Project FY22-HW-004: Developing Winter Wheat Varieties with Enhanced Resistance to FHB for South Dakota

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1. **What are the major goals and objectives of the research project?**
   Our primary goal is to develop and release new superior winter wheat varieties with enhanced resistance to FHB and reduce fungal mycotoxins, primarily deoxynivalenol (DON) to limit the loss of grain yield and quality. The specific objectives of this proposal are 1) to develop FHB-resistant and low DON winter wheat varieties for South Dakota and surrounding regions; (2) pyramiding major and minor genes for FHB resistance by developing and implementing phenotypic and genomic selection models for SDSU winter wheat program.

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

   What were the major activities?

   More than 110 crosses were performed to combine FHB resistance including *Fhb1*, *Fhb6*, and native sources of resistance to FHB into South Dakota breeding materials. Nearly 80 populations were advanced F2:3 using speed breeding of mini bulks and plants were selected from 45 F2:4 mini bulk populations (from the last season) in the field in summer 2024.

   Breeding lines and released cultivars from other public and private breeding programs were evaluated in a locally grown mist-irrigated and inoculated FHB field nursery. These nurseries include the South Dakota Crop Performance Testing nursery (CPT), and Hard Winter Wheat FHB nursery (Public and Private). State Variety/Crop Performance trials (with and without fungicides at Brookings) were conducted to determine the impact of FHB on different varieties and elite lines.

   Evaluation of genome-wide selection models was performed along with the development of high throughput phenotyping-based machine learning models for FHB using RGB/NIR/ hyperspectral imaging, for disease incidence, FDK, and DON content.

   What were the significant results?

   SD18B025-8 (HRW) demonstrated excellent yield potential, protein, and test weight, was released as ‘SD Pheasant’ in Fall 2023. It has a good resistance package for leaf rust and an average tolerance for FHB. ‘SD Pheasant’ was rated excellent for milling and baking quality and won the miller’s choice ‘Best of Show’ award at the 2023 Wheat Quality Council meetings. In 2024 NRPN trials seven SDSU lines ranked in the top 20. In the 2024 SD State Variety Trials, two advanced breeding lines SD20B088-2, and SD20D100-9 ranked in the top yielding group. A large seed increase for SD20B088-2 is underway for potential release in 2025.

   In 2024, FHB data collected data on 46 Elite, and 126 Advanced Yield Trial entries from the SDSU winter wheat breeding program in mist-irrigated FHB nurseries.

Additionally, two of the eight experimental lines carrying *Fhb1* were evaluated in 2024 PYT showed good FHB resistance and good agronomic characteristics and were advanced to AYT for 2025.

The FHB disease ratings on regional germplasm in the Northern Hard Winter Wheat FHB Public and Private Nurseries and South Dakota CPT are made available to South Dakota producers, and colleagues at other participating institutions and private industries.

State Variety/Crop Performance trials (with and without fungicides at Brookings) were conducted to determine the impact of FHB on different varieties and elite lines. In 2024 application of fungicide (Prosaro) at flowering showed a yield benefit of 9 bu/acre at Brookings in State Variety Trials (CPT) trial. The data has been shared through extension publications and with the cooperators.

Evaluation of genome-wide selection models was performed along with the development of AI assisted high throughput phenotyping-based machine learning models for FHB using RGB/NIR/ hyperspectral imaging, for disease incidence, FDK, and DON content. GS using AI-based FDK (FDK_QVIS/FDK_QNIR) showed a two-fold increase in predictive ability (PA) compared to GS for traditionally estimated FDK (FDK_V). Next, the AI-based FDK was evaluated along with other traits in multi-trait (MT) GS models to predict DON. The inclusion of FDK_QNIR and FDK_QVIS with days to heading as covariates improved the PA for DON by 58% over the baseline single-trait GS model. We next used hyperspectral imaging of FHB-infected wheat kernels as a novel avenue to improve the MT GS for DON. The PA for DON using selected wavebands derived from hyperspectral imaging in MT GS models surpassed the single-trait GS model by around 40%.

Finally, we evaluated phenomic prediction for DON by integrating hyperspectral imaging with deep learning to directly predict DON in FHB-infected wheat kernels and observed an accuracy (R^2 = 0.45) comparable to best-performing MT GS models. Our results demonstrate the potential application of AI and vision-based platforms to improve PA for FHB-related traits using genomic and phenomic selection.

In another study, we selected 243 advanced breeding lines from the South Dakota State University (SDSU) wheat breeding program that were evaluated in FHB nurseries (2019–2020 and 2020–2021). The wheat meal samples were analyzed for DON content using GC-MS and subsequently subjected to close-range hyperspectral imaging. We evaluated three conventional machine learning (ML), two DL models and data augmentation. Among the conventional ML models, partial least squares regression (PLSR) (with R^2_P = 0.88 and 0.90 for original and augmented datasets, respectively) demonstrated the highest prediction accuracies for DON content. However, the one-dimensional convolutional neural network (1D-CNN) achieved the highest prediction accuracies (R^2_P = 0.90 and = 0.96 for original and augmented datasets, respectively) compared to all tested models and demonstrated the lowest error. In conclusion, integration of advanced hyperspectral imaging with ML approaches exhibits significant

potential for high-throughput and cost-effective estimation of DON content in wheat, thereby accelerating wheat breeding efforts for reduced DON levels.

List key outcomes or other achievements.

Advanced breeding line SD20B088-2 (HRW) ranked 4th overall in eastern, 1st central and 1st western SD in state variety trials over 2 years (2023 and 2024). SD20B088-2 demonstrated excellent yield potential, grain protein, and test weight, and is potential for 2025 release.

3. **What opportunities for training and professional development has the project provided?**
A graduate student (100%) and postdoc (partially 61%) supported this grant. The research was presented at the 2024 FHB forum, McFadden Symposium at UNL and other meetings.

4. **How have the results been disseminated to communities of interest?**
FHB resistance ratings collected on released cultivars are made available to growers as a part of the annual South Dakota Crop Performance Testing Hard Winter Wheat report. Additionally, data collected from Northern Hard Winter Wheat FHB Public and Private Nurseries is shared with colleagues from both public and private breeding programs. The results from this project were shared through field days and articles in appropriate popular press sources, word of mouth, Twitter, brochures, and Extension press releases from the Agricultural Experiment Station.

5. **What do you plan to do during the next reporting period to accomplish the goals and objectives?**
We will continue to 1) develop FHB-resistant and low DON winter wheat varieties for South Dakota and surrounding regions; (2) to pyramid major and minor genes for FHB resistance by developing and implementing phenotypic and genomic selection models for the SDSU winter wheat program.