Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 03, Issue: 06 (NOV-DEC, 2023)
Available online at http://www.agriarticles.com

Heat Stress Effects on Rice: Morphological and Physiological Perspectives

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Introduction

Global warming is a critical issue impacting crop growth and distribution. The IPCC predicts a significant increase in global temperatures, posing a major challenge to agriculture. Heat waves are becoming more frequent and longer, threatening crop productivity. With every 1°C rise in global temperatures, major crops like wheat, rice, maize, and soybean face yield reductions. As the world's population grows, there is a pressing need to increase food production to meet demand.

Rice, a staple food for over half of the world's population, is particularly vulnerable to global warming, with regions like Southeast Asia at risk. Rising temperatures cause heat stress, leading to irreversible damage to rice growth and development. It has been shown that heat stress can significantly reduce rice yields. To ensure food security, there is an urgent need to develop thermotolerant rice varieties. Understanding the physiological, genetic, and molecular responses of rice to heat stress is crucial for developing strategies to enhance its resilience to global warming.

Key words: Direct seeded Rice and anaerobic germination

Growth and Developmental Effects of Heat Stress

Vegetative Stage: During the vegetative stage, particularly the seedling phase, rice faces detrimental consequences under high-temperature stress. With temperatures soaring to 42–45°C, seed germination potential is diminished, resulting in poor germination rates and reduced seedling vigour. The visible signs of heat stress include increased water loss, wilting and yellowing leaves, stunted seedling and root growth, and even seedling mortality. Different rice cultivars exhibit varying degrees of tolerance to heat stress, with indica varieties generally displaying better resilience. Moreover, heat stress during the tillering stage leads to symptoms like leaf wilting, curling, and reduced tiller number and biomass. Tiller count becomes a critical marker for selecting thermotolerant rice cultivars.

Reproductive Stage: As rice transitions to the reproductive stage, it becomes more susceptible to the adverse effects of heat stress. This stage encompasses essential processes such as panicle initiation, gametophyte development, anthesis, pollination, and fertilization. Elevated temperatures impair panicle initiation, spikelet development, and floral organ formation, leading to deformed floral organs, reduced spikelet number, and smaller spikelets. Different rice varieties may exhibit varying sensitivities to heat stress. In particular, anther development and pollen viability are more susceptible to high temperatures than female reproductive structures, leading to pollen grain abortion and reduced spikelet fertility.

Varietal differences in sensitivity highlight the importance of breeding for thermotolerant strains (Shi et al., 2018)

Grain-Filling Stage: The grain-filling stage, a crucial period in crop development, is affected significantly by heat stress. This phase involves the synthesis and transport of carbohydrates, proteins, and lipids to developing seeds. Exposure to high temperatures during this time leads to a higher grain-filling rate and a shorter total grain-filling duration, causing poor endosperm and embryo development. Grain size, grain weight, and overall yield are also adversely affected, with grain weight reduced by up to 39.1% in certain cases. Furthermore, heat stress during grain filling results in poor rice quality, characterized by undesirable grain appearance, chalkiness, and reduced palatability. Chalkiness, a prominent symptom of heat stress during this stage, is defined by opaque portions within the otherwise translucent white endosperm, negatively impacting rice grain quality. Additionally, heat stress disrupts starch biosynthesis, causing irregular starch granules, loosely packed granules, and reduced amylose content. As with previous stages, the degree of impact varies among rice varieties, underscoring the necessity of breeding for heat tolerance (Sreenivasulu et al., 2015).

Physiological Effects of Heat Stress

Membrane Damage: High temperatures affect plant cell membranes, particularly the plasma membrane, which is sensitive to heat-induced changes. Elevated temperatures disrupt the structure and function of membranes, increasing fluidity and permeability. This leads to compromised membrane integrity and the leakage of organic and inorganic ions from the cells. Additionally, heat stress alters the composition of membrane fatty acids, impacting plant adaptation to heat.

Reactive Oxygen Species Accumulation: Heat stress results in a significant increase in intracellular reactive oxygen species (ROS). This heightened ROS level leads to oxidative damage and various detrimental effects such as cell death, growth inhibition, grain chalkiness, and seedling and spikelet sterility. Heat stress impairs the activities of antioxidant enzymes, such as superoxide dismutase and catalase, and contributes to disrupted ROS homeostasis. High ROS levels further damage bio membranes by increasing membrane lipid peroxidation and protein oxidation.

Photosynthesis Damage: Photosynthesis is highly sensitive to elevated temperatures. Heat stress affects the permeability of the thylakoid membrane and reduces chlorophyll content, leading to changes in photochemical reactions, a lower photosynthetic rate, and decreased Fv/Fm (variable fluorescence to maximum fluorescence) ratio. Photosystem II (PSII), a crucial component of photosynthesis, is particularly sensitive to heat-induced oxidative stress, causing dissociation of the oxygen-evolving complex (OEC) in PSII and inhibiting electron transport. Heat stress also affects the activity of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), primarily due to Rubisco activase inactivation.

Disturbance of Carbohydrate Metabolism and Partitioning: Heat stress disrupts carbohydrate metabolism and photo assimilate partitioning in plants. High temperatures lead to low abundances of key enzymes in glycolysis, affecting energy generation. During anthesis, heat stress causes disorder in sugar content within anthers, impacting nutrition supply for pollen development. Heat-sensitive rice cultivars express the Carbon Starved Anthers (CSA) gene, while heat-tolerant cultivars show high expression of sugar transporter genes. This sugar starvation contributes to spikelet sterility.

Phytohormone Imbalance: Heat stress leads to an imbalance in phytohormones. Levels of active cytokinin's, gibberellins, and indole-3-acetic acid are reduced in rice spikelets and developing kernels under heat stress, affecting cell proliferation, panicle formation, and reducing spikelet number, pollen fertility, and kernel weight. Heat stress also affects the transportation and synthesis of cytokinin's. Exogenous application of 6-benzylaminopurine, a synthetic cytokinin, mitigates heat-induced damage. Heat stress increases abscisic acid levels in anthers and seeds, causing pollen abortion and inhibiting germination and seedling establishment.

Conclusion

The escalating challenge of global warming threatens rice production, a staple food for over half of the world's population. Heat stress during various growth stages results in detrimental effects, including poor germination, reduced fertility, and lower grain quality. Physiologically, heat stress damages membranes, increases reactive oxygen species, impairs photosynthesis, disrupts carbohydrate metabolism, and causes phytohormone imbalances. To address this critical issue, developing thermotolerant rice varieties is essential for ensuring food security. Understanding the physiological, genetic, and molecular responses to heat stress is crucial for breeding resilient rice strains and implementing sustainable agricultural practices. This effort not only secures the future of rice production but also addresses the broader challenge of global food security in a warming world.

References

1. P. Shi, L. Tang, L. Wang, T. Sun, L. Liu, W. Cao, Y. Zhu, D. (2015)Hui, Post-heading heat stress in rice of South China during 1981–2010, PLoS ONE 10.
2. N. Sreenivasulu, V.M. Butardo, G. Misra, R.P. Cuevas, R. Anacleto, P.B. Kavi Kishor, designing climate-resilient rice with ideal grain quality suited for high-temperature stress, J. Exp. Bot 66 (2015) 1737–1748.