Rice is particularly vulnerable when drought and temperature stress coincide at sensitive stages such as booting, flowering, and grain filling. Field experiments imposing combined drought and heat during flowering and early grain filling in contrasting cultivars recorded 20%-80% yield reductions, with cultivar-specific differences in which stage was most vulnerable and strong increases in panicle tissue temperature due to reduced panicle conductance under stress. Controlled-environment studies further demonstrated that simultaneous drought and high temperature at early stages (seedling, tillering) can completely prevent panicle formation and thus eliminate yield in susceptible cultivars, while tolerant genotypes maintain some productivity and show distinct patterns in grain quality and health-promoting compounds under combined stress.

3.3 Regional differences in rice production systems

Temperature-water interactions, and thus yield responses, vary widely among regions and production systems. A modeling study for Africa, covering irrigated and rainfed upland and lowland systems under multiple RCP scenarios, projected that without adaptation, higher temperatures shorten crop duration and reduce yields by about 24% under RCP8.5 by 2070; with higher-temperature-sum varieties, some rainfed systems gained modestly, but yields remained constrained by water availability, and irrigated dry-season rice in West Africa still faced large losses driven by photosynthesis reductions at extreme heat. In China, a comprehensive review found that climate change has shifted single and double rice belts northward, altered precipitation patterns, and increased the frequency of droughts and floods, leading to regionally divergent impacts where warming can either increase yields in cooler areas or reduce them in already warm zones through heat damage around flowering (Saud et al., 2022).

Finer-scale analyses highlight that regional differences in climate, water resources, and management produce contrasting yield trajectories and adaptation needs. Regional inequality assessments using ORYZA(v3) combined with climate projections for China showed average yield declines of 3.7-16.4% across regions, with central, eastern, and northwestern China most at risk under both rainfed and irrigated conditions, while northeastern and some southern areas may benefit under low-emission scenarios due to more favorable temperatures and water regimes (Zhan et al., 2023). At the farm scale in Indonesia, qualitative work revealed that upstream irrigated farmers mainly perceive climate impacts through pest outbreaks and heat, whereas downstream farmers, despite nominal irrigation access, experience climate change primarily as water shortages and rising temperatures, leading them to adopt distinct, locally tailored adaptation strategies for managing water scarcity and heat risk (Arifah et al., 2022).

4 Modeling Approaches for Rice Yield Formation

4.1 Empirical and statistical models

Empirical and statistical models relate rice yield directly to weather and agrometeorological indices, providing relatively simple tools for forecasting at regional scales. Panel regression and time-series analysis across 15 major rice-producing countries showed that increases in temperature tend to reduce production, while rainfall volume strongly affects output, highlighting rice’s sensitivity to both warming and hydrological variability (Joseph et al., 2023). At subnational scales, climate-index-based regression models using modified Hendrik and Scholl methods successfully linked yields to maximum and minimum temperature, rainfall, humidity and other indices, with good coefficients of determination and accurate forecasts for Maharashtra districts (Sasane, 2023).

Comparisons of alternative statistical formulations emphasize the importance of choosing appropriate regression structures for non-linear climate-yield relationships. In Sri Lanka, multiple linear, power, robust and Gaussian process regressions, together with several machine learning methods, were applied to three decades of climate and yield data; Gaussian process regression achieved the lowest errors and highest correlation between observed and simulated yields (Wickramasinghe et al., 2021). Similar work in Uttarakhand used stepwise linear regression, LASSO, ridge and elastic net on seasonal weather variables, finding that penalized regressions such as LASSO and elastic net generally outperformed ordinary multiple regression, especially when multicollinearity among climate predictors was substantial (Setiya et al., 2023).