Leaf position dependent hyperspectral responses to drought in wheat

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Introduction

Understanding how drought alters plant physiological functioning across canopy positions is critical for improving phenotyping of drought resilience in wheat.

However, most spectral studies focus either on the flag leaf or canopy level, potentially overlooking informative variation in leaf age, light distribution, microclimate, nitrogen status, pigment composition, photosynthetic activity, and water status.

This study tested whether integrating spectral measurements from the flag leaf (FL) and bottom sixth leaf (BL; counted from the top) could predict wheat performance under drought stress.

Conclusion

Spectral responses in wheat were leaf position dependent.

Leaf position provided complementary information for characterizing drought stress in wheat.

Inclusion of lower leaves within the canopy provided modest improvements in the predictive performance of PLSR and RF models.

Spectral reflectance can be used to predict wheat performance under drought.

Effective phenotyping approaches enable physiology assisted selection for climate-resilient wheat breeding.

Results and Discussion

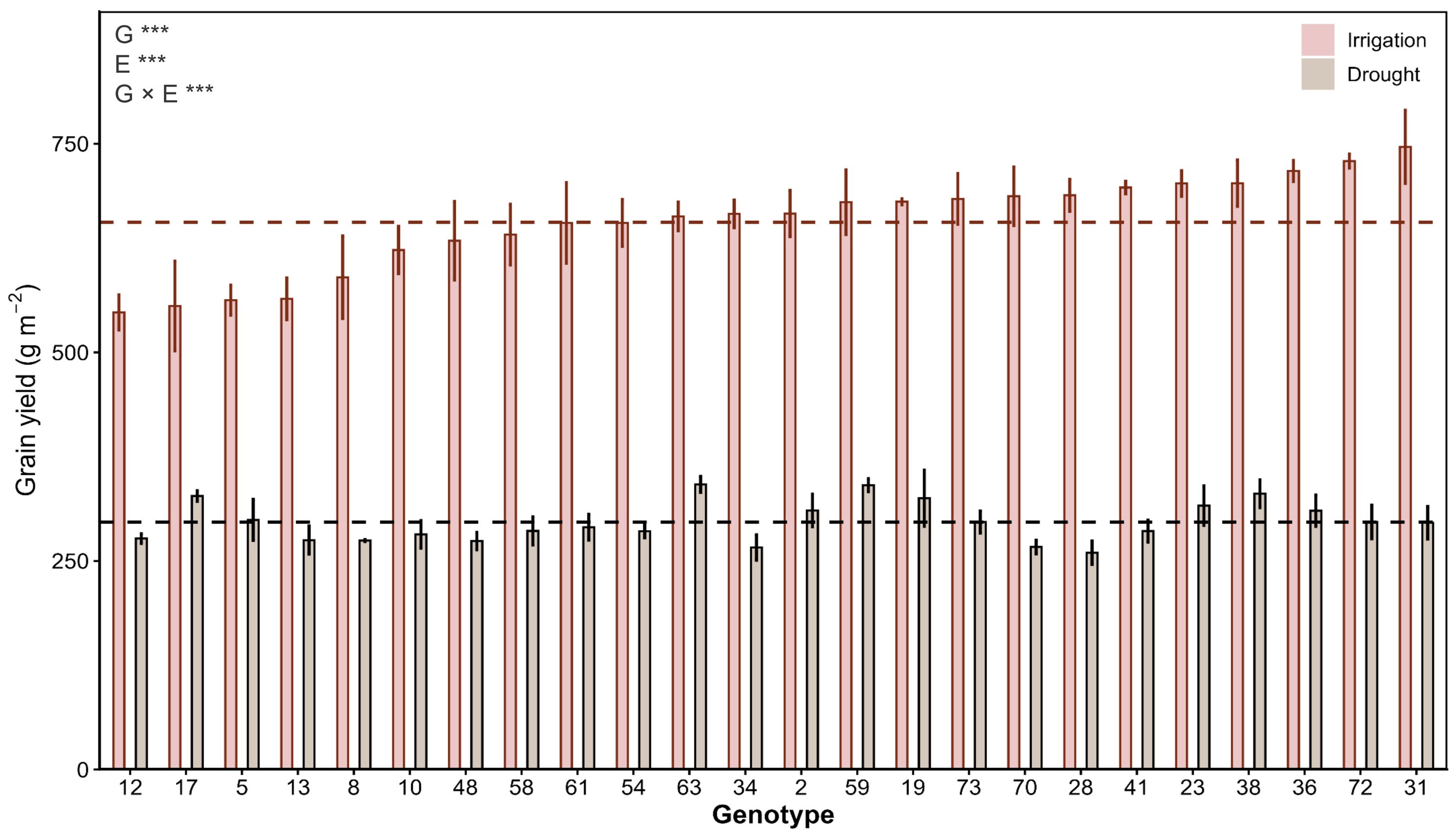

Fig. 1. Grain yield of 24 wheat genotypes under irrigation and drought. Bars represent means ± SE (n = 3); dashed lines denote environment means. Genotypes are ordered by grain yield under irrigation. Genotype (G), environment (E), and G × E interaction were significant (*P* < 0.001).

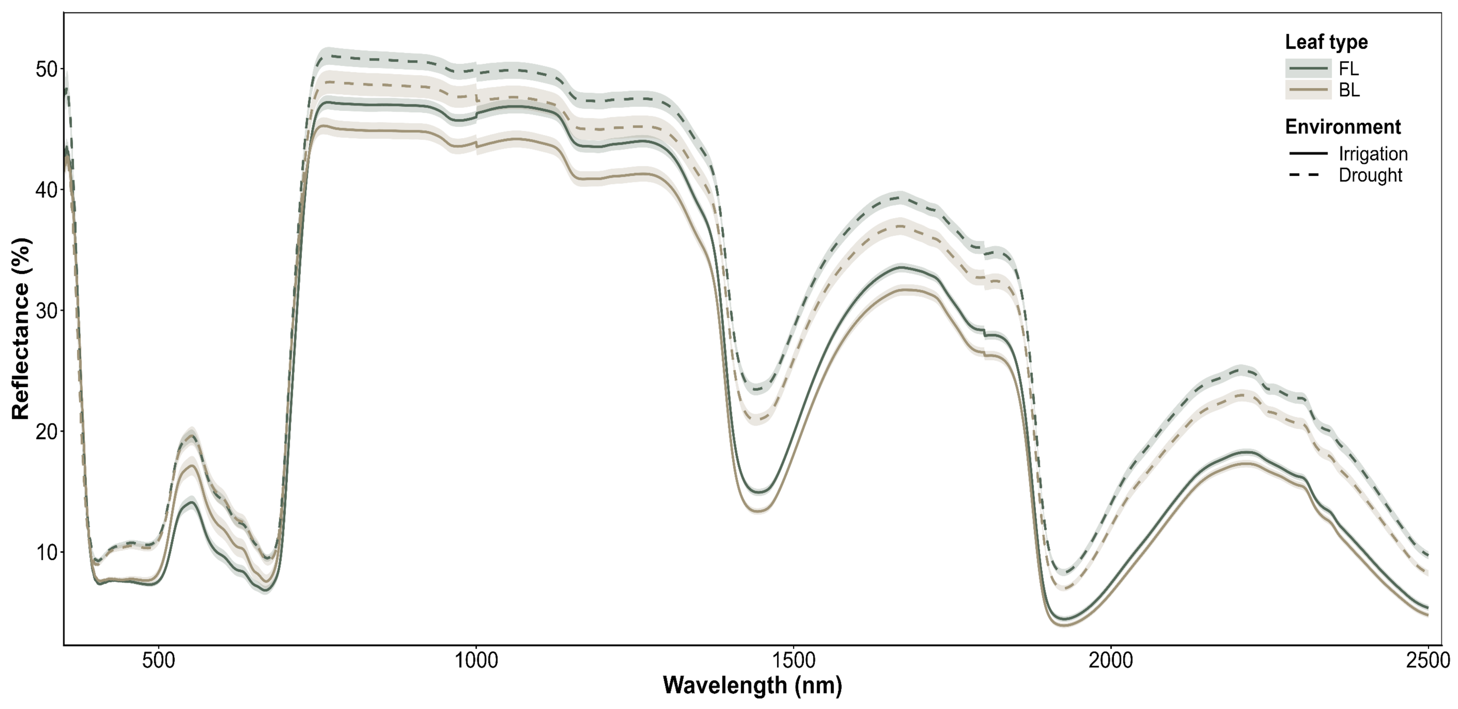

Fig. 2. Spectral reflectance profiles of flag (FL) and bottom sixth leaves (BL) under irrigation and drought across 400-2500 nm. Shaded areas indicate 95% confidence intervals.

Drought decreased grain yield (GY) on average 54.8% (P < 0.001).

Drought stress significantly increased leaf spectral reflectance across the 400–2500 nm range, indicating reduced leaf pigment content, affected water status and carbon metabolism (Fig. 2).

Under irrigation, BL showed higher reflectance than FL, particularly in the visible range (400–700 nm). Under drought, FL and BL reflectance in the visible range were no longer distinguishable (Fig. 2), which may be attributed to drought-induced accelerated flag leaf senescence, potentially driven by enhanced photosynthate remobilization to the developing grains.

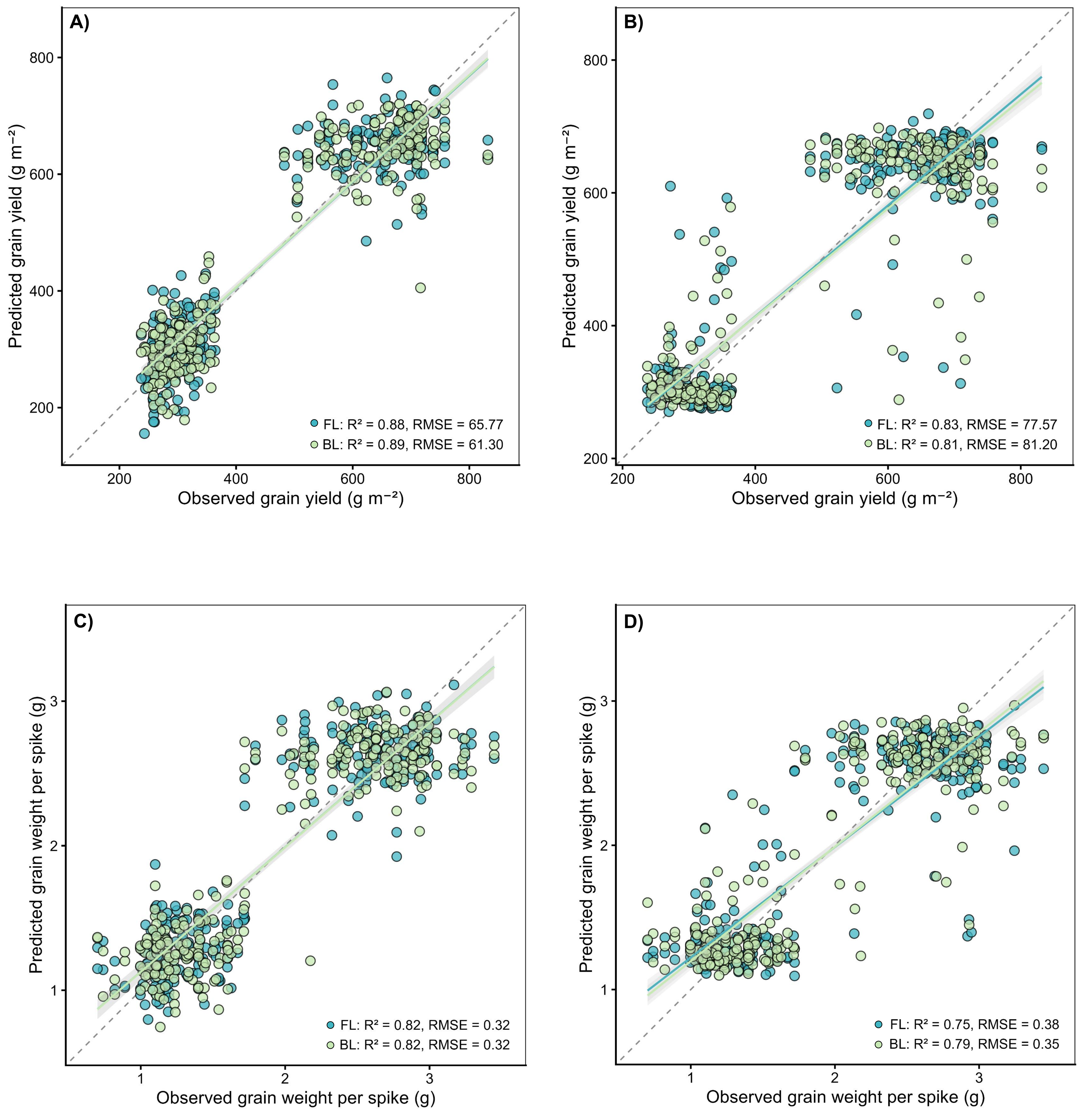

Fig. 3. Cross validated prediction of grain yield (GY) and grain weight per spike (GWSP) from FL and BL spectral reflectance using partial least squares regression (PLSR; left panels) and Random Forest (RF; right panels) across combined irrigation and drought environments.

Spectral reflectance exhibited consistently high predictive accuracy across both modelling frameworks for the GY and grain weight per spike (GWSP) (Fig. 3).

When BL reflectance is used to predict GY and GWSP instead of FL, only marginal improvements were achieved for GY using PLSR (Fig. 3A) and for GWSP using RF (Fig. 3D).

Materials and Methods

A field experiment was conducted at CIMMYT-CENEB, Ciudad Obregón, Mexico, during the 2023–2024 growing season using 24 wheat genotypes from CIMMYT's Best Physiological Traits panel under irrigation and drought. During grain filling, leaf spectral reflectance (400–2500 nm) was measured using an ASD FieldSpec 3 spectroradiometer (Boulder, CO, USA) with a leaf clip equipped with a halogen bulb light source. PLSR and RF models were developed to predict yield and its components from leaf spectral reflectance using 10-fold cross-validation in R (version 4.4.0).