U.S. Wheat & Barley Scab Initiative

ACTION PLAN

Last Updated: May 2023

USWBSI Mission Statement

To enhance food safety and supply by reducing the impact of Fusarium Head Blight (scab) on wheat and barley. Action Plan goals are organized by the USWBSI's five core research categories.

ACTION PLAN GOALS OVERVIEW

FHB MANAGEMENT (MGMT)

FHB Goal 1: Develop integrated sustainable management strategies for FHB and mycotoxins that are robust to conditions experienced in production fields of wheat and barley.

FHB Goal 2: Help develop and validate the next generation of management and mitigation tools to reduce FHB and associated mycotoxins.

FHB Goal 3: Develop a comprehensive understanding of the *Fusarium* populations and the factors influencing infection and toxin accumulation that can be used to develop the next generation of FHB and DON risk assessment measures.

FHB Goal 4: Enhance communication and end-user education/outreach for an audience including, but not limited to, producers, agricultural advisors, research community, and grain processors.

FOOD SAFETY AND TOXICOLOGY (FST)

FST Goal 1: Provide analytical support for DON/trichothecene quantitation for stakeholders.

FST Goal 2: Provide requisite information on DON/trichothecene safety issues to producers, millers, researchers, risk assessors, and regulators.

GENE DISCOVERY AND ENGINEERING RESISTANCE (GDER)

GDER Goal 1: Gene discovery and identifying mechanisms of resistance and susceptibility: Increased efficiency of identifying mechanisms of resistance and susceptibility, and detection and validation of host genes for resistance and susceptibility to FHB or DON accumulation.

GDER Goal 2: Identify and validate natural variants and mutations for incorporation into breeding programs.

PATHOGEN BIOLOGY AND GENETICS (PBG)

PBG Goal 1: Characterize plant-fungal interactions to identify important genes, proteins, or small molecules that may be used to develop FHB resistance or reduce DON contamination in barley and wheat.

PBG Goal 2: Discover epiphytic and endophytic microbes and microbial communities useful for development of control for FHB.

VARIETY DEVELOPMENT AND HOST RESISTANCE (VDHR)

VDHR Goal 1: Increase and document the number of varieties with FHB resistance and high productivity, that are tested in state variety trials and available to farmers, to reduce DON in the U.S. grain supply.

VDHR Goal 2: Increase the efficiency of germplasm selection and cultivar development.

VDHR Goal 3: Evaluate and implement new breeding technologies to further enhance short-term and long-term improvement of FHB resistance.

FHB MANAGEMENT (MGMT)

The FHB Management (MGMT) research area supports research to develop effective and economical disease management practices that reduce FHB severity and mycotoxins in small grain crops to meet the immediate and long-term needs of the wheat and barley industries.

FHB Goal 1: Develop integrated sustainable management strategies for FHB and mycotoxins that are robust to conditions experienced in production fields of wheat and barley.

Milestones/Performance Expectations: Conduct experiments that evaluate the flexibility of the integrated management strategies in a wide range of production conditions and environments.

- These experiments should: 1) consider the best available varieties with a range of FHB resistance for all wheat market classes and malting barley, 2) be conducted in multiple states and production regions, and 3) use the best available fungicides and/or biocontrol agents and application technology.
- Specific areas of emphasis will include but are not limited to 1) developing fungicide and/or biocontrol agent recommendations that are more robust to conditions experienced in commercial production, and 2) evaluating the efficacy and economics of these strategies using multi-year, multi-variety, multi-location data.

Performance Measures: Summaries of results that will facilitate further evaluation and refinement of management strategies for FHB and mycotoxin in production fields.

Research Needs: Identify the best management methods for FHB/DON or Good Farming Practices (GFP) for FHB/DON management - through integrated management studies. Studies to measure integrated effects should include but are not limited to:

- Validating the integrated management strategies with next generation of wheat and barley varieties in multiple production environments.
- Developing economic analyses of effective integrated management strategies used alone and in combination (i.e., fungicide, biological control, cultivar, residue management, crop rotation).
- Evaluating flexibility of fungicide and/or biocontrol agent application timing within the context of the integrated management strategies.
- Utilizing data generated from integrated management experiments to maintain, improve, and refine current FHB forecasting models.

Outputs:

- FHB/DON management recommendations that are more flexible and robust to conditions experienced in production fields of wheat and barley.
- Documenting increased adoption of integrated management for FHB/DON on regional and national basis.
- Improved forecasting systems that help producers and their advisors evaluate the risk of disease based on environment, cultivar resistance, and cropping system.

Resources: Multiple collaborative locations distributed across grain classes. A team approach will be used to reflect overlap across traditional research areas and regional/national scope. Teams will be composed of breeders, pathologists, agronomists, economists, and other scientists from other disciplines as needed.

Anticipated Impact: Producers will make integrated management decisions based on regionally validated science-based information to enhance food security.

FHB Goal 2: Help develop and validate the next generation of management and mitigation tools to reduce FHB and associated mycotoxins.

Milestones/Performance Expectations:

- Improved forecasting models of FHB epidemics and DON contamination.
- Test new fungicides and biological controls that have potential application as part of integrated management programs for FHB/DON.
- Investigate new ways to use current technologies that may improve flexibility of integrated management strategies or address specific knowledge gaps for these technologies.
- Acquire new data on harvest and post-harvest grain handling.

Performance Measures: Evaluate the potential of new technologies for the management of FHB/DON.

Research Needs:

- Enhance and validate forecasting capabilities for FHB in small grains and explore new opportunities to integrate local weather data.
- Validate efficacy of biological control agents and fungicides for use in production fields through multi-environment testing. This includes new products and compounds with preliminary data indicating high levels of efficacy.
- Evaluate application timing of new fungicides or biological control agents that may increase flexibility of integrated management.
- Investigate factors that may compromise the efficacy of fungicide and/or biocontrol products including quantifying properties such as spray application technologies, rain-fastness and systemic movement within plants.
- Determine if fungicides and biocontrol agents can be used to suppress the DON contamination of wheat and barley straw.
- Harvest and post-harvest grain handling: conduct experiments to identify practices that minimize DON and yield/test weight losses.

Outputs:

- Increased accuracy and availability of FHB forecasts.
- Validated data on efficacy of fungicide and biocontrol products.

Resources: Multiple collaborative locations distributed across grain classes. A team approach will be used to reflect overlap across traditional research areas and regional/national scope. Teams will be composed of breeders, pathologists, agronomists, and other scientists from other disciplines as needed.

Anticipated Impact: These projects provide the next generation of strategies that will be tested through larger multi-state projects on integrated management. These projects address specific knowledge gaps identified through interaction with wheat and barley producers.

FHB Goal 3: Develop a comprehensive understanding of the *Fusarium* populations and the factors influencing infection and toxin accumulation that can be used to develop the next generation of FHB and DON risk assessment measures.

Milestones/Performance Expectations:

- Improved understanding of the: 1) conditions leading to high DON with low/no visual symptoms; 2) relative contributions of in-field vs. external inoculum sources; 3) fungicide resistance in natural populations of *Fusarium* species in different production regions and implications for fungicide efficacy.
- Refined management recommendations based on new information gained through these applied research projects.
- Research results incorporated into the FHB and DON risk forecasting models.

Performance Measures: Information is acquired regarding factors essential for the next generation of FHB and DON risk assessment models, including: the role of post-flowering weather and late/secondary infections, the conditions leading to high DON with low/no visual symptoms, relative contributions of in-field vs. external inoculum sources, and the diversity of *Fusarium* populations and associated fungicide resistance.

Research Needs:

- Assess fungicide resistance in *Fusarium* populations within different cereal production regions in the U.S.
- Evaluate the role of post-flowering weather on toxin accumulation.
- Determine the potential contribution of late/secondary infections on toxin accumulation.
- Further define the influence of weather and variety on infection efficiency between heading and grain maturity and how the timing of infection influences symptom development and toxin accumulation.
- Evaluate the relative contributions of inoculum from in-field debris vs. airborne spores from nearby and distant sources.

Outputs:

- Models describing associations among inoculum density/dose, inoculation timing, weather and variety on infection, fungal biomass, and toxin accumulation.
- Improved accuracy of FHB risk assessment models.
- Regionally appropriate, specific recommendations for corn and small-grain debris management based on full understanding of relative contributions of inoculum from in-field debris vs. nearby and distant sources.
- Establish and document a fungicide resistance monitoring program for *Fusarium* species.

Resources: A multi-state collaborative effort involving researchers from all major U.S. wheat and barley-growing regions.

Anticipated Impact: Improved risk forecasting and management recommendations available to growers.

FHB Goal 4: Enhance communication and end-user education/outreach for an audience including, but not limited to, producers, agricultural advisors, research community, and grain processors.

Milestones/Performance Expectations:

- Resources and recommendations related to the integrated management of FHB/DON on the USWBSI website.
- Information on FHB resistance from VDHR efforts is made readily available to growers through local Extension or on the USWBSI website.
- Dissemination of FHB information and management techniques using relevant communications platforms.

Performance Measures: Best FHB/DON management methods, validated by science-based research, are thoroughly publicized to producers, their professionals, and grain processors.

Research Needs:

- Development of informational material on FHB and DON.
- Make commentaries from the FHB forecasting site available via USWBSI blog website and sent to users via mobile devices.
- Conduct surveys of growers to assess how they acquire and adopt information on FHB management techniques, and potential barriers to adoption.
- On-farm demonstrations of best available management options for FHB and DON (when appropriate).

Outputs:

- Timely information about scab risk is reaching growers through relevant communication platforms.
- Information on FHB management is made available via national websites and communicated through Extension or Land Grant Universities.

Resources: Multi-state national Extension resources are developed with multiple collaborators across grain classes. A multi-discipline team including pathologists, crop consultants, agronomists, breeders, economists, and scientists as well as communications and design.

Anticipated Impact: Increased awareness and adoption of practices by producers will result in FHB/DON reduction and lead to substantially reduced frequency of unacceptable DON levels in grain.

FOOD SAFETY AND TOXICOLOGY (FST)

The Food Safety and Toxicology (FST) research area supports research on food safety and food processing issues related to the presence of *Fusarium* spp. mycotoxins in wheat and barley grain.

FST Goal 1: Provide analytical support for DON/trichothecene quantitation for stakeholders.

Milestones/Performance Expectations:

- Maintain awareness of standardized sampling protocols adopted for regional (commercial field) and research testing for DON.
- Maximize coordination and efficiencies amongst labs with an effort towards matching lab utilization to potential impact to provide DON data in a timely manner.
- Provide accurate information and occurrence data regarding DON, ADONs and DON glucoside in a form accessible to the FHB research community.

Performance Measure 1.1: Ensure awareness about optimal sampling, grinding and test protocols for mycotoxin analysis.

Research Needs: There is an ongoing need to increase and maintain awareness about optimal sampling and grinding protocols for the grain industry and Initiative researchers. This will minimize incorrect data and enhance the effort to reduce DON.

Outputs:

- Session/meeting devoted to sampling /analytical methods will be provided as needed.
- Protocols will be included on USWBSI web page.
  - Links to protocols will be provided to Initiative users.
  - Recommended methods will be updated/modified taking into account FGIS- and EU-recommended protocols.

Resources: Diagnostic lab directors.

Anticipated Impact: Clarify stakeholder concerns over test accuracy and repeatability of data. Implementation of standardized sampling and grinding protocols can improve comparability/quality of data.

Performance Measure 1.2: Maximize capacity for the analysis of DON and other trichothecenes.

Research Needs: Initiative members need to maintain test capacity and turnaround time to make progress since the future focus will continue to be less DON.

Outputs: Diagnostic labs

- Survey of Initiative users for anticipated needs, and continued evaluation of new technology
- Workshop(s)/continuing education devoted to sampling/analytical methods at Initiative meeting(s) in order to optimize use of lab resources.
- Coordinate use of labs to maximize USWBSI impact:
  - Solicit bulk discounts for Initiative users.
  - Continued evaluation of new technologies.
  - Facilitate on-site rapid testing.
- Suggested rapid assay protocols (e.g. FGIS) will be included on USWBSI website. Links to protocols will be provided to Initiative users.

Resources: Diagnostic lab directors.

Anticipated Impact: Increased testing will enable breeders to achieve goals of DON reduction sooner.

Performance Measure 1.3: Diagnostic labs will include measurement of ADONs, other trichothecenes and DON conjugates and matrix-associated toxins in selected surveillance samples.

Research Needs: There is concern about change in *Fusarium* genotypes and masked (conjugated) trichothecene forms but there is limited data on occurrence of individual toxins other than DON. FDA survey data is very limited.

Outputs: An archive of data on occurrence of different trichothecenes and their relative ratios of these analytes.

Resources: Diagnostic lab directors.

Anticipated Impact: This data will assist discussion of "shifts" in observed mycotoxin profiles.

FST Goal 2: Provide requisite information on DON/trichothecene safety issues to producers, millers, researchers, risk assessors, and regulators.

Milestones/Performance Expectations:
- Validate current FDA standard of DON ppm in flour and grain.
- Scientific studies of DON and related trichothecenes that enable extrapolation from animals to humans.
- Presentation of scientific study data at meetings and in high impact journals.
- Utilization of information to produce accessible outreach materials for the public.

Performance Measure 2.1: Conduct research on adverse effects of consuming DON and related trichothecenes that allow extrapolation from animals to humans and inform regulators thus enabling science-based risk assessment. Key considerations are groups at high risk and biomarkers of exposure/toxicity.

Research Needs: EU has established DON regulatory standards that are much lower than U.S. and there is pressure on CODEX to follow suit. There is continued concern about change in *Fusarium* genotypes and mycotoxin profiles as well as the occurrence of masked forms of DON.

Outputs:
- Publication of research/reviews in high impact journals that inform international risk assessors and regulators.
- Participation in national/international research meetings/forums/committees that inform risk assessors.
- Monitor Food Safety and Modernization Act (FSMA) requirements and serve as conduit of this information to stakeholders.
- Develop preliminary data for getting grant funding from government or foundational sources.

Resources: Food safety researchers.

Anticipated impact: Risk assessors and regulators will use data to make sound scientifically valid decisions that ensure public health but minimize economic effects to wheat and barley industries.

Performance Measure 2.2*:* Summarize known toxicology information on DON/other trichothecenes, their risks and rationale for regulations.

Research Needs: There is lack of easily comprehensible information on DON and its risks. This creates confusion among producers, millers, and Initiative scientists.

Outputs:
- Webpages with questions and answers about DON safety.
- Initiative-originated reviews/position paper(s).

Resources: Scab website support facility, food safety researchers.

Anticipated Impact: Improved understanding/communication of the importance of the problem among the producers, millers, researchers, and government.

GENE DISCOVERY AND ENGINEERING RESISTANCE (GDER)

The Gene Discovery and Engineering Resistance (GDER) research area (RA) places its primary focus on understanding the mechanisms of resistance to Fusarium head blight (FHB) and identification of wheat and barley gene variants that can be deployed to increase FHB resistance and/or reduce DON accumulation.

GDER Goal 1: Gene discovery and identifying mechanisms of resistance and susceptibility: Increased efficiency of identifying mechanisms of resistance and susceptibility, and detection and validation of host genes for resistance and susceptibility to FHB or DON accumulation.

Milestones/Performance Expectations:

- Utilize high-throughput genomics (e.g., next generation sequencing, metabolomics, functional genomics in model systems, etc.) and molecular plant pathology approaches to identify mechanisms and genes that confer resistance or susceptibility to FHB and DON accumulation.

Performance Measures: Identify mechanisms and genes that exhibit resistance or susceptibility to FHB and DON accumulation.

Research Needs:

- Rapid identification of mechanisms and genes conferring resistance or susceptibility to FHB and DON accumulation.
- Rapid high-capacity assays for functional validation of genes for resistance or susceptibility to FHB and DON accumulation.
- Develop transformation of elite wheat and barley genotypes.
- Develop efficient gene editing technology for wheat and barley.
- Robust centralized transgenic field trials for barley, and greenhouse trials for wheat and barley.

Outputs: An understanding of the mechanisms of resistance or susceptibility will be used to isolate and validate specific genes. Validated gene sequences will be used as targets for gene editing, and mining wheat and barley germplasm collections and mutant populations for alleles that confer resistance to FHB and DON accumulation.

Resources:

- USWBSI funding.
- USWBSI-funded centralized wheat and barley transformation facilities.

Anticipated Impact:

- Increased understanding of mechanisms of resistance and susceptibility, providing novel targets for gene discovery.
- Validated genes conferring resistance or susceptibility to FHB and DON.
- Proof of gene efficacy will provide options for incorporating novel alleles conferring resistance into commercial wheat and barley.

GDER Goal 2: Identify and validate natural variants and mutations for incorporation into breeding programs.

Milestones/Performance Expectations:

- Mine germplasm and mutant collections and identify alleles that increase FHB and DON resistance.
- Edit target genes and promoters to identify alleles that increase FHB and DON resistance.
- Provide germplasm to breeders for incorporating novel resistance into wheat and barley breeding programs.

Performance Measure:

- Demonstrate that novel variants increase resistance.
- Introgress novel variants into adapted wheat and barley genotypes for breeders.

Research Needs:

- Robust technology for gene and promoter editing of elite wheat and barley genotypes.
- Sequenced wheat and barley collections for rapid identification of useful variants and mutants.
- More collaboration with breeders to incorporate validated FHB and DON resistance genes into VDHR programs.

Outputs: Germplasm provided to breeders that confer resistance to FHB and/or reduced levels of DON accumulation in wheat and/or barley.

Resources:

- USWBSI funding for research identifying and developing effective solutions for FHB resistance and reduced DON accumulation.
- USWBSI-funded centralized wheat and barley transformation facilities.

Anticipated Impact:

- Development of novel wheat and barley germplasm with FHB resistance and DON reduction that can be used to complement the breeding effort or as a novel standalone solution.

PATHOGEN BIOLOGY AND GENETICS (PBG)

Research in this area includes studies that address mycotoxin biosynthesis in vivo or in planta, host-pathogen interactions, pathogen natural diversity, and responses of the pathogen to host resistance mechanisms and pathogen control strategies. Research in PBG should complement and be linked to whole plant research that will lead to disease control and/or toxin reduction strategies.

PBG Goal 1: Characterize plant-fungal interactions to identify important genes, proteins, or small molecules that may be used to develop FHB resistance or reduce DON contamination in barley and wheat.

Milestones/Performance Expectations:

- Characterization of cultivar/strain interactions with respect to colonization, disease spread, and mycotoxin production.
- Determine where and when DON is produced in different resistant backgrounds.
- Examine abiotic factors that impact pathogen biology, infection, and mycotoxin accumulation.

Performance Measure: New information will be gained regarding how plant infection occurs, and DON accumulates in plants over time, and how these processes vary between resistant and susceptible cultivars and different *Fusarium* species and strains.

Research needs:

- Elucidate the infection process, including late infections, the influence of environment on infection, and the role of trichothecenes in initial infection.
- Understand the interaction between FHB resistance and resistance to DON accumulation.
- Identify fungal effectors and plant targets for use in developing FHB resistant cultivars.
- Develop novel approaches to modulate pathogen genes for disease control and mycotoxin reduction (e.g., blocking DON biosynthesis) and collaborate with GDER for evaluation.
- Elucidate the dynamics of trichothecene production during infection of floral tissue and grain development in both wheat and barley.
- Identify genes under selection in the pathogen that function in survival, fitness, or aggressiveness under field conditions.
- Characterize the mechanism of DON accumulation during infection.
- Characterize functionally significant variation in the pathogen in relation to agronomic practices and environmental conditions.

Outputs:

Short term

- Identify fungal effectors and potential plant targets.
- Conduct pathogen surveys to more fully characterize population structure of *Fusarium* spp. associated with FHB.
- Standardize techniques for screening, sampling, and testing varieties based on knowledge of pathogen biology.
- Characterize the process of infection and accumulation of DON in different backgrounds (R-genes & QTL).

Long term

- Understanding of the biology of DON accumulation and the role of DON as a pathogenicity factor.
- Collaboration with VDHR, GDER, and MGMT to implement discoveries into management programs.
- Use knowledge of pathogen population structure and adaptation to inform agronomic control practices and disease forecasting.
- Establish a national, curated collection of FHB-associated *Fusarium* strains, and a national, curated database for genomic and population genetic information relevant to FHB-associated *Fusarium* spp.

Resources: USWBSI funding for understanding the infection process and mycotoxin accumulation over time.

Anticipated Impact:
- Understanding how infection and grain colonization occurs.
- Novel genetic traits are used in development of resistant plants.
- Fungicide efficacy is enhanced as management is increasingly informed by biological insights into pathogen behavior in planta.
- Novel molecular targets or biochemical strategies are made available for managing the FHB pathogen.
- Progress in breeding for resistance is accelerated due to improved understanding of pathogen population structure, infection processes, and the spatial and temporal dynamics of DON production.

PBG Goal 2: Discover epiphytic and endophytic microbes and microbial communities useful for development of control for FHB.

Milestones/Performance Expectations:
- Discovery of microbes or microbial consortia useful for FHB control.
- Identify microbial metabolites or enzymes from microbial communities useful for control of FHB or DON.
- Characterize interactions among microbes useful for control.

Performance Measure: Strategies for disease and mycotoxin management using microbes, microbial communities, or microbial products.

Research Needs:
- Characterize the microbiome of wheat and barley.
- Identify how plant-associated microbiomes change with management practices, host genotypes, pathogen genotypes, over time, and in response to abiotic factors.
- Discover microbes, microbial consortia, or microbial metabolites useful for reduction of FHB and lower DON, improved grain quality, and reduced sporulation of *F. graminearum* on potential sources of inoculum.

Outputs:
Short-Term
- Identify microbial community features related to reduced FHB, lower DON, or limited inoculum production.
- Enable sharing of data on the web describing microbiome under different conditions and locations.

Long-Term
- Identify microbial enzymes or other processes that detoxify DON.
- Develop novel strategies for FHB control based on microbiome management.

Resources
- Funding from USWBSI and competitive funding for wheat and barley phytobiome research.
- Utilize expertise of management group to inform development of applied approaches for integrating understanding of microbiomes and microbial products into management protocols.

Anticipated Impact
- New technologies based on biologicals are available for FHB and DON control.
- Microbiome management is used to reduce inoculum, infection rates, and pathogen secondary spread.
- Detoxifying enzymes or processes are available for use in plant protection and in preserving value of agricultural products.
- Improved grain quality and reduced DON.

VARIETY DEVELOPMENT AND HOST RESISTANCE (VDHR)

The VDHR research area for spring wheat and soft winter wheat is organized around participation in Uniform Nurseries. Each Uniform Nursery is coordinated by an appointed chair and advised by a regional committee.

VDHR Goal 1: Increase and document the number of varieties with FHB resistance and high productivity, that are tested in state variety trials and available to farmers, to reduce DON in the U.S. grain supply.

Milestones/Performance Expectations

- Document the varieties released annually by USWBSI-funded projects with improved FHB resistance to monitor the year-to-year change in FHB resistance in varieties and breeding lines.
- Where possible, determine the percentage of acreage planted to varieties with acceptable FHB resistance. This information will measure the change of commercial availability of wheat varieties with improved FHB resistance to document progress on reducing this disease.

Performance Measures:

- Continued improvement of the FHB resistance of breeding lines being increased for commercial release and/or varieties released and targeted for FHB prone regions by USWBSI breeders.
- Annual evaluation of state performance trial entries and advanced breeding lines for FHB traits in inoculated nurseries.

Research needs:

- Published results from comprehensive evaluation of breeding lines and current commercial cultivars for FHB reaction (DON, index, severity, etc.) and other important traits.
- Evaluation of cultivars with improved FHB resistance in best-management practices for control of DON in conjunction with MGMT.
- Improved data sharing supported by practical website development and/or utilization.
- Incorporation of data on relevant FHB resistance traits into all regional nursery and statewide variety trial datasets, where possible, for streamlined data dissemination.

Outputs:

- Grower access to comprehensive information on FHB resistance of adapted cultivars so they can fully incorporate FHB resistance in their variety selection.
- New released varieties that outperform standard checks for FHB resistance and productivity.

Resources:

- Multi-location FHB nurseries for lines in regional and commercial trials.
- Collaborative assessment of FHB resistance using phenotypic and genetic screening across breeding to enable improved selection.

Anticipated Impacts:

- Growers will be able to select new varieties with continually improving FHB resistance and therefore the acreage of such varieties will increase.
- A package of Best Management Practices involving new varieties with FHB resistance can be promoted and adapted by growers.
- A more stable supply of adapted, high-yielding cultivars for the wheat industry.
- New wheat cultivars with improved FHB resistance will have reduced DON levels when grown commercially to support farmer profitability and end-user food safety.

VDHR Goal 2: Increase the efficiency of germplasm selection and cultivar development.

Milestones/Performance Expectations

- Continue to improve the FHB resistance of entries submitted to the USWBSI sponsored FHB nurseries, in other regional performance nurseries, and among breeding lines that are in preparation for release.
- Continue and strengthen collaboration among USWBSI sponsored projects for enhanced germplasm development, sharing, and evaluation.
- Documenting the progress of the mapping and introgression of resistance from multiple sources. Annually, breeders/geneticists in each market class contribute data on the progress of the introgression.
- Facilitate sharing of information and genetic resources among breeding programs, which may or may not include a combination of the following breeding assets: crosses made to improve FHB resistance, doubled haploids (DHs), speed breeding applications, performance data from non-USWBSI funded trials (yield, quality, resistance to other diseases etc.) on lines with improved FHB resistance, populations and plans for marker-assisted selection (MAS), plans and results from use of genomic selection, native FHB resistance QTL already present in advanced lines, new sources of FHB resistance, and increased haplotyping of known FHB QTL by Genotyping Labs.

Performance Measures:

- FHB related phenotypic and genotypic data is shared among all USWBSI sponsored breeders.
- Improved FHB resistance (DON, index, severity, etc.) of entries submitted to the USWBSI sponsored FHB nurseries and other regional nurseries.
- Number of breeding lines from USWBSI sponsored breeding programs with enhanced FHB resistance that are being increased for commercial release and/or have been released.
- Number of new cultivars released with high-yield and enhanced resistance to FHB.

Research Needs:

- Increased capacity for field testing in mist-irrigated inoculated nurseries.
- Increased capacity for DON testing labs, including centralized service to grind samples.
- Increased capacity for MAS including backcrossing and haplotyping as appropriate.
- Sharing of information and breeding populations developed with USWBSI support that are relevant to FHB improvement to enhance individual programs and germplasm exchange.
- Increased resources for genomic selection, including development and refinement of an inexpensive, rapid, and flexible genotyping platform.
- Increased access to double-haploids, particularly for winter wheat breeding programs.
- Increased resources for high throughput phenotyping.

Outputs:

- Increased breeding efficiency resulting from improved data sharing among breeding programs.
- More frequent release of FHB resistant varieties with high yield and other desirable attributes that insure widespread adoption by producers and end-users.

Resources:

- Mist-irrigated, inoculated nurseries.
- Genotyping labs.
- DON testing labs.
- Existing infrastructure of sponsored breeding programs.
- Needed resource – shared/collaborative doubled haploid facilities.

Anticipated Impacts:

- New varieties with improved FHB resistance will be released and available more frequently.
- Every grower in an FHB affected region will have an expanded and enhanced array of commercially competitive varieties with adequate FHB resistance to select for their farm.
- Commercially available FHB resistant cultivars within all production environments will result in (1) lower DON levels in grain that is delivered to end-users (2) increased food safety and (3) enhanced grower profitability.

VDHR Goal 3: Evaluate and implement new breeding technologies to further enhance short-term and long-term improvement of FHB resistance.

Milestones/Performance Expectations:

- Development and implementation of improved breeding and selection methods for FHB resistance.
- Accelerated QTL stacking using genotyping, machine learning, and model training and validation.
- Implementation of genomic selection in breeding programs as appropriate to increase efficiency of selection and increase rate of genetic gain.
- Development of advanced phenotyping approaches to enable breeders to evaluate FHB resistance with increased accuracy and throughput.
- Identification of basic research needs of the breeding programs in each region and class of wheat. Coordinate activities to address agreed upon priorities.
- Identification and incorporation of different types of FHB resistance into adapted germplasm.
- Implementation of speed breeding or other approaches to expedite breeding pipeline.

Performance Measures:

- When appropriate, establish cooperative teams of researchers to undertake the strategic testing of putative sources of resistance, all proposed mapping, and subsequent introgression.
- Identification of novel QTL and markers systems for the QTL.
- Introgression of discovered genes and QTL through phenotypic and MAS.
- Performance of breeding lines with new sources of resistance in their pedigree.
- Validation of genomic selection prediction models on new breeding lines.
- Use of genomic predictions to select parents that produce superior crosses.
- Updated breeding methods based on current technology including some or all of the following, as appropriate: double haploids, genomic selection, speed breeding, high-throughput phenotyping (HTP), using AI and other technologies, which increases accuracy and efficiency.

Research Needs:

- Improved technology to establish novelty of sources of FHB resistance and inventory the frequency of resistance alleles in current breeding programs.
- Coordination to develop teams to conduct basic research and initiate introgressions.
- Investigate and elucidate the genetic basis of different types of FHB resistance gene expression.
- Identify novel mechanisms of FHB resistance and ways to screen for them.
- Sharing of pre-breeding populations, germplasm, and information for MAS.
- Enhanced cooperative phenotyping of mapping populations (more environments in fewer years).
- Investigation of integrated methods to improve FHB resistance to commercially needed levels.
- Enhanced technology for accurate testing of DON content.
- Development of breeder friendly tools for use of genome-wide markers in FHB resistance breeding.
- Centralized service for grinding DON samples, HTP for FDK, and generating DHs.

Outputs:

- Computational science and machine learning capabilities that facilitate prediction of valuable genetics and estimate breeding value for implementation.
- Identification of new, high-throughput phenotyping approaches that reduce the time required to accurately evaluate *Fusarium*-damaged kernels and other FHB-related traits.
- Identification of novel genetics for FHB resistance made feasible from new technologies.
- Development of improved germplasm with durable resistance.

Resources:

- The capacity for assessing potential sources of FHB resistance.
- Shared information on resistance sources, breeding population development, marker haplotypes, and mapping and introgression efforts.
- Regional or multi-regional coordination meetings to facilitate collaboration and share information on emerging technologies.
- Genotyping labs.
- DON testing labs.
- T3 database of data management.

Anticipated Impacts:

- Enhanced efficiency of breeding for FHB resistance from development of improved breeding methodology and combination of effective approaches.
- Improved understanding of genetic mechanisms underlying FHB resistance. More collaborative, rapid, and efficient execution of applied research and heightened adoption of favorable genetics and breeding methodology for cultivar development.