Computational Molecular Biology 2026, Vol.16, No.3, 205-217
http://bioscipublisher.com/index.php/cmb

Feature Review Open Access

Modeling Yield Formation in Sorghum Based on Temperature and Rainfall

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Computational Molecular Biology, 2026, Vol.16, No.3 doi: 10.5376/cmb.2026.16.0015
Received: 05 May, 2026
Accepted: 07 Jun., 2026
Published: 22 Jun., 2026

Preferred citation for this article:
Zhou M.L., 2026, Modeling yield formation in sorghum based on temperature and rainfall, Computational Molecular Biology, 16(3): 205-217 (doi: 10.5376/cmb.2026.16.0015)

Abstract Sorghum (*Sorghum bicolor* L.) is one of the most important cereal crops in semi-arid and drought-prone regions due to its remarkable tolerance to heat and water limitation. However, sorghum productivity remains highly dependent on climatic conditions, particularly temperature and rainfall variability. This review synthesizes current knowledge on the biological and physiological mechanisms underlying sorghum yield formation and examines how temperature, rainfall, heat stress, drought stress, and their interactions influence grain number, grain weight, and overall yield stability. The review further evaluates major approaches used in sorghum yield prediction, including empirical statistical models, process-based crop simulation models, remote sensing technologies, and machine learning methods. Case studies from semi-arid regions demonstrate that reproductive-stage heat stress, post-flowering drought, and irregular rainfall distribution are among the most critical factors limiting yield. Future climate change is expected to intensify these challenges, highlighting the need for climate-resilient cultivars, adaptive agronomic management, and integrated decision-support systems. The review concludes that combining biological understanding with advanced modeling techniques can substantially improve yield prediction accuracy and support sustainable sorghum production under changing climatic conditions.

Keywords Sorghum; Temperature; Rainfall; Yield prediction; Climate change

1 Introduction

Sorghum remains one of the most important cereals for dryland farming systems because it combines food, feed, fodder, and industrial value with a comparatively strong ability to function under water limitation and high temperature. That practical resilience explains why it is deeply embedded in semi-arid production systems across Africa and Asia, and why recent reviews increasingly frame sorghum as a strategic crop for climate adaptation rather than only a "fallback" crop for marginal lands. At the same time, this reputation should not hide the fact that sorghum productivity in many regions remains low and unstable, especially where smallholders depend on rainfed systems, shallow soils, and short, erratic wet seasons. In those environments, modest shifts in seasonal onset, dry-spell frequency, or reproductive-stage heat can have outsized effects on grain set and final harvest. The literature therefore increasingly treats sorghum not simply as a hardy crop, but as a crop whose performance is highly conditional on stage-specific weather patterns and local management. That is exactly why climate-based yield modeling has become central to sorghum research and planning (Hossain et al., 2022; Liaqat et al., 2024; Mwamahonje et al., 2024).

Temperature and rainfall influence sorghum yield through different but tightly linked pathways. Temperature controls developmental pace, especially through accumulated thermal time, and therefore shapes the timing of leaf appearance, panicle initiation, anthesis, and maturity. Rainfall, by contrast, determines whether the crop can maintain canopy expansion, transpiration, reproduction, and grain filling at those stages. In practice, yield formation depends less on either variable in isolation than on their interaction with plant development. A warm season can shorten the crop cycle, reduce the duration of grain filling, and increase atmospheric demand for water; if rainfall is poorly distributed at the same time, the combined effect can sharply reduce grain number or grain weight. Conversely, moderately warm conditions paired with timely rainfall can improve stand establishment and biomass production, especially where cold stress or delayed phenology is otherwise limiting. This stage-specific interaction is the reason recent sorghum studies rarely analyze temperature and rainfall as simple seasonal