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

FY22 Performance Progress Report

Due date: July 26, 2023

Cover Page

USDA-ARS Agreement ID:	59-0206-2-127
USDA-ARS Agreement Title:	High Fidelity/Temporal Detection of Field Fusarium Head Blight (FHB)
Principle Investigator (PI):	Cory Hirsch
Institution:	University of Minnesota
Institution UEI:	KABJZBBJ4B54
Fiscal Year:	2022
FY22 USDA-ARS Award Amount:	$169,047
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Period of Performance:	May 1, 2022 – April 30, 2024
Reporting Period End Date:	April 30, 2023

USWBSI Individual Project(s)

USWBSI Research Category*	Project Title	ARS Award Amount
TSCI	High Fidelity/Temporal Measurement of FHB for Improved Detection and Monitoring	$169,047
	FY22 Total ARS Award Amount	$169,047

I am submitting this report as an: ☒ Annual 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.

Principal Investigator Signature

7/26/2023

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: High Fidelity/Temporal Measurement of FHB for Improved Detection and Monitoring

1. **What are the major goals and objectives of the research project?**

The overall goal of this project is to test and refine the use of an imaged-based phenotyping rover and FHB detection models for breeding, pathology, and management groups. The collected data will be used to understand FHB development and to provide more information to improve disease forecasting models. The specific objectives of this project are:

1. Replicate, refine, and validate previously developed machine learning models for FHB severity in imaged wheat/barley plots.
2. Assess FHB severity for field plots multiple times a week using developed and tested FHB models.
3. Use high temporal FHB monitoring with environmental variables to understand FHB progression and forecast models.

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

This report covers progress for our FY22 project funded by the USWBSI. This was a collaborative project at the University of Minnesota with several key groups essential to the success of the project-wheat and barley FHB field plot establishment for breeding by Kevin Smith and Jim Anderson and wheat and barley germplasm evaluation trial establishment by Brian Steffenson. The groups planted and maintained the trials used in this project. They have FHB breeding and evaluation programs and contributed by providing visual assessments of FHB severity in the field using project specific conventional methods. The research reported took place at two locations, St. Paul, and Crookston MN, with both visual assessments and rover imaging conducted at both locations.

1. Replicate, refine, and validate previously developed machine learning models for FHB severity in imaged wheat/barley plots.

a) What were the major activities?

To complete this objective, we needed a good way to validate that the model could at least perform as good as human raters (in field and looking at images), with the goal of the model being better than an individual rater by being a composite of multiple raters. For this objective we used 5 different raters on a subset of 100 FHB inoculated wheat plots and 100 FHB inoculated barley plots. The raters rated FHB on a 0-100% scale looking at the whole plot, using 5% increments. This will be used as our ground-truth data set moving forward. The same raters manually annotated the location of FHB on heads from the rover images. Each of the 5 raters annotated approximately 2,000 heads for disease. These annotations will be used to tune the FHB detection model for new conditions, level of disease, and camera angles/resolution. In addition, the 5 raters also annotated the disease for the same 200 heads. This will be used to compare the variation within raters when they are looking at images to be used as a metric for model assessment. These activities are being used for inter-rater variation at the field level and image level to see the threshold of model performance to be achieved for a success FHB detection model.

b) What were the significant results?

The main results of this objective was to gather the necessary human based FHB disease detection methods to be able to assess the viability of the image-based model for FHB detection and quantification. We have begun to look at the variation between raters across the different modes of FHB quantification (in field and image based), for wheat and barley. Based on the in-field ground truth ratings FHB is much harder for raters to rate consistently with each other than wheat. In barley, the pairwise correlation of raters in-field assessments ranged from 0.04-0.65 with an average correlation of 0.37. In wheat, the range in pairwise correlation was 0.41-0.89 with an average correlation of 0.77. These are being used to benchmark the developed model performance. Ratings were also done on multiple different days on the same plots, an early rating day, a peak rating day, and a somewhat late rating day. We have noticed that as the disease progresses raters also don't correlate as well with each other, presumably because the range of disease in the field is more variable.

Also, in the objectives many imaged heads were manually annotated for FHB disease. The number of heads annotated across 5 different people doing the annotation was ~10,000 heads. They heads were from our 2022 field season from images taken with updated camera configurations. These images are being used to fine tune the FHB detection model developed from our 2021 field season. This work is ongoing. We anticipate being able to fully assess the tuned model in the coming months and are excited to see the improvement in the model.

c) List key outcomes or other achievements.

The key outcome of this objective is that barley is harder for raters to agree on in-field ratings compared to wheat for FHB quantification and that as the disease progresses in barley and wheat raters don't agree as well either. The other outcome of the improved model isn't fully realized yet, but we think there will be good improvements made with the extensive training data added to fine tune the previously developed model.

2. Assess FHB severity for field plots multiple times a week using developed and tested FHB models.

a) What were the major activities?

For this objective we successfully worked with Mineral to use the rover to image wheat/barley plots in both St. Paul and Crookston, MN. To provide as high quality of images as possible there was a coordination and partnership established with the team who developed the rover at Mineral. With our collaborators at the University of Minnesota a total of ~10,000 wheat/barley FHB screening plots were established at the St. Paul and Crookston, MN field sites. Before being able to use the rover to image the plots of interest we collected and reformatted all the field maps and provided the information to the Mineral team. The maps were loaded into the operational user interface that communicates with the rover to tell it where it is in the field while taking images to ensure proper labeling of plots in the images taken.

The rover was used to image plots at both locations on average 2 times per week throughout the summer. All the plots inoculated with FHB for evaluation could be imaged within a single day with the use of the rover. The last imaging day was decided as the last time that FHB was visually distinguishable from plant senescence. After this day FHB disease detection would be complicated by trying to separate disease and dried tissue.

Based on our previous years' work we realized that to improve FHB disease detection we need to increase the number of high resolution heads in each image taken. For the FY22 season we made several modifications to the types and way images were acquired by the rover. To increase the resolution of heads we decreased the speed of the rover. Instead of moving through the field at ~1.2 mph as in our first year, the speed was decreased to ~0.75 mph. This was a fair trade off to increase the resolution of images and therefore heads but also not sacrificing in throughput too much. Another problem we wanted to solve in the FY22 year was the ability to capture 4-row plots at one time with high quality heads. To do this two cameras were removed from the side of the rover. These cameras returned images of high quality heads but were unable to capture the inner two rows of the plot. The two cameras were remounted on the rover as overhead cameras. The cameras were set back from the middle of the rover, lowered to get closer to the object of interest, and pointed at ~60 degree angles to capture not good angles of wheat and barley heads. These camera configurations were implemented in the beginning of the season.

b) What were the significant results?

We were able to capture high quality images this year compared to the previous year. This will allow us to be able to look at more heads per plot, which should give us a better idea of true disease levels across the plot. Also, the ability to capture multiple rows in images at one time was key as well for being able to phenotype in breeding and management style plot layouts. We successful applied these changes to multiple rover runs per week, collecting millions of images of thousands of plots 10 to 15 times throughout the season.

c) List key outcomes or other achievements.

There were two significant results from the object so far in the project. The first being that we are still able to capture images from thousands of plots in a single day. Although we made speed changes we have limited the impact on throughput. The second significant result is that we were able to capture images with high resolution of wheat and barley heads from 4 rows in a single image. This was achieved through learning from previous years' work and making the proper adjustments. Being able to acquire images in this way is the first step to being able to work at scale. We are now working on being able to dynamically separate the 4 rows across the images.

3. Use high temporal FHB monitoring with environmental variables to understand FHB progression and forecast models.

a) What were the major activities?

We are currently in the process of tuning and improving our FHB detection model. The accuracy, recall, and precision of the model will be important to be able to improve current forecasting models. We also collected images, which will be rated for FHB using the detection model, multiple times a week while disease was present. Although these activities aren't developing the model, they are key components that must be in place before this objective can be achieved.

b) What were the significant results?

The significant results for this specific objective haven't been realized yet. In the near future we will be combining the FHB detection results across many timepoints with weather and development information to inform new forecast models.

c) List key outcomes or other achievements.

Currently we don't have any outcomes from this objective.

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

The project has provided numerous training activities for project personnel and members of collaborators groups. In the field, a new round of students on the project have been trained in FHB disease rating for both wheat and barley. This is important for them to understand for completion of project objectives. Also, students and project participants are also getting exposure and active hands-on work with the development of machine learning models. They are actively working in image annotation, model performance, and platform improvement. These are highly sought-after skills in high-throughput phenotyping. Members of the project have gained professional development activities by attending the 2022 National Fusarium Head Blight Forum and through regular video meetings and on campus visits with industry leaders at Mineral.

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

The results of the project have been presented to the plant community through two seminars at conferences, the 9th Plant Genomics & Gene Editing Congress and the 2023 American Society of Plant Biologists Annual Midwestern Meeting. These were the first presentations to the large outside public facing groups and the work was well received. We have also held several field talks at the University of Minnesota about the rover, project goals, and outcomes. These have been attended by faculty, staff, post docs, and graduate students from a variety of disciplines.

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 FY22 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 May 1, 2022 – April 30, 2023?

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

☐ No, I have nothing to report.

Journal publications as a result of FY22 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).

N/A – The first manuscript is being written with submission by the end of 2023

Books or other non-periodical, one-time publications as a result of FY22 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).

N/A

Other publications, conference papers and presentations as a result of FY22 award

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

1. Hirsch CD. Invited Talk. April 2023. Machine learning to advance crop stress resilience. *2023 American Society of Plant Biologists Annual Midwestern Meeting*. Acknowledgement of federal support: Yes
2. Hirsch CD. Invited Talk. October 2022. Utilizing a high-throughput field-based approach for high fidelity and temporal FHB phenotyping. *9th Plant Genomics & Gene Editing Congress*. Acknowledgement of federal support: Yes