At the same time, emerging statistical and machine learning approaches demonstrate the feasibility of robust peach yield prediction when temperature and other climatic variables are explicitly incorporated. Yield models calibrated on multiyear orchard data in subtropical climates, using inputs such as chilling hours, mean temperature, and leaf nutrient status, have identified chilling and temperature as dominant predictors, with machine learning methods (e.g., Random Forest) outperforming multiple linear regression (Moura-Bueno et al., 2026). Parallel work in subtropical regions using growing degree-days (GDD) to characterize fruit development shows that thermal accumulation strongly differentiates cultivars in terms of fruit size and mass, underscoring the central role of temperature metrics for explaining variability in agronomic performance. However, these data-driven models rarely integrate detailed fruit-quality indicators, and are seldom evaluated under projected future temperature scenarios.

The present study addresses these gaps by developing and testing models that explicitly quantify the effects of temperature on peach fruit yield and quality. Building on controlled-environment and field evidence that high and low temperature regimes differentially affect photosynthesis, growth, and key quality traits, the study formulates the hypothesis that specific temperature indices (e.g., mean temperature, GDD, extreme heat indicators) are systematically associated with both yield components and multi-dimensional quality attributes, and incorporating these indices into statistical and machine learning frameworks significantly improves the prediction of combined yield-quality outcomes compared with models using generic climate covariates. By integrating physiological knowledge with modern modeling techniques, the research aims to identify temperature thresholds and response patterns critical for maintaining yield and quality, compare alternative modeling strategies for capturing these relationships, and provide a transferable framework to support cultivar selection, orchard climate adaptation, and precision management decisions in current and future temperature regimes.

2 Temperature Regulation of Peach Phenology and Fruit Development

2.1 Temperature effects on bud break and flowering dynamics

Bud break and flowering in peach are governed by the interaction of winter chilling and subsequent heat accumulation. Studies across many cultivars show that increasing chilling accumulation generally reduces the heat requirement and days to flowering, but the strength of this chilling-heat trade-off differs with the cultivar's chilling requirement; high-chill genotypes respond strongly to small increases in chilling, whereas low-chill types show weaker reductions in heat requirement (Yan et al., 2024). Classic work demonstrated an exponential decline in heat needed for floral budbreak as chilling increases, with insufficient chilling leading to extended, asymmetric budbreak and greater sensitivity to spring temperature variation.

Across wide climatic gradients, the timing of rest completion and the balance between chill and heat strongly shape bloom dates. Multi-site trials of peach and nectarine in Europe found that in colder sites, rest was completed earlier and bloom time was more tightly controlled by spring heat accumulation, while in warmer sites delayed or incomplete rest made bloom timing more sensitive to winter temperatures (Drogoudi et al., 2023). Long-term modeling shows that warming winters in major peach regions are already reducing chill accumulation, shifting the relative roles of chilling and forcing and complicating the prediction of budbreak and bloom under climate change (Yan et al., 2024).

2.2 Heat accumulation and fruit development rate

After bloom, heat accumulation is a primary driver of fruit development rate and the length of the fruit development period (FDP). Thermal-time models using growing degree hours with cultivar-specific base, optimum, and critical temperatures have been shown to predict harvest dates within 1-4 days across cultivars with FDPs ranging from 70 to 150 days, and are especially accurate when based on heat accumulated in the first 25-52 days after bloom. Analyses of spring temperature effects indicate that high early-season heat (GDH30) accelerates phenological development and shortens the period from full bloom to a reference developmental stage, but can reduce fruit size at that stage because trees cannot supply resources rapidly enough to match the higher growth potential.