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

# FY21 FINAL Performance Progress Report

**Due date:** July 26, 2023

## Cover Page

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| **USDA-ARS Agreement ID:** | 59-0206-1-198 |
| **USDA-ARS Agreement Title:** | Efficacy of Mineral Rover for High Fidelity/Temporal Resolution of Field FHB Severity |
| **Principle Investigator (PI):** | Cory Hirsch |
| **Institution:** | University of Minnesota |
| **Institution UEI:** | KABJZBBJ4B54 |
| **Fiscal Year:** | 2021 |
| **FY21 USDA-ARS Award Amount:** | $182,019 |
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| **Period of Performance:** | 05/15/21 - 05/14/23 |
| **Reporting Period End Date:** | 5/14/2023 |

## USWBSI Individual Project(s)

| USWBSI Research Category[ǂ] | Project Title | ARS Award Amount |
|---|---|---|
| TSCI | Efficacy of Mineral Rover for High Fidelity/Temporal Resolution of Field FHB Severity | $182,019 |
| | **FY21 Total ARS Award Amount** | $182,019 |

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.*

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:** Efficacy of Mineral Rover for High Fidelity/Temporal Resolution of Field FHB Severity

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

The overall goal of this project is to determine the effectiveness of a phenotyping rover developed by Mineral, a project of X which is a division of Alphabet Inc, the parent company of Google, for high temporal and fidelity FHB detection in wheat and barley. The specific objectives of this proposal are:

1. Deploy the Mineral phenotyping rover to assess FHB severity in wheat and barley plots.
2. Team with Mineral to develop machine learning models for FHB severity in imaged plots.
3. Determine the efficiency and cost-benefits of the Mineral rover compared to conventional assessment methods.
4. Use image based FHB detection to model terminal FHB severity and DON levels.

## 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 FY21 project funded by the USWBSI. This was a collaborative project 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 all have long running FHB breeding and evaluation programs and also 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. Deploy the Mineral phenotyping rover to assess FHB severity in wheat and barley plots.

### a) What were the major activities?

In this project we were able to successfully work 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 reformat 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.

To establish the locations of plots early in the season, at the St. Paul location we began running the rover on June 11, 2021 and imaged the field for the last time on August 10, 2021. At the Crookston location we began running the rover June 16, 2021 and continued until August 3, 2021. All of 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.

### b) What were the significant results?

The rover used at the St. Paul and Crookston MN locations is sophisticated, with remote control driving, 8 cameras, lighting for consistent imaging, WiFi, and GPS as some of its features. The operation of the rover is conducted by a single person while in the field. As with all new equipment it took time getting comfortable using it. The rover was used to image 2 different plot setups, 1) 4-

row plots with each row consisting of a different genotype and 2) 4-row plots with the outer two rows a dwarf variety and the inner 2 rows consisting of the same genotype (2-row paired). The rover was equipped with 3 cameras on each side and 2 more cameras imaging directly overhead the plots. The cameras took ~7 images per second as the rover moved throughout the field and all images from the 8 cameras were collected in tandem. The side cameras were used to capture heads and detect FHB disease from the 2-row paired plot configuration and the overhead cameras were used to assess the 4 unique genotype plot configuration.

The rover deployment is currently not in production mode, although only a single person was operating in the field to take images a larger team at Mineral was available to assist with image calibration and any troubleshooting that was needed to keep the rover operational. Over the 10-week period we imaged at the St. Paul field, all the FHB plots were imaged 18 times, with at least 2 times a week during peak disease infections week. During the 7-week period of imaging at the Crookston location, all the FHB plots were imaged 13 times, with at least 2 times a week during peak disease timing.

**c) List key outcomes or other achievements.**

This is a massive increase in the number of times each plot has the potential to have FHB evaluated compared to if done visually by human raters where each plot is typically only rated one time per season. With the potential amount of information we could collect we have the potential to produce on FHB disease detection and disease progression at a very high scale. Across the two locations we imaged ~10,000 wheat/barley plots that were inoculated with FHB. Noteworthy is that imaging these plots takes 4-5 hours of rover operation, so there is room to scale to even more plots and be able to image them all in a single day.

**2. Team with Mineral to develop machine learning models for FHB severity in imaged plots.**

**a) What were the major activities?**

Every week after imaging with the rover took place hard drives containing all the images were sent to Mineral for quality control, processing, and image analysis. The first step is assigning the correct plot to each image taken. Then a set of ~1,000 images were manually annotated by members of the project. This first step of annotation was to identify wheat/barley heads present in a set of images. Images taken by the rover were complex, to develop a machine learning model to accurately detect wheat/barley heads in images manual curation of images was needed. This began with manual annotation of heads within images by drawing boxes where heads were located. This was done across a large set of images, ~500. This information was then used by Mineral to develop a model capable of identifying heads in images. This model was then applied across all the days and plots that images were taken on. After heads were identified across images, individual heads were then annotated by project members to indicate where, if any, FHB disease was present on the head in the image. Project members used polygons to select the location of FHB on ~3,000 wheat and barley heads. This set of annotated heads for FHB were then used as data to build a model to identify FHB from wheat/barley heads. The annotation steps were conducted by multiple people (3) to incorporate the variation of human raters in the model.

**b) What were the significant results?**

The two main results of this part of the project were to build models to determine the heads in images (plots) and to effectively detect FHB disease on the heads. For a single season of data and working with a new system we are very pleased with the results. There are also areas for improvement. The model to detect the heads in images is tunable, meaning there is a confidence level given to each 'head' detected in an image. This level is based on how confident the model is that what it detected as a head is a head. The influences on this confidence level are many, including resolution of the image and amount of occlusion of parts of the head by awns or other plant parts.

We were able to threshold the confidence to return a high number of true heads, at a high-resolution, that left us with typically between 80-100 heads per plot for FHB rating by models.

The next step was to detect and rate the percent of FHB on each head using models we developed. The percent of FHB per head in a plot was calculated by taking the number of pixels detected to be FHB infected divided by the total number of pixels of the head times 100. We then checked the quality of our image-based FHB detection model in several different ways. One way was to compare the model percent FHB from a head versus a human rater percent FHB by visually looking at the image. A second way is to compare how the model percent FHB correlates with the in-field manual visual measurements. All this is to keep in mind that there is variation between human raters too. A summary of the model performance is presented in the following table:

| Crop | Assessment Type | Correlation (r value) |
|---|---|---|
| Barley | 1. FHB model vs human looking at same image of head | 0.79 |
| | 2. Different human raters looking at the same image | 0.63 |
| | 3. FHB model (plot average) vs in-field human rating | **0.49** |
| | 4. Human image rating vs in-field human rating | 0.34 |
| Wheat | 1. FHB model vs human looking at same image of head | 0.90 |
| | 2. Different human raters looking at the same image | 0.76 |
| | 3. FHB model (plot average) vs in-field human rating | **0.73** |
| | 4. Human image rating vs in-field human rating | 0.61 |

These results are very encouraging. The model to measure FHB infection is highly correlated with what humans looking at the same image would rate, 0.79 and 0.90 for barley and wheat, respectively. The model is performing adequately when compared on a per plot average vs what was rated for the plot visually in the field, 0.49 and 0.73 for barley and wheat, respectively.

Higher correlations between FHB assessment methods are ideal, but there are some limitations for the dataset currently. One of the biggest challenges we faced during this initial project was in image quality. We didn’t appreciate the need for close, highly focused cameras to obtain the resolution of image needed to detect FHB at a single spikelet per head level. This limitation means that our above cameras were not successful in capturing the disease across the 4 row of different genotype plantings. The cameras were simply too far away to obtain clear images of heads. Therefore, the data presented above is for our 2-row paired plot design in which the cameras are closer and provided much clearer images. In the next iteration the type and location of the overhead cameras will be adjusted to improve top-down image quality. This is essential to be able to ascertain FHB across a 4-row plot disease with different genotypes in each row. The second limitation is the difficulty in rating the disease. The variation between human raters, both in a field setting and rating the same images is substantial. Moving forward we will focus effort on ensuring the highest quality images are taken by the rover (improve camera type, location, slow speed of rover) to be able to detect more heads per plot and to improve consistency in image annotation and model performance. To be able to account for more of the variation between raters both on images and in the field, we will increase the number of people involved at the necessary steps.

**c) List key outcomes or other achievements.**

We have three main outcomes for this objective: 1) we were able to identify between 80-100 heads per plot, which is a large increase in the number of heads that can be rated compared to the amount human raters typically do if looking at individual heads in a field setting. 2) The FHB models developed perform on-par with humans on image-based rating and in-field rating. 3) We identified the current limitations to improve results moving forward.

**3. Determine the efficiency and cost-benefits of the Mineral rover compared to conventional assessment methods.**

**a) What were the major activities?**

We are currently in the process of determining the cost-benefits of using this image-based rover platform for FHB detection. There are many positives to the system, even after just one season of use, including the number of times plots can be rated and a more aggregate score from the model of what multiple raters would rate instead of relying on a single rater for each plot. We are also working with Mineral to determine the cost of using the platform if models were already developed.

**b) What were the significant results?**

We have collected the necessary information on the amount of time and effort spent by groups collecting in-field visual FHB ratings for all the plots. We also know the capacity of the rover in terms of number of plots it can image per hour (~10,000 plots in 4-5 hours in rover operation), and heads that can be rated. We have limits in this analysis currently as we are trying to get what potential future costs would be without the necessity for model development and evaluation. We are also working to get costs of all the other tangential factors such as shipping data, running models, etc.

**c) List key outcomes or other achievements.**

We are actively working to assess the economics behind the system. Currently, we think this is a feasible method if used at a large enough scale.

**4. Use image based FHB detection to model terminal FHB severity and DON levels.**

**a) What were the major activities?**

Unfortunately, we weren't able to make progress on this objective of the project. We are working with collaborators on the project to obtain the DON levels for each of the plots that were imaged and rated for FHB.

**b) What were the significant results?**

We are working with collaborators to get the DON levels for the plots rated by the rover. There have been delays in getting the samples processed, but we hope to have the data in hand soon to be able to address this objective.

**c) List key outcomes or other achievements.**

Currently we don't have any outcomes from this objective as we are waiting to receive the DON analysis for the FHB rated plots. Once the data is available we will work towards developing models to predict DON levels from our image-based FHB rated plot scores.

## 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, new 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 2021 National Fusarium Head Blight Forum.

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

The results of the project have been presented to the wheat and barley scab community through two seminars at conferences/workshops put on through the USWBSI, the U.S. Wheat & Barley Scab Initiative-Gene Discovery and Engineering Resistance (GDER) Mid-year Meeting and the National Fusarium Head Blight Forum. Although we haven't presented to large outside public facing groups, we have 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 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?**

X 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).

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 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).

N/A

## 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.

1. Hirsch CD. Invited Talk (Virtual). May 2021. Efficacy of a phenotyping rover for high fidelity and temporal resolution of field FHB severity. *U.S. Wheat & Barley Scab Initiative-Gene Discovery and Engineering Resistance (GDER) Mid-year Meeting*. Acknowledgement of federal support: Yes
2. Hirsch CD. (2021). Utilizing a high-throughput field based rover for high fidelity and high temporal resolution of FHB phenotyping. Proceedings of the 2021 National Fusarium Head Blight Forum. Invited Talk (Virtual). December 6-7, 2021. Retrieved from: https://scabusa.org/forum/2021/2021NFHBForumProceedings.pdf

   Acknowledgement of federal support: Yes