

Influence of Heat Stress on Photosynthetic Efficiency and Yield Components in Wheat

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Prafulla Kumar^{1*}, Sushmita², Ankit Agrawal³¹Department of Biotechnology, University institute of Engineering and Technology, Guru Nanak University²Department of Agronomy, College of Agriculture, SVPUAT, Meerut³School of Biotechnology, IFTM University, Moradabad

Global air temperatures are projected to rise by 1.8 to 5.8°C by the end of the 21st century, which could threaten plant production and food security. Wheat (*Triticum aestivum*), a key global crop, is vulnerable to heat stress, especially during anthesis and grain filling stages, when temperatures exceed 30°C. Delayed sowing shifts the reproductive period into warmer periods, exacerbating heat stress.

While controlled-environment experiments are commonly used to study heat stress, they face challenges in simulating natural conditions, such as differences in solar radiation and temperature variations. Despite these limitations, studies have shown that with proper experimental design, heat stress evaluation can be successfully conducted in the field. The flowering and grain filling stages in wheat are highly susceptible to heat stress, particularly in

cultivars exposed to rising temperatures in major wheat-growing regions. Heat stress during reproduction reduces photosynthesis, limits yield, and accelerates plant senescence. High temperatures shorten grain filling duration, decreasing 1000-grain



weight. Heat stress can reduce photosynthesis through stomatal or non-stomatal limitations, and impair chloroplast enzymes due to oxidative stress, inhibiting repair of

photosystem II. The chlorophyll fluorescence parameter (Fv/Fm) is commonly used to assess the effects of heat stress on photochemistry efficiency.

1. Heat Stress And Wheat Growth Stages

Wheat is particularly vulnerable to heat stress during its reproductive stages, especially flowering and grain filling. These stages are crucial for determining the final yield, and exposure to high temperatures during this period can cause severe reductions in grain size

and number, ultimately impacting total yield. In many wheat-growing regions, rising temperatures due to climate change are causing heat stress during these critical stages, even when planting occurs at optimal times. The flowering stage, where the plant's reproductive organs develop, and the grain filling stage, where nutrients are accumulated in the developing seeds, are especially sensitive to heat stress. Heat stress during these stages can accelerate plant senescence, reduce photosynthetic activity, and disrupt the transport of assimilates to the grains.

2. Stomatal Non-Stomatal Limitation

Photosynthesis is the primary process through which plants convert light energy into chemical energy, fueling growth and development. Under heat stress, wheat plants experience several physiological disruptions that reduce photosynthetic efficiency. High temperatures can lead to stomatal closure, a plant's natural response to limit water loss. However, this also restricts CO₂ uptake, decreasing the rate of photosynthesis. Studies show that under heat stress, stomatal conductance (gs) is reduced, which indirectly limits photosynthesis by preventing CO₂ from entering the leaf. High temperatures also directly affect the photosynthetic machinery within the chloroplasts. Heat stress can reduce the efficiency of photosystem II (PSII), the protein complex responsible for the first step of photosynthesis. This leads to a decline in the electron transport chain's efficiency, reducing the plant's ability to fix carbon. Additionally, photorespiration increases, which further lowers the net photosynthetic rate.

3. Chlorophyll Degradation and Oxidative Stress

Excessive heat can lead to oxidative stress, which damages cellular structures, including chlorophyll. This degradation reduces the plant's photosynthetic capacity. Heat stress may also inactivate chloroplast enzymes, impeding the plant's ability to repair damage to PSII. As a result, the maximum quantum efficiency of PSII (Fv/Fm), a key indicator of photosynthetic efficiency, declines under high-temperature conditions.

4. Impact on yield components

a. Grain number, weight and Filling duration:

Heat stress during flowering and grain filling stages leads to a reduced number of grains per spike and a decrease in 1000-grain weight. The acceleration of senescence during heat stress shortens the grain filling period, limiting the time available for the grains to accumulate reserves. As a result, grains become smaller and lighter. This reduction in grain size directly translates into lower overall yield. The duration of the grain-filling period is crucial for determining wheat yield. Heat stress reduces the length of this period, leading to incomplete grain development. Shortened grain filling not only affects grain size but also reduces the overall yield potential. Longer grain-filling periods allow for more assimilates to be transported to the developing seeds, leading to larger grains and higher yields.

b. Biomass Accumulation

Heat stress also reduces total biomass production by limiting the photosynthetic capacity of wheat plants. The reduced photosynthetic rate means less carbon is available for growth, resulting in smaller plants and a reduced ability to produce grains. The shortened

growing period and reduced photosynthesis also limit the plant's ability to store energy for reproductive development.

5. Mechanisms of Heat Stress Tolerance In Wheat

Although heat stress negatively impacts wheat photosynthesis and yield, certain wheat cultivars possess mechanisms that confer heat stress tolerance. These mechanisms may help mitigate the damage caused by high temperatures:

a. Heat Shock Proteins (HSPs)

Wheat plants produce heat shock proteins as part of their protective response to heat stress. These proteins help stabilize cellular structures, protect enzymes, and assist in the repair of damaged proteins. Breeding for wheat varieties with enhanced HSP expression can improve heat tolerance. Wheat plants also have antioxidant defense mechanisms that help mitigate oxidative stress caused by high temperatures. The ability to scavenge reactive oxygen species (ROS) can reduce cell damage and maintain photosynthetic function under heat stress.

b. Enhanced Photosynthetic Capacity

Some wheat varieties possess the ability to maintain higher photosynthetic rates under heat stress, often due to better regulation of stomatal conductance and more efficient functioning of the photosynthetic machinery. These varieties tend to produce higher yields under heat stress conditions.

6. Strategies To Mitigate Heat Stress Effects

a. Breeding For Heat-Tolerant Varieties

Developing heat-tolerant wheat varieties is a long-term solution to maintaining yields under increased temperatures. By selecting for traits such as enhanced

photosynthetic efficiency, better water use efficiency, and improved grain filling duration, breeders can create wheat cultivars more resilient to heat stress.

b. Agronomic Practices

Agronomic practices such as adjusting planting dates, optimizing irrigation schedules, and applying foliar fertilizers can help reduce heat stress during critical growth periods. Early sowing, for example, can avoid the heat stress during flowering and grain filling stages. The application of plant growth regulators (PGRs) has been explored as a way to mitigate heat stress. PGRs such as cytokinin can help delay senescence, extend the grain filling period, and enhance photosynthetic activity under heat stress.

c. Crop management techniques

Using mulches or shading techniques to reduce soil temperature and increase moisture retention can help wheat plants cope with heat stress. Additionally, intercropping with heat-tolerant species or using cover crops may help buffer wheat plants from the direct impact of high temperatures.

Conclusion

Heat stress is a major challenge for wheat production, particularly during reproductive stages, when it disrupts photosynthetic efficiency and reduces key yield components like grain number and weight. While heat stress diminishes the capacity of wheat plants to perform photosynthesis by affecting stomatal conductance, enzyme activity, and chlorophyll content, there are potential mechanisms of heat tolerance that can be exploited through breeding and agronomic practices. As climate change continues to increase global temperatures, understanding and developing

heat-tolerant wheat varieties will be crucial for ensuring future wheat productivity and food security.

References

1. Ali, Q., & Wang, Y. (2024). Impact of heat stress on wheat photosynthetic efficiency and grain yield: A comprehensive review. *Agronomy for Sustainable Development*, 44(1), 36.
2. Hussain, M., Rehman, A., & Farooq, M. (2023). Heat stress and its effect on wheat's physiological traits: Implications for yield and photosynthesis. *Environmental Science and Pollution Research*, 30, 15045-15059.
3. Raza, A., Awais, M., & Rehman, M. (2024). Photosynthetic decline and yield loss in wheat due to heat stress: Physiological and biochemical mechanisms. *Journal of Agronomy and Crop Science*, 210(3), 503-514.
4. Zhao, Z., Wang, L., & Wu, Z. (2022). Heat stress impacts on wheat photosynthesis and grain yield: Mechanisms and mitigation strategies. *Environmental and Experimental Botany*, 192, 104637.