climate variables should not be interpreted independently in yield models when they co-determine plant demand and stress timing (Ndlovu et al., 2021; Carcedo et al., 2022).

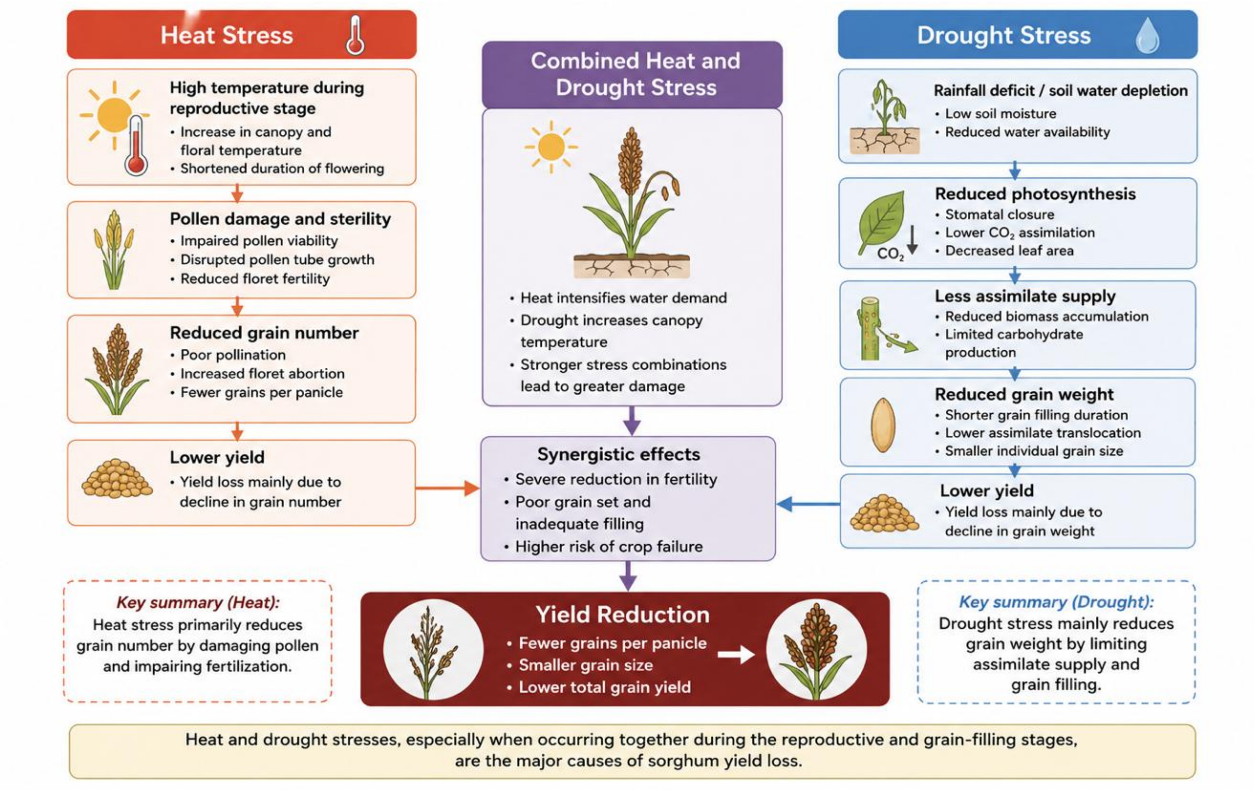

Figure 2 Mechanisms of yield loss under heat and drought stress

3.5 Climatic thresholds influencing yield stability

Thresholds in sorghum are real, but they are not universal constants. They depend on genotype, developmental stage, and stress duration. Even so, the literature gives useful working thresholds. For reproductive heat, mean daily temperatures above about 25°C during panicle emergence and early reproductive development begin to depress fertility, and sustained exposure to higher temperatures causes sharply larger losses. During grain filling, elevated temperatures mainly reduce kernel weight. For water-related thresholds, the message is less about a single rainfall total than about distribution. In Babile district, for example, August and September rainfall variability and the number of rainy days in September were among the strongest predictors of yield, whereas seasonal rainfall totals had weaker relationships. Dryland management studies likewise show that adaptation measures perform differently across rainfall bands, with some rainwater-harvesting practices helping under certain conditions but not across all semi-arid settings. In practical modeling, this means threshold thinking should focus on stage-specific heat episodes, rainfall sequence, and stress duration, not on a single whole-season cutoff (Prasad et al., 2015; Kubiku et al., 2022; Tolosa et al., 2023).

4 Modeling Approaches for Sorghum Yield Prediction

4.1 Statistical and empirical models

Statistical and empirical models remain the most straightforward entry point for sorghum yield prediction. Their usual strength is clarity: the analyst can directly test how yield covaries with rainfall totals, rainy-day frequency, monthly temperatures, or growing degree days. In data-scarce regions, that simplicity is a genuine advantage. The Babile study is a good example. Using 1995-2020 data, the authors found that a multiple regression based on monthly rainfall, rainy days, and temperature explained about 77% of the annual variation in sorghum yield, underscoring how much explanatory power can be obtained from carefully chosen climate predictors in a local rainfed system. At the same time, empirical models are only as stable as the relationships they learn from the past. They often struggle when management changes, cultivars change, or climate enters combinations outside the