Understanding The Impact of Heat Stress on Photosynthetic Apparatus

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The Earth's climate has shifted dramatically in recent decades, with global temperatures gradually rising. One of the most severe implications of this phenomenon is an increase in heat stress on plant systems, specifically the photosynthetic machinery. Photosynthesis, the primary mechanism by which plants transform light energy into chemical energy, is highly sensitive to temperature changes.

Heat stress affects the delicate balance of biochemical reactions and structural components in the photosynthetic apparatus, reducing productivity and crop yields. In this paper, we look at the complex effects of heat stress on photosynthesis, clarifying the fundamental mechanisms and investigating the astounding impact on worldwide agricultural production.

Stress

The World Health Organization (WHO) defines stress as a state of physical, mental, or emotional strain resulting from adverse or demanding circumstances. When applied to plants, stress is any factor that disrupts their normal physiological processes, compromising their growth, development, and overall health.

Temperature stress

Temperature above and below the optimum hinders the growth and development of crop plants and is considered as heat and cold stress, respectively. Temperature, an important factor in the rate of plant development, can hasten physiological maturity

Heat stress

Heat stress on the photosynthetic machinery occurs when plants are subjected to temperatures higher than their optimum range for an extended period. This temperature assault affects the precise machinery of photosynthesis, limiting the plant's capacity to convert sunlight into chemical energy, which is critical for existence.

Photosynthetic apparatus

The photosynthetic apparatus is a complex network of structures and chemicals found predominantly in plant cells' chloroplasts. Chlorophyll pigments, thylakoid membranes, photosystems I and II (PSI and PSII), electron transport chains, and carbon fixation enzymes like ribulose-1,5-bisphosphate carboxylase/oxygenase are all important components. These components work together to capture light energy, transfer electrons, and convert carbon dioxide (CO2) into organic molecules.

Effect of heat stress on plants

- Seedling establishment is hampered
- Drying of leaf margins and scorching effect on leaves
- Reduction in plant growth
- Pollen development is affected
- Reduced photosynthetic Efficiency
- Total biomass is reduced
- Spikelet sterility
- Grain and fruit development and quality are affected
- Oxidative stress
- Harm to photosynthetic machinery

Crop response to heat stress

Morphological responses

Scorching leaves and twigs.

- Sunburns on leaves, branches, and stems (sunscald)
- Senescence and abscission of leaves
- Inhibition of shoot and root growth.
- Fruit browning and damage.
- Reduced internode length.
- Strangulation Sickness.

i. **Anatomical Changes**

- Reduced cell size
- Closed stomata to reduce water loss
- Increased stomatal and trachomatous density
- Increased root and shoot xylem vessels
- Mesophyll cells were damaged, leading to increased plasma membrane permeability.
- The structural arrangement of thylakoids changed, reducing photosynthesis.
- Grana stacking or swelling was lost.

ii. **Phenological changes**

- High temperatures can damage leaf gas exchange properties during the vegetative stage
- increase flower abortion during reproduction
- Impairment of pollen and anther development
- Decrease in days to ear emergence, anthesis, and maturity in wheat
- Grain filling duration is also decreased.

Molecular responses

- Heat stress may cause oxidative damage.
- **Heat shock proteins (HSPs)** are a plant's primary defense against heat stress. These molecular chaperones are essential for protein stability, avoiding denaturation, and aiding refolding under stress.
- **Antioxidant defense system:** Plants strengthen their antioxidant defense system to combat the negative effects of reactive oxygen species (ROS) produced during heat stress. Superoxide dismutase (SOD), catalase (CAT), and peroxidases are enzymes that scavenge ROS and protect cellular components from oxidative damage.

Physiological responses

i. **Plant-Water Relationships**

- Enhanced transpiration leads to water deficit in plants, resulting in decreased physiological processes.
- High temperatures cause plants to lose water more during the day than at night.

ii. **Compatibility of Osmolytes**

- **Osmoprotectants** are compatible solutes that plants acquire to sustain cellular turgor and osmotic balance during heat stress. These include sugars (e.g., sucrose, trehalose), amino acids (e.g., proline), and polyols (e.g., sorbitol), which stabilize proteins, scavenge ROS, and keep cellular structures hydrated.

Effect on photosynthesis

- Generally, Heat Stress reduces photosynthetic efficiency, thus shortening the plant life cycle and diminishing productivity.
- Heat stress disrupts thylakoid membranes, thereby inhibiting the activities of membrane-associated electron carriers and enzymes, reducing the rate of photosynthesis.
- Heat Stress influences chloroplast structure and the thermal stability of components of the photosynthetic system, reducing ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) activity, amounts of photosynthetic pigments, and the carbon fixation capacity (Song *et al.*, 2014). High temperature has a greater influence on the photosynthetic capacity of plants, especially C_3 plants than C_4 plants. Closure of stomata under HT impairs photosynthesis which affects the intercellular CO_2.

Example

- (Mohammed *et al.*, 2010) Studies concluded that the decline in chlorophyll pigment also a result of lipid peroxidation of chloroplast and thylakoid membranes as observed in sorghum due to heat stress (40/30 °C, day/night).

Effect of heat stress on photosynthetic apparatus

- Altering structural organization of thylakoids
- Swelling of grana
- Impairing Grana stacking ability
- High-temperature stress affects photosynthetic pigments

Symptoms of heat stress

Fig. 1 Sunscald on cucumber leaves and fruit. (Image: Gerald Holmes, Strawberry Center, Cal Poly San Luis Obispo, Bugwood.org)

Conclusion

Heat stress is a huge danger to worldwide agricultural output and food security because it disrupts the fundamental mechanism of photosynthesis. Addressing this challenge would necessitate collaborative efforts to minimize climate change, produce heat-tolerant crop types, and deploy adaptive agricultural methods. Understanding the concept of stress, particularly heat stress, its effects on photosynthesis, and the crops most affected can help us protect our agricultural systems and ensure a sustainable future for future generations.

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