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Radiation-use efficiency, cumulative light interception, and crop senescence dynamics as physiological traits for wheat resilience under heat and drought stress

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Abstract

Radiation-use efficiency (RUE) is the amount of above-ground biomass produced per unit of photosynthetically active radiation (PAR) intercepted by a crop. It is a central integrative trait of canopy photosynthetic performance and a key driver of genetic yield gains in wheat under optimal growing conditions, although its importance under heat and drought stress remains uncertain. In addition, canopy-level determinants of radiation capture, namely total intercepted PAR (IPAR), and post-heading senescence dynamics, play critical roles in crop productivity under abiotic stress. However, the contribution of these traits to RUE and wheat performance under drought and heat has not been established. This study aims at filling this knowledge gap using 50 elite wheat genotypes from three CIMMYT nurseries targeting specific environments: ESWYT (well-watered, WW), SAWYT (drought-stressed, DRT), and HTWYT (heat-stressed, HT). Genotypes were grown during the 2024–2025 season in Cd. Obregón, Mexico. WW received full irrigation, DRT was restricted to two irrigations (sowing and tillering). HT was sown in late February to impose heat stress and was fully irrigated.

Normalized difference vegetation index was measured at canopy level as a proxy for greenness using a GreenSeeker at weekly intervals from post-heading to physiological maturity. An ACCUPAR ceptometer was used to estimate the fraction of IPAR. Above-ground biomass was determined through destructive harvest at physiological maturity to calculate total RUE.

Multivariate regression analysis showed strong environment-dependent associations between physiological traits and grain yield. RUE explained yield variation with R^2 values of 0.50 (WW), 0.57 (HT), and 0.25 (DRT). Post-anthesis senescence dynamics accounted for R^2 values of 0.24 (WW), 0.44 (H), and 0.20 (DRT), whereas total IPAR showed R^2 values of 0.43 (WW), 0.47 (H), and 0.004 (DRT). Stepwise regression further confirmed RUE as the primary determinant of yield under WW and HT (WW: R^2_adj = 0.63; HT: R^2_adj

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= 0.64), while under DRT, yield variation was modestly explained by a combination of RUE and crop senescence dynamics (R^2_adj = 0.32), indicating a marginal contribution of canopy persistence under drought. These findings demonstrate RUE as the main driver of yield across environments, with a weak complementary contribution of senescence dynamics under drought.

Keywords: Crop senescence dynamics, drought stress, heat stress, intercepted PAR (IPAR), normalised difference vegetation index (NDVI), radiation-use efficiency (RUE), remote sensing