ADVANCING DEVELOPMENT OF WINTER DURUM WHEAT USING GENOMIC APPROACHES

Ritesh K. Yadav[1,2], Raja Ragupathy[2], Gavin Humphreys[3], Demissew Sertse[2], André Laroche[1], Harmeet S. Chawla[2], Marcos Cordeiro[4], Akshaya Vasudevan[5], Harpinder S. Randhawa[1], Curt A. McCartney[2]

[1]Lethbridge Research and Development Centre, Agriculture and Agri-Food Canada (AAFC), 5403 1st Avenue South, Lethbridge, Alberta, Canada T1J 4B1
[2]Department of Plant Science, University of Manitoba (Fort Garry Campus), 66 Dafoe Road, Winnipeg, MB, Canada, R3T 2N2
[3]Ottawa Research and Development Centre, Agriculture and Agri-Food Canada (AAFC), 960 Carling Avenue, Ottawa, Canada, ON K1A 0C6
[4]Department of Animal Science, University of Manitoba (Fort Garry Campus), 12 Dafoe Road, Winnipeg, MB, Canada, R3T 2N2
[5]Department of Plant Breeding, Hochschule Geisenheim University, Geisenheim 65366 Hesse, Germany

Connect with me

Introduction

Rainfed farming in Canada's southern prairies faces threats from drought and recurrent Fusarium head blight (FHB) epidemics, endangering the durum wheat industry. In the wake of climate change, winter cereals, including winter durum wheat, offer a sustainable alternative with higher yields, reduced disease and weed pressure, reduced risk of soil erosion and better water use efficiency. At present, no winter durum wheat candidates are available for testing in Western Canada. Our research leverages **Genome-Wide Association Studies (GWAS)** and **Genomic Selection (GS)** to advance the accelerated development of winter durum wheat cultivars with focus on the two priority traits, **FHB resistance** and **winter hardiness.** These approaches have shown great potential for deciphering the genetic basis of complex traits, facilitating more accurate prediction of breeding values, and enhancing genetic gains for difficult-to-phenotype and complex traits such as FHB resistance and winter hardiness.

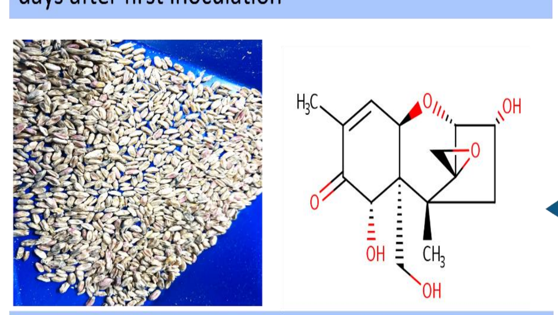
Materials and Methods

Winter Durum Diversity Panel
295 winter durum accessions (durum x durum, durum x hexaploid winter wheat cross-derivatives)

Pre- and Post-winter plant emergence rating to estimate winter survival (%)

Two inoculations at 50% anthesis stage and 3 days later with mixture of four aggressive *Fusarium graminearum isolates*

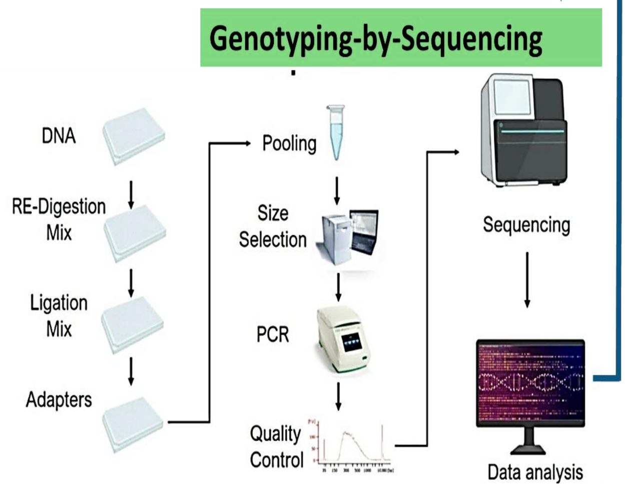
FHB incidence (%) and severity (%) recorded 21 – 25 days after first inoculation

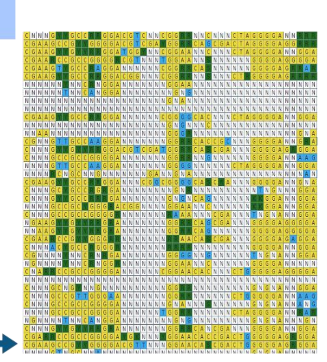


Data on Fusarium Damaged Kernels (FDK, %) and Deoxynivalenol (DON, ppm) generated using composite samples.

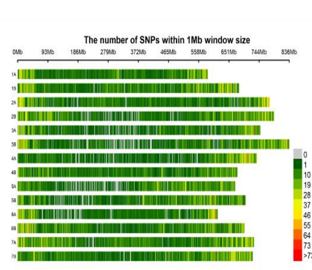
Field Phenotyping (2021-23)
(Replicated trials at Carman, Winnipeg and Ottawa)

Genotyping-by-Sequencing





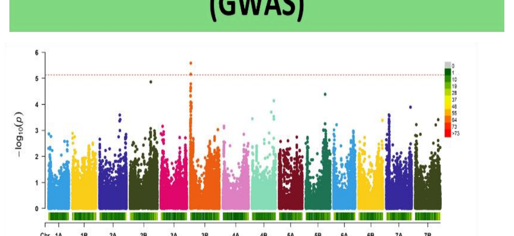
SNP calling against Svevo.v1 durum assembly and filtering of markers (MAF<0.05, Missing rate > 0.2, heterozygous call rate > 0.05.



68994 SNPs obtained after filtering.

Population structure and Kinship analyses

Genome-wide Association Studies (GWAS)



Six multi-locus GWAS models (ISIS EM-BLASSO, mrMLM, FASTmrMLM, FASTmrEMMA, pLARmEB and pKWmEB) implemented in R package (**mrMLM**)

Genomic Prediction (GP)

Parametric models: RRBLUP, GBLUP, Extended GBLUP (EGBLUP), LASSO and Elastic Net (EN)
Bayesian Models: Bayes A, Bayes B, Bayes C, BRR , Bayesian LASSO (BL)
Non-parametric models: Reproducing Kernel Hilbert Space (RKHS) and Multiple Kernel RKHS (MKRKHS) (semi-parametric), Random Forest Regression (Machine learning)

Five-fold Cross Validation (50 times)

Prediction accuracy = Pearson correlation coefficient (r^2)

- The one-way ANOVA was used to preselect SNPs based on phenotype at five different p-value thresholds.
- The one-way ANOVA based GWAS was performed on 146 accessions, excluded from the GS training set of 149 accessions, with the full panel of 295 accessions partitioned using stratified sampling based on population structure.

Results and Discussion

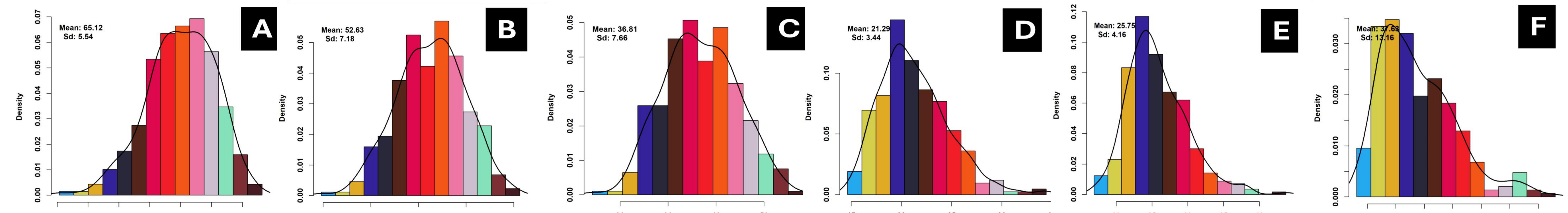


Fig. 1 Distribution of BLUP values across the site-years derived from single stage analysis for FHB associated traits, (**A**) Incidence (**B**) Severity (**C**) FHB Index (**D**) Fusarium Damaged Kernels (FDK) (**E**) Deoxynivalenol (DON), and (**F**) Winter Survival in Winter Durum Diversity Panel

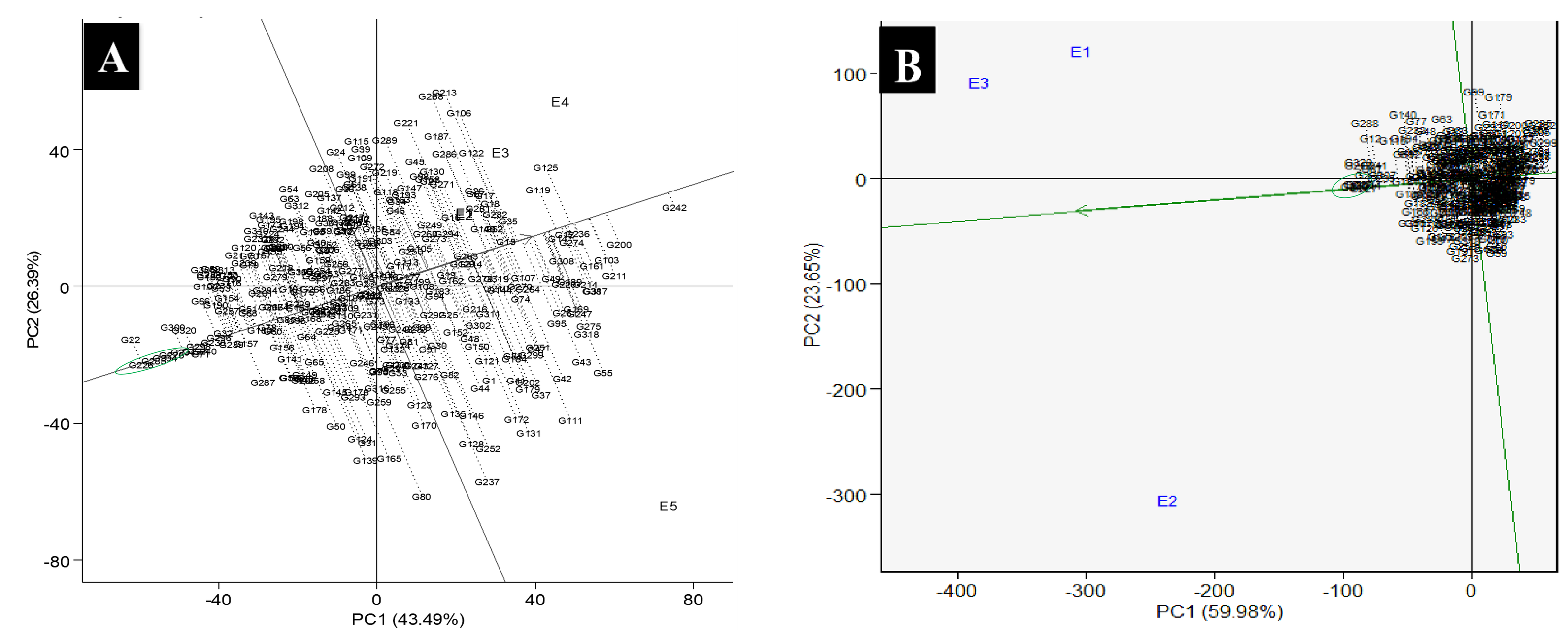


Fig. 2 Average environment coordination (AEC) view of the GGE biplot based on the environment-focused scaling for the mean performance and stability of winter durum accessions for (**A**) FHB index and (**B**) winter survival; **E1**: Carman (2021-22), **E2**: Ottawa (2022-23), **E3**: Carman (2022-23), **E4**: Winnipeg (2022-23), **E5**: Ottawa (2022-23)

Table 1. Top performing genomic prediction models across marker sets in terms of prediction accuracy (r^2)

Traits	Top performing genomic prediction models
Winter Survival	EGBLUP (0.705 – 0.726) , RKHS (0.698 – 0.717) and RRBLUP (0.693 – 0.712)
FHB Index	RF (0.424 – 0.514), LASSO (0.354 – 0.499) and MKRKHS (0.417 – 0.496)
FDK	MKRKHS (0.577 – 0.631) , RKHS (0.575 – 0.626) and EGBLUP (0.574 – 0.619)
DON	MKRKHS (0.540 – 0.627) , RKHS (0.545 – 0.621) and EGBLUP (0.544 – 0.606)

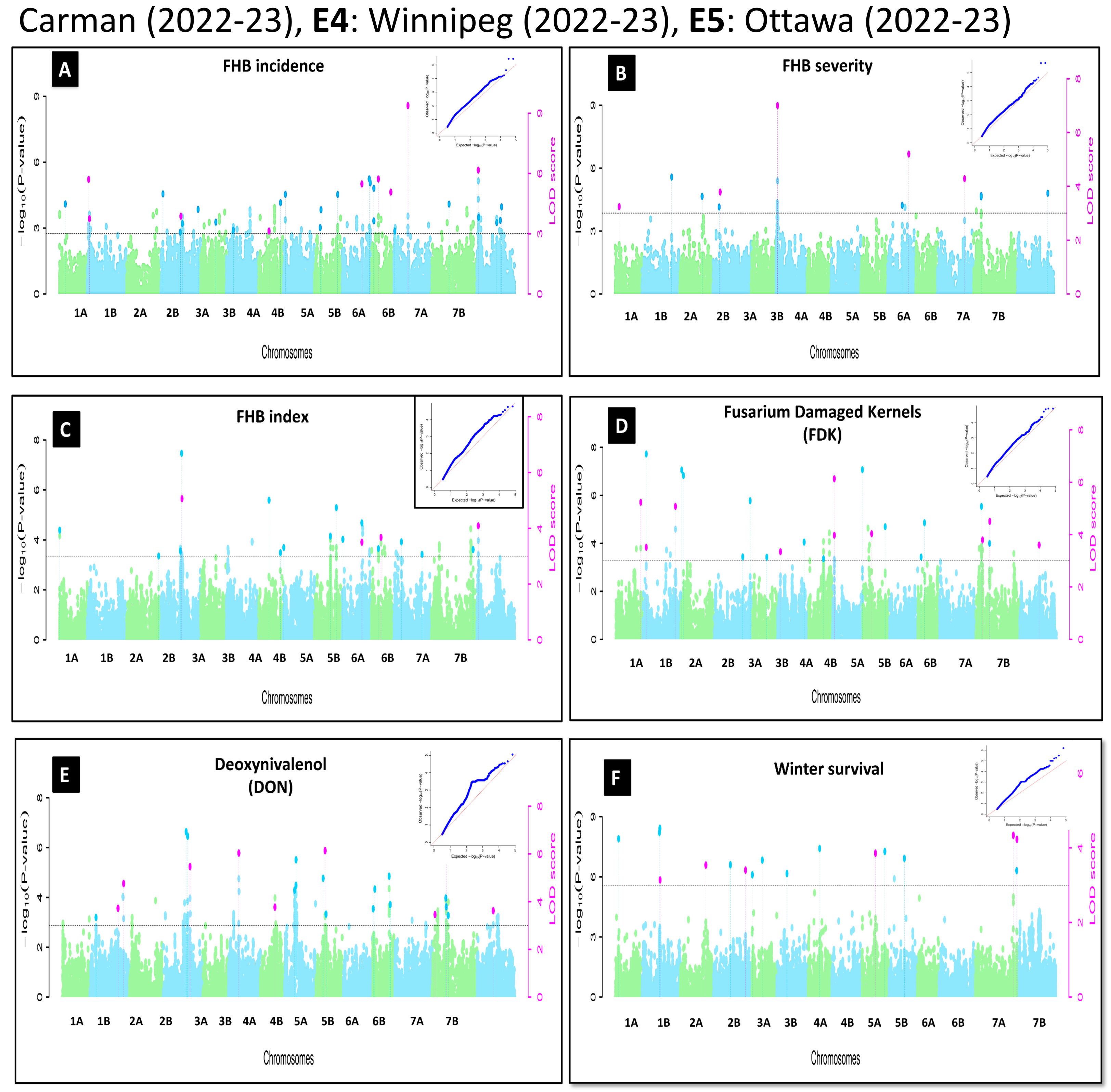


Fig. 3 Manhattan (**left panels**) and Quantile–Quantile (Q-Q) plots (**top-right panels**) of multi-locus GWAS models of FHB-related traits and winter survival

- **Stable winter-hardy superior accessions**: 17KS15 (67.07%), Kandur-1120 (60.40%), 13DW34-28 (60.30%); **Winter hardy Checks:** Wildfire (73.02%), Norstar (63.49%)
- **Stable and superior FHB-resistant accessions in terms of FHB Index**: OR2001209 (35.67), 13DW030-3 (37.63), 13DW030-70 (38.71)**; FHB-resistant Checks**: Wildfire (29.64), Ava (37.71), Emerson (39.06)
- **121 QTNs** associated with FHB resistance and **15 QTNs** for winter hardiness detected.

Conclusions

The superior and stable winter durum accessions identified in our study are being integrated into new crossing schemes to develop elite winter durum populations. By elucidating the genetic basis of FHB resistance and winter hardiness in our winter durum diversity panel, our research enables the application of marker-assisted and gene stacking in winter durum breeding program. Furthermore, moderate prediction accuracies demonstrate the potential of genomic selection for early-generation screening, enhancing genetic gains and accelerating the development of elite winter durum cultivars.

Acknowledgments

WGRF Advancing Agriculture through Research
Sask Wheat Development Commission
Wheat Breeding and Genetics Lab – University of Manitoba