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Agronomic Interventions for Mitigating the Adverse Impact of Temperature Stress

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ABSTRACT

Temperature extremes, both high (heat) and low (cold), significantly reduce crop productivity, affecting plant physiology, reproduction, and yield stability. Agronomic interventions provide practical, cost-effective, and field-ready solutions to mitigate these adverse effects. This review summarizes key agronomic practices including sowing date adjustments, irrigation management, mulching, nutrient management, foliar sprays, and conservation agriculture that enhance crop resilience to temperature stress.

INTRODUCTION

Temperature stress is one of the most critical abiotic stresses affecting global agriculture. Heat stress, defined as temperatures above the optimal range for a specific crop, impairs photosynthesis, enzyme activity, and reproductive processes. Cold stress, on the other hand, damages cell membranes, reduces seedling emergence, and affects pollen viability. These stresses lead to significant yield reductions across cereals, legumes, and horticultural crops worldwide (Teran *et al.,* 2024).

With climate change increasing the frequency of temperature extremes, developing agronomic strategies that help crops cope with heat and cold is essential. Agronomic interventions are adaptable, region-specific, and often inexpensive compared to genetic or breeding solutions (Lamaoui *et al.,* 2018).

Effect of High Temperature (Heat Stress)

Germination and Early Growth

High temperature delays seed germination and decreases seedling vigor. It reduces the percentage of germination by impairing enzyme activity and destabilizing membranes, leading to poor establishment in crops such as wheat, maize, and rice (Hasanuzzaman *et al.,* 2013).

Photosynthesis and Membrane Stability

Heat stress damages chloroplasts, reduces chlorophyll content, and impairs photosystem II efficiency. It also alters membrane permeability and enzyme conformation, which decreases photosynthetic efficiency and increases respiration rates.

Reproductive Development

The reproductive stage is the most sensitive to high temperature. Heat stress during anthesis causes pollen sterility, reduced fertilization, and poor seed set. In wheat, a 2–3 °C rise above optimum during grain filling can reduce yield by 15–40%.

Biochemical and Molecular Effects

Heat stress triggers accumulation of reactive oxygen species (ROS) that damage proteins, lipids, and DNA. Plants respond by activating antioxidant enzymes (SOD, CAT, POD) and heat-shock proteins (HSPs) that maintain cellular homeostasis (Hasanuzzaman *et al.,* 2013).

Impact on Yield and Quality

High temperature shortens the grain-filling period, decreases seed weight, and lowers quality attributes such as protein and starch content. In cereals, it leads to chalky grains, while in legumes and vegetables, it causes reduced seed viability and nutritional loss (Farooq *et al.,* 2011).

Effect of Low Temperature (Cold or Chilling Stress)

Germination and Seedling Establishment

Cold temperatures slow or prevent germination by restricting enzyme function and cell division. In rice and maize, chilling leads to poor root growth and delayed emergence.

Cellular and Membrane Damage

Cold stress reduces membrane fluidity and induces electrolyte leakage. Ice crystal formation during freezing can cause cell rupture and tissue necrosis (Zhou *et al.,* 2019).

Physiological Effects

Low temperature inhibits photosynthesis, reduces chlorophyll synthesis, and limits CO_2 assimilation. It also triggers excessive ROS production, causing oxidative stress (Hasanuzzaman *et al.,* 2013).

Reproductive and Yield Impacts

Cold stress during flowering or fruiting reduces pollen germination and ovule fertilization, resulting in flower abortion and low fruit set. For example, chilling during booting in rice reduces spikelet fertility and grain filling. (Zhou *et al.,* 2019)

Overall Consequences for Crop Productivity

Temperature stress, whether heat or cold, disrupts every stage of plant growth, from germination to seed development. Yield reductions vary from 10 % to > 50 %, depending on stress intensity and timing. Moreover, quality losses (e.g., lower grain protein, oil content, or nutrient density) reduce market value and nutritional quality (Farooq *et al*., 2011; Hasanuzzaman *et al.,* 2013).

Example Studies

- **Wheat + High Temperature during Grain Filling**: Wheat exposed to high temperature (HT) for 14 days in the grain filling period showed ~25% decline in photosynthesis and ~44% drop in yield per plant.
- **Cold Stress & Cold Tolerance Mechanisms**: Plants under cold stress accumulate osmoprotectants (like sugars), increase antioxidant enzyme activity, modify membrane lipid composition (higher unsaturation) to maintain fluidity and reduce damage.

Agronomic Interventions for Mitigating the Adverse Impact of Temperature Stress

1. Adjustment of Sowing Time

- **Changing the sowing date** helps crops avoid critical growth stages (like flowering and grain filling) coinciding with extreme temperature periods.
- In **wheat**, early sowing allows the crop to mature before terminal heat stress during late spring.
- Similarly, **delayed sowing** in cold-prone regions prevents chilling injury to seedlings.
- Location-specific sowing recommendations are crucial for temperature stress management (Gupta *et al.,* 2020).

2. Development and Use of Tolerant Varieties

- Breeding and selecting **heat-tolerant or cold-tolerant cultivars** is one of the most effective long-term strategies.
- Heat-tolerant varieties maintain stable yields by protecting photosynthesis and reproductive success.
- Examples: Wheat varieties **HD 2967**, **HD 3086**, and **PBW 343** show resilience to high temperatures.
- Such varieties have improved canopy temperature depression and membrane stability under stress.

3. Nutrient Management

Balanced nutrient supply strengthens plants' defense mechanisms against temperature stress.

- **Potassium (K)** improves osmotic regulation, stomatal function, and antioxidant enzyme activity.
- **Micronutrients** like zinc (Zn) and boron (B) enhance enzyme function and pollen viability under heat stress.
- Nitrogen management is critical, excessive N increases susceptibility to heat stress by promoting lush vegetative growth.

4. Use of Growth Regulators and Biostimulants

Application of **plant growth regulators (PGRs)** such as **salicylic acid, glycine betaine, abscisic acid (ABA), and brassinosteroids** enhances tolerance.

These compounds protect chlorophyll, stabilize cell membranes, and activate antioxidant defense systems.

- Example: Foliar spray of **abscisic acid (ABA)** has been found to enhance heat tolerance in chickpea (Kumar *et al.,* 2017).

5. Irrigation Scheduling and Water Management

- Adequate and timely irrigation is essential to reduce canopy temperature and maintain transpiration cooling.
- **Deficit irrigation** during critical stages such as flowering or grain filling increases yield loss.
- Use of **drip irrigation** or **mulch-based irrigation** conserves water and keeps soil temperature moderate.
- Irrigation just before heat waves can reduce plant canopy temperature by 2–4°C *(Jat et al.,* 2019).

6. Mulching and Soil Temperature Regulation

- **Organic mulching** (using crop residues, straw, or leaves) moderates soil temperature fluctuations.
- Reduces soil evaporation and helps maintain moisture, especially under high temperature.
- **Plastic mulching** can also be used in cold regions to warm soil and promote germination.
- Mulching thus creates a favorable root zone environment for plants under thermal stress *(Jat et al., 2019).*

7. Conservation Agriculture Practices

- Conservation agriculture (CA) emphasizes **minimum soil disturbance, crop residue retention, and crop rotation**.
- CA improves soil organic matter, water retention, and biological activity—enhancing the plant's tolerance to thermal stress.
- Long-term CA in rice–wheat systems has shown improved yield stability and reduced input costs under variable climate conditions *(Jat et al., 2019).*

8. Shading and Microclimate Management

Use of **shade nets or intercropping systems** helps modify the microclimate and reduce direct heat load on plants.

- Agroforestry systems also act as natural buffers against extreme temperatures.

CONCLUSION

- Agronomic management practices are vital tools to **combat temperature stress** in crops.
- **Sowing time adjustment, tolerant varieties, nutrient and water management, mulching, and conservation agriculture** are effective in maintaining yield and crop health.
- Integrated approaches combining these interventions ensure long-term sustainability and resilience against climate change.

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