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Breeding for portfolios: A risk-oriented perspective on yield stability and food security

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Abstract

Traditional breeding programmes typically assess new crop varieties based on their potential to replace the current market leader. However, in practice, farmers cultivate multiple varieties to stabilise yields amid environmental uncertainty, and regionally, the result is a portfolio of varieties grown concurrently across the landscape. Consequently, breeders introduce new varieties into a portfolio-structured system by default, even if individual farms do not. This study formalizes portfolio-oriented breeding as a constrained optimisation problem using mean-variance portfolio theory. The breeder–farmer system is conceptualised as a coupled decision process: breeders select new genotypes from a feasible set defined by breeding budgets and genetic trade-offs, while farmers incorporate these genotypes into the regional variety mix to maximise risk-adjusted yield. Three breeding strategies are evaluated across approximately 195,000 simulated scenarios representing the genetic positions of incumbent varieties: a yield-maximising replacement strategy (BeatBest), a stability-seeking replacement strategy (BeatBestS), and a portfolio-contribution strategy (MVP). Portfolio-oriented breeding outperforms BeatBestS by at least 20 % in 28.6 % of scenarios and BeatBest in 47.2 %, with utility gains in dominant cases exceeding four times those of replacement heuristics. This advantage is most pronounced when two conditions are met: incumbent varieties exhibit negative covariance across enviroty-pes, and the higher-yielding incumbent occupies a niche that cannot be replaced by the breeder. Breeding for individual-variety stability is often the least effective approach, as it promotes environmental generalism in new releases and diminishes the diversity essential for portfolio performance. An empirical analysis of 12 Kansas wheat varieties from 1993 to 2006 supports the framework: the three varieties with the largest planted acreage ranked only 6^{th}, 7^{th}, and 11^{th} in mean yield, indicating that farmers collectively select for portfolio complementarity at the regional level rather than for standalone performance. The yield covariance matrix is approximately rank one, suggesting that conventional selection has homogenized environmental responses across varieties and suppressed the covariance structure that portfolio-oriented breeding could leverage. A depth-two decision rule based on the sign of the incumbent covariance and yield hierarchy correctly identifies four out of five scenarios where portfolio-aware breeding is optimal, offering breeders a practical, immediately applicable selection criterion.

Keywords: Climate risk, food security, genotype × environment interaction, plant breeding strategies, varietal portfolios, yield stability

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