

case evidence from overwinter tomato production in North China further showed that soft-shell solar greenhouses raised average daily temperature by 10°C-15°C, reduced low-temperature stress duration by 25%, and improved net returns when combined with variety optimization and scenario-based sales, indicating that greenhouse temperature regulation can generate both biological and commercial benefits when paired with cultivar and market strategy (Liu et al., 2025).

8 Conclusions and Future Perspectives

Temperature exerts a pervasive influence on tomato performance because developmental, physiological, and reproductive processes respond differently to thermal conditions across the crop cycle. Tomato is sensitive to temperatures below 12°C and above 32°C, and high temperature particularly decreases fruit yield while also altering multiple physiological traits and fruit quality attributes. Reviews of sub-optimal and supra-optimal conditions further show that cooler conditions can slow leaf and truss initiation, increase leaf thickness, reduce relative growth rate, and impair pollen quality, whereas warmer conditions can accelerate early development yet compromise later vegetative growth, fruit set, and seasonal yield stability. The overall yield outcome reflects the integration of many distinct temperature-sensitive processes rather than a single limiting trait. High temperature negatively affects both vegetative growth and reproductive development, leading to losses in fruit set, yield, and quality, while genotype-dependent differences in pollen viability, photosynthesis, and fruit-setting ability explain why some cultivars perform better under stress than others. Experimental and field-based evidence also indicates that elevated temperature can reduce fruit number, fruit weight, and marketable quality, although moderate chilling in some systems can induce acclimation and preserve yield, highlighting that the effect of temperature regulation depends on stress intensity, duration, and developmental stage.

Future research in temperature-controlled tomato production should move beyond describing stress injury and focus on predictive, trait-based, and mechanistic strategies for intervention. High-throughput phenotyping, including thermal infrared, hyperspectral, and chlorophyll fluorescence imaging, now offers non-destructive ways to detect heat-response traits, while GWAS and integrated genomics can identify markers for targeted breeding of thermotolerant cultivars. At the same time, molecular research increasingly supports the use of candidate genes related to flowering, pollen development, fruit set, heat shock responses, and epigenetic regulation as practical targets for breeding under recurrent heat stress. A second priority is to connect crop genetics with greenhouse engineering and climate-control technologies at commercial scale. Survey evidence from 326 ha of high-tech hydroponic greenhouses exposed to extreme summer heat showed that even advanced systems suffered yield loss and rising water, fertilizer, and electricity use, indicating that current climate-control capacity is often insufficient under future warming. Research should therefore test combinations of improved cooling, renewable-energy integration, season shifting, and heat-resilient varieties, while also evaluating emerging interventions such as prime editing, which increased tomato yield by 33% under heat stress without fruit-quality penalties through heat-responsive regulation of source-sink relations.

The implications for sustainable tomato production are both agronomic and systemic. Climate warming is projected to reduce processing tomato production in major producing regions by about 6% by 2050, with some leading areas facing additional water constraints, which implies that climate resilience will depend not only on plant tolerance but also on regional shifts in production systems and resource availability. In greenhouse systems, adaptation will require integrated approaches that combine structural innovations, precision irrigation, decision-support tools, and climate-resilient cultivars, because elevated temperature increasingly acts together with high radiation, water shortage, and vapor pressure deficits rather than in isolation. Sustainable and climate-resilient tomato production will therefore depend on combining biological resilience with technological and management innovation. Multidisciplinary strategies that unite breeding, genetic engineering, physiological knowledge, agronomic adjustment, precision monitoring, and beneficial microorganisms are increasingly viewed as essential for maintaining yield and food security under climate change. For tomato specifically, advanced ventilation, shading, renewable-energy-supported climate buffering, and cultivar selection for reproductive heat tolerance appear especially important because stable temperature and humidity are central to fruit set, lycopene formation, and marketable yield preservation in warmer production environments.