while its RMSE and MAE were reduced by more than 70% relative to a traditional crop-coefficient approach, and further partitioning by growth stage decreased RMSE by up to 97% at night during fruiting, illustrating gains in stability under different regimes (Tong et al., 2023). A neural-network yield model for solar greenhouse tomato across fertility levels reported that an improved particle-swarm-optimized network produced the smallest MSE and MAE and the largest $R^2$ (up to about 0.94), outperforming baseline networks under low, medium, and high fertility and thus demonstrating robustness across diverse environmental and management contexts (Peng et al., 2023). Broader crop-yield and evapotranspiration studies similarly adopt RMSE, MAE and $R^2$ as core indicators, emphasizing their usefulness for comparing alternative algorithms and for assessing generalization to unseen seasons or regions.

## 8 Case Studies of Greenhouse Tomato Temperature-Yield Modeling

### 8.1 Case study in solar greenhouses under winter cultivation

Winter tomato production in northern China has been used to demonstrate how temperature-yield relationships can be modeled in solar greenhouses. In soft-shell solar greenhouses, dynamic monitoring of light, temperature, and humidity for six cherry and three large-fruited cultivars was combined with yield and quality measurements to build correlation and partial least-squares path models linking microclimate to cluster yield and Brix (Liu et al., 2025). These analyses showed that soft-shell structures raised average daily temperature by 10 °C-15 °C and reduced low-temperature stress duration by 25%, with cherry tomato yield proving more temperature-sensitive than large-fruited types.

A complementary modeling approach integrated a mechanistic climate model with a tomato yield module specifically for Chinese solar greenhouses. This open-source model was calibrated and validated against three experiments, including two commercial winter production greenhouses, and achieved an RMSE of about 1.6 °C for indoor air temperature and 0.61-0.71 $kg \cdot m^{-2}$ for yield, while sensitivity analysis highlighted air-exchange parameters and optimal leaf area index as key determinants of simulated winter yield (Zhou et al., 2025). Active solar heating systems provide another winter case: in paired Canarian greenhouses, an active solar heating installation improved nocturnal thermal conditions and increased total tomato yield by 55% during the cold season, illustrating the strong leverage of improved temperature profiles on winter productivity (Bazgaou et al., 2021).

### 8.2 Case study in plastic tunnel systems under high-temperature stress

Plastic and walk-in tunnel systems in warm climates offer clear examples of modeling and managing high-temperature impacts on tomato yield. In southern China, daily maximum temperature and mean relative humidity inside plastic greenhouses were simulated using an extreme learning machine to identify high-temperature-high-humidity (HTHH) events, and response surfaces were then used to relate event frequency and return period to tomato physiological losses, showing that flower bud differentiation was the most temperature-sensitive stage (Zhang et al., 2022). The analysis revealed that HTHH events mainly occurred from June to September and that high temperature played a larger role than humidity in reducing growth indicators, providing a quantitative basis for risk assessment and regional layout of plastic-house tomato.

Experimental work in arid regions has focused on modifying tunnel microclimates and quantifying associated yield responses. In late-summer trials comparing a shaded net tunnel, a net tunnel with fogging, and a plastic tunnel with evaporative cooling, all powered by solar energy, cooled tunnels significantly improved leaf area, chlorophyll content, cell membrane stability, and relative water content, while reducing physiological disorders such as sunscald and blossom-end rot (Sharaf-Eldin et al., 2023). These microclimate changes translated into about 31.5% higher marketable yield with evaporative cooling and 28.8% with fogging relative to open field, demonstrating how engineered temperature reductions within plastic systems can be directly linked to yield gains.

### 8.3 Comparative case study of intelligent greenhouse temperature control strategies

Recent case studies in intelligent greenhouses explicitly couple temperature control strategies with crop and profit models. In the second “Autonomous Greenhouse Challenge”, five AI-supported teams remotely operated high-tech cherry tomato compartments for six months, using sensor data and algorithms to determine temperature,