; **6)** Miravis Ace at Feekes 10.5.1 followed by Prosaro at 4 days after early anthesis (DAA); **7)** Miravis Ace at anthesis followed by Caramba at 4 DAA; and **8)** Miravis Ace at anthesis followed by Folicur at 4 DAA; and **9)** Miravis Ace at 4 DAA.

   Obj 4 (Rainfastness): During the 2020, 2021, and 2022 growing seasons, separate plots of a susceptible wheat cultivar were treated with Miravis Ace, Prosaro, or Caramba at Feekes 10.5.1 or left nontreated, after which separate groups of plots were subjected to simulated rainfall treatments of different durations (15, 30, 60, and 120 min), beginning at different times (0, 15, 30, and 60 min) after fungicide application.

   In all trials, Prosaro, Caramba, Miravis Ace, and Folicur were applied at 6.5, 13.5, 13.7, and 4 fl. oz./A, respectively, along with a non-ionic surfactant (except for a few treatments in the rainfast experiment), plots were spray-inoculated with a spore suspension *Fusarium* *graminearum* at Feekes 10.5.1 (unless otherwise stated), and FHB index (IND), DON, FDK, foliar diseases severity, yield, and test weight data were collected and analyzed.

b) What were the significant results?

Obj 1 (IM_CP - Ohio): Across the four growing seasons, for all tested resistance classes, all fungicide treatments resulted in significantly lower mean FHB IND and DON than the nontreated check, with treatments applied at Feekes 10.5.1 having lower mean responses, particularly for DON, than the Feekes 10.3 application of Miravis Ace. Management programs consisting of a fungicide application to an MR or MS cultivar had the lowest overall mean levels of IND and DON than other cultivar resistance by fungicide treatment combinations.
Obj 2 and **3 (UFT - Ohio):** Across the four growing seasons, all fungicide-treated plots had significantly lower mean IND and DON than the nontreated check. For both responses, treatments consisting of sequential applications of Miravis Ace at anthesis followed by a DMI at 4-6 DAA resulted in significantly lower mean IND and DON than single-application treatments. Among single-application treatments, the Feekes 10.3 application of Miravis Ace had the highest mean level of DON.
Obj 4 (Rainfastness): Across the three growing seasons, when applied with a surfactant, all fungicide-treated plots had significantly lower mean IND and DON than the nontreated check, with Prosaro, Caramba and Miravis Ace having similar mean levels of IND and DON across rainfall treatments. Mean IND and DON levels were considerably higher when the fungicides were applied without the surfactant and plots were subjected to 120 min of simulated rainfall, beginning immediately after the treatments were applied.

c) List key outcomes or other achievements.

Coordinated IM and UFT trials were successfully conducted in 16 US states over four growing seasons. Based on the pooled data, efficacy of the tested fungicide treatments and integrated management programs were consisted across location-years and wheat market classes. Trends in terms of the overall mean responses were comparable to those observed in Ohio.
Obj. 1: Relative to the nontreated, susceptible check, IM programs that consisted of an anthesis application of Prosaro or Miravis Ace to a moderately resistant or moderately susceptible cultivar were the most effective, reducing FHB IND by 87 to 93% and DON by 82 to 89%.
Obj. 2: When applied at anthesis, Miravis Ace was more effective than Prosaro and Caramba, reducing IND and DON by 85 and 68%, respectively, relative to the check, compared to 75 and 60% for Caramba and 63 and 58% for Prosaro. The Feekes 10.3 application of Miravis Ace was the least effective of all tested fungicide treatments, reducing IND by 56% and DON by 32%, relative to the check.
Obj. 3: Treatments consisting of sequential applications of Miravis Ace at early anthesis followed by a DMI 4-6 days later were the most effective of all tested treatments, reducing IND by 91 to 94% and DON 74 to 85%.
Obj. 4: Averaged across simulated rainfall durations, Prosaro, Caramba, and Miravis Ace were rainfast immediately after application, when applied with the nonionic surfactant Induce, reducing IND by 69 to 85% and DON by 59 to 71% relative to the check. However, when applied without the surfactant and subjected to two hours of rainfall beginning immediately after application, efficacy again IND and DON decreased substantially to 8 to 47% and 19 to 40%, respectively.

3. **What opportunities for training and professional development has the project provided?**
Postdoctoral researchers, research technicians, and graduate students contributed to the project, learning how to design field experiments and collect data to evaluate FHB and DON management programs. They also learned and contributed to data analysis and the preparation of abstracts, posters, and talks for scientific meetings; graphs and tables for extension talks; and manuscripts for publication.

4. **How have the results been disseminated to communities of interest?**
Results were disseminated by way of posters, abstracts, and talks at scientific meetings, electronic newsletter articles, extension talks, and field days.

Project 2: Application of Model Ensembles and Machine Learning to the Prediction of Fusarium Head Blight

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1. **What are the major goals and objectives of the research project?**
   The overall goal of this project is to create better models for predicting Fusarium head blight (FHB). The objectives ware to:
   1) Enhance the FHB data matrix with observations collected in collaboration with the MGMT IM-CP during recent growing seasons (**Paul lab**).
   2) Improve predictive models for FHB through "ensemble modeling" approaches that combine estimates from multiple models resulting in a more robust estimate of disease risk (**DeWolf lab**).
   3) Further apply machine learning algorithms that better address non-linear relationships between weather and FHB risk (**DeWolf lab**).

2. **What was accomplished under these goals or objectives?** *(For each major goal/objective, address these three items below.)*

   a) What were the major activities?
   Obj 1: During each year of the project, integrated management trials were conducted as part of the MGMT_CP in several wheat-growing states (AL, DE, IL, IN, KS, KY, LA, MD, MI, MO, MN, ND, NE, NY, OH, PA, SD, TN, VA, and WI). In each trial, at least two commercial wheat cultivars, classified as susceptible, moderately susceptible, or moderately resistant, were planted. FHB index, incidence and DON data were collected from nontreated, naturally infected, non-irrigated plots of each cultivar and edited for inclusion in the master data file for FHB risk model development and validation.
   Obj 2: Several ensemble modeling approaches, including soft voting, weighted model averaging, and stacking were used to combine logistic regression models (developed during previous funding cycles) that are correlated in their predictions of FHB epidemics. Model ensembles were validated for their accuracy and compared to the original logistic regression models.
   Obj 3: Using the GPS coordinates for each trial-location-year, weather data were mined, checked, edited, cleaned, and then summarized to generate potential weather-based predictors. Working closely with the DeWolf lab, the master dataset (a matrix of FHB observations and weather variables) was used to develop and validate models to predict FHB epidemics using Random Forest algorithms for variable selection.

   b) What were the significant results?
   Obj 1: Each year, several new cases (unique combination of cultivar resistance class x trial/environment) with a range of mean IND levels representing epidemics (mean IND $\geq 10\%$) and non-epidemics (mean IND $< 10\%$) were collected across states and wheat market classes, expanding the range of environmental conditions available in our master dataset for model development.
   Obj 2: The stacking ensemble modeling approach outperformed the soft voting and weighted regression averaging approaches, resulting in an overall increase in prediction accuracy relative to the original logistic regression models.

Obj 3: A total of 58 RF models were built, each with no more than 14 predictors.

c) List key outcomes or other achievements.

Obj 1: Each year, FHB IND data were successfully mined from MGMT_CP trials conducted in several US stated, generating new observations that represented a range of environmental conditions and wheat market classes for FHB model development.

Obj 2: Several ensembles of simple, correlated logistic regression models were successfully developed and tested, yielding promising results in terms of prediction accuracy. This bodes well for possible utilization of this approach to develop more accurate FHB risk assessment models.

Obj 3: We successfully developed RF models that were superior to previously developed logistic regression models in terms of predictive performance.

3. What opportunities for training and professional development has the project provided?

The postdocs and graduate student who contributed to the MGMT_CP learned certain basic aspects of data mining for predictive model development.

4. How have the results been disseminated to communities of interest?

One manuscript was published in *PLOS Computational Biology* and another in Phytopathology.

Publications, Conference Papers, and Presentations

Please include a listing of all your publications/presentations about your FHB work that were a result of funding from your FY21 grant award. Only citations for publications published (submitted or accepted) or presentations presented during the **award period** should be included.

Did you publish/submit or present anything during this award period?

☒ Yes, I've included the citation reference in listing(s) below.

☐ No, I have nothing to report.

Journal publications as a result of FY21 award

List peer-reviewed articles or papers appearing in scientific, technical, or professional journals. Include any peer-reviewed publication in the periodically published proceedings of a scientific society, a conference, or the like.

Identify for each publication: Author(s); title; journal; volume: year; page numbers; status of publication (published [include DOI#]; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).

PEER-REVIEWED ARTICLES:

1. Shah, D. A., De Wolf, E. D., Paul, P. A., and Madden, L. V. 2021. Accuracy in the prediction of disease epidemics when ensembling simple but highly correlated models. *PLoS Computational Biology* 17(3): e1008831. https://doi.org/10.1371/journal.pcbi.1008831 Published. Acknowledgement of federal support (yes)
2. Moraes, W. B., Madden, L. V., and Paul, P. A. 2022. Characterizing heterogeneity and determining sample sizes for accurately estimating wheat Fusarium head blight index in research plots. Phytopathology 112:315-334. https://apsjournals.apsnet.org/doi/10.1094/PHYTO-04-21-0157-R. Published. Acknowledgement of federal support (yes)
3. Moraes, W. B., Madden, L. V., and Paul, P. A. 2022. Efficacy of genetic resistance and fungicide application against Fusarium head blight and mycotoxins in wheat under persistent pre- and post-anthesis moisture. Plant Dis. 106:2839-2855. https://apsjournals.apsnet.org/doi/10.1094/PDIS-02-22-0263-RE. Published. Acknowledgement of federal support (yes)
4. Moraes, W. B., Madden, L. V., Baik, Byung-Kee, Gillespie, J., and Paul, P. A. 2023. Environmental conditions after Fusarium head blight visual symptom development affect contamination of wheat grain with deoxynivalenol and deoxynivalenol-3-glucocide. Phytopathology 113:206-224. https://apsjournals.apsnet.org/doi/10.1094/PHYTO-06-22-0199-R Published. Acknowledgement of federal support (yes)
5. Moraes, W. B., Madden, L. V., Gillespie, J., and Paul, P. A. 2023. Environment, grain development, and harvesting strategy effects on zearalenone contamination of grain from Fusarium head blight-affected wheat spikes. Phytopathology 113:225-238. htps://apsjournals.apsnet.org/doi/10.1094/PHYTO-05-22-0190-R Published. Acknowledgement of federal support (yes)
6. Shah, D. A., De Wolf, E. D., Paul, P. A., and Madden, L. V. 2023. Into the trees: random forests for predicting Fusarium head blight epidemics of wheat in the United States. Phytopathology 113: https://doi.org/10.1094/PHYTO-10-22-0380-R. Published (first look March 2023). Acknowledgement of federal support (yes)

Books or other non-periodical, one-time publications as a result of FY21 award

Report any book, monograph, dissertation, abstract, or the like published as or in a separate publication, rather than a periodical or series. Include any significant publication in the proceedings of a one-time conference or in the report of a one-time study, commission, or the like.

Identify for each one-time publication: Author(s); title; editor; title of collection, if applicable; bibliographic information; year; type of publication (book, thesis, or dissertation, other); status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).

DISSERTATION:

1. Moraes 2021. Sampling for Fusarium Head Blight (FHB) Index Estimation and Quantifying the Effects of Environmental Conditions on FHB Development, Mycotoxin Contamination of Grain, and their Management in Wheat. Doctoral Dissertation. Department of Plant Pathology, The Ohio State University, Columbus, OH.
Published. Acknowledgement of federal support (yes)

Other publications, conference papers and presentations as a result of FY21 award

Identify any other publications, conference papers and/or presentations not reported above. Specify the status of the publication.

ABSTRACTS

1. Ng, S. J., Bucker Moraes, W., Madden, L. V., and Paul, P. A. 2021. Rainfastness of fungicides for Fusarium head blight and deoxynivalenol reduction in soft red winter wheat. Phytopathology 111:S2.58.
2. Bucker Moraes, W., Schwarz, P. B., Madden, L. V., and Paul, P. A. 2021. Effect of moisture on wheat grain contaminating with zearalenone, an estrogenic metabolite produced by the fungus *Fusarium graminearum*. Phytopathology 111:S2.70.
3. Moraes, W. B., Madden, L. V., and Paul, P. A. 2022. Sample size matters: Interpretation of Fusarium head blight results in field experiments. (Abstr.) Phytopathology 112:S3.18. doi.org/10.1094/PHYTO-112-11-S3.1.
4. Moraes, W. B., Schwarz, P. B., Baik, B. K., Madden, L. V., and Paul, P. A. 2022. Environmental conditions after Fusarium head blight visual symptom expression affect the fate of deoxynivalenol in wheat grain. (Abstr.) Phytopathology 112:S3.201. doi.org/10.1094/PHYTO-112-11-S3.200.

PROCEEDINGS

1. Bucker Moraes, W., Schwarz, P., B., Baik, B-K, Madden, L. V. and Paul, P. A. (2021). Effects of environmental conditions after Fusarium head blight visual symptom expression on deoxynivalenol-3-glucoside accumulation in wheat. Proceedings of the 2021 National Fusarium Head Blight Forum; Virtual. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2021/2021NFHBForumProceedings.pdf
2. Bucker Moraes, W., Schwarz, P., B., Baik, B-K, Madden, L. V. and Paul, P. A. (2021). Temperature, moisture, grain development, and harvesting strategy effects on zearalenone contamination of grain harvested from Fusarium head blight affected wheat spikes. Proceedings of the 2021 National Fusarium Head Blight Forum; Virtual. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2021/2021NFHBForumProceedings.pdf
3. Cinderella, J. A., Anderson, K., Bergstrom, G. C., Bockus, W. W., Bradley, C. A., Breunig, M., Byamukama, E., Chilvers, M. I., Cowger, C., Faske, T. R., Friskop, A. J., Kelly, J., Kleczewski, N. M., Mideros, S., Paul, P. A., Price, T., Rawat, N., Rupp, J., Shim, S., Stevens, J., Telenko, D., Koehler, A. M. (2021). Baseline Fungicide Sensitivity to Pydiflumetofen in Fusarium graminearum isolated from wheat across 16 states. Proceedings of the 2021 National Fusarium Head Blight Forum;

Virtual. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2021/2021NFHBForumProceedings.pdf
4. Paul, P. A. (2021). Pre-flowering fungicide applications for Fusarium head blight management in wheat. Proceedings of the 2021 National Fusarium Head Blight Forum; Virtual. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2021/2021NFHBForumProceedings.pdf
5. Moraes, W. B., Madden, L. V., and Paul, P. A. (2022). Post-anthesis Rainfall Effects on the Efficacy of Genetic Resistance and Fungicide Application against Fusarium Head Blight and Mycotoxins in Wheat. Proceedings of the 2022 National Fusarium Head Blight Forum; Tampa, FL. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2022/2022NFHBForumProceedings.pdf
6. Moraes, W. B., Ng, S. J., Luis, M., Duffeck, M. R., Valle, J., Madden, L. V., and Paul, P. A. (2022). Rainfastness of Fungicides for Fusarium Head Blight and Deoxynivalenol Reduction in Soft Red Winter Wheat. Proceedings of the 2022 National Fusarium Head Blight Forum; Tampa, FL. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2022/2022NFHBForumProceedings.pdf
7. Moraes, W. B., Bergstrom, G., Bissonnette, K., Bowen, K., Bradley, C., Byamukama, E., Chilvers, M., Collins, A., Cowger, C., Darby, H., De Wolf, E., Dill-Macky, R., Esker, P., Friskop, A., Kleczewski, N., Koehler, A., Langston Jr., D., Madden, L. V., Marshall, J., Mehl, H., NegelKirk, M., Rawat, N., Smith, D., Telenko, D., Wegulo, S., Young-Kelly, H., and Paul, P. A. (2022). Fusarium Head Blight Management Coordinated Project: Integrated Management Trials 2022. Proceedings of the 2022 National Fusarium Head Blight Forum; Tampa, FL. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2022/2022NFHBForumProceedings.pdf
8. Moraes, W. B., Bergstrom, G., Bissonnette, K., Bowen, K., Bradley, C., Byamukama, E., Chilvers, M., Collins, A., Cowger, C., Darby, H., De Wolf, E., Dill-Macky, R., Esker, P., Friskop, A., Kleczewski, N., Koehler, A., Langston Jr., D., Madden, L. V., Marshall, J., Mehl, H., NegelKirk, M., Rawat, N., Smith, D., Telenko, D., Wegulo, S., Young-Kelly, H., and Paul, P. A. (2022). Fusarium Head Blight Management Coordinated Project: Uniform Fungicide Trials 2022. Proceedings of the 2022 National Fusarium Head Blight Forum; Tampa, FL. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2022/2022NFHBForumProceedings.pdf
9. Onofre, K. A., De Wolf, E., Moraes, W. B., and Paul, P. A. (2022). MGMT Coordinated Project Overview and Kansas Perspective. Proceedings of the 2022 National Fusarium Head Blight Forum; Tampa, FL. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2022/2022NFHBForumProceedings.pdf

PRESENTATIONS

1. Pierce A. Paul. (2021). Pre-flowering Fungicide Applications for Fusarium Head Blight Management in Wheat. Proceedings of the 2021 National Fusarium Head Blight Forum; Virtual. December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2021/2021NFHBForumProceedings.pdf