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Terminal Heat in Wheat: Impact and Management

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Introduction:

The term "terminal heat" describes the extreme temperature stress that wheat experiences during the grain filling stage, which typically occurs in March or April. Early maturity and yield loss result from temperatures rising above 30 to 32°C during the late reproductive and grain development periods. High temperatures can hasten plant senescence, shorten grain filling times, and result in poor kernel development, all of which have a detrimental effect on wheat output and quality. Climate change is making terminal heat a bigger problem, particularly in areas where wheat is farmed under rainfed conditions. The stress is a major worry for wheat growers around the world because it causes smaller, shriveled grains, lower test weight, and overall decreased crop output.

The grain filling period, which lasts from post-anthesis (after blooming) to physiological maturity, is the crucial stage in wheat that is impacted by terminal heat. High temperatures during this period shorten the time it takes for grains to form by speeding up plant senescence. Because of this, wheat plants are unable to produce their grains to their full potential, which results in smaller, lighter grains that weigh less. The crop's quality and yield are mostly determined during this time, and terminal heat stress severely reduces grain size, which lowers total productivity.

Impacts of Terminal Heat

Wheat is subject to substantial and varied effects from terminal heat, which mainly impair the crop's yield and quality. Grain development is shortened by high temperatures during the grain filling phase, which hasten plant senescence. Overall yield is decreased as a result of the smaller, lighter grains having a lower test weight. Additionally, poor kernel filling from terminal heat results in undeveloped and shriveled grains. It may also have an impact on the wheat's nutritional value by lowering its protein level and degrading the quality of baked goods. These impacts can result in large output losses in areas where terminal heat is frequent, which is why wheat producers are

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quite concerned about it, especially in light of climate change. Following are the major effects of terminal heat in wheat (Table. 1):

Table. 1: Effect of terminal heat in different parameters of wheat	
Parameter	**Effect**
Grain weight	Decreases due to shortened filling duration
Yield	Can reduce by 15–40% under severe stress
Protein content	May increase (due to shriveled grains)
Crop maturity	Forced early maturity
Photosynthesis	Reduced due to leaf senescence and heat stress
Pollen viability	Reduced, affecting grain set

Important Management Practices

1. Selection of Heat-Tolerant Varieties

One important tactic for controlling terminal heat stress is the selection of wheat types that can withstand high temperatures. Farmers can either avoid or better endure the effects of high temperatures during the crucial grain filling phase by selecting early-maturing or heat-resilient cultivars. These cultivars are developed to sustain superior grain development under stress or to mature more quickly, minimizing the amount of time plants are exposed to terminal heat. These types include HD 2967, HD 3086, DBW 187, and HI 1563 in India. They have all shown increased heat tolerance and are generally advised for areas that experience high temperatures during the wheat growing season.

2. Adjusting Sowing Time

Changing the time of sowing is a good way to lessen the effects of terminal heat on wheat. In order to prevent the negative impacts of terminal heat, early sowing, usually between late October and early November, allows the crop to finish its grain filling period before high temperatures occur. Early seeding contributes to the production of larger, heavier grains and the maintenance of total yield by guaranteeing that the crop develops earlier. Late sowing, on the other hand, pushes the grain filling process into hotter months, increasing the danger of heat stress, decreasing grain size, and lowering yield. Therefore, reducing the detrimental effects of terminal heat requires timely seeding.

3. Mulching and Conservation Tillage

In wheat production, mulching and conservation tillage are useful techniques for reducing the effects of terminal heat. By creating a protective layer that cools the soil, lowers evaporation, and holds onto moisture—all of which are vital during times of heat stress—mulching aids in controlling soil temperature. This maintains a more favorable soil environment for grain filling and root development. Minimal soil disturbance, or conservation tillage, can also assist reduce soil temperature and shield the root zone from intense heat. These techniques improve the growing environment's resilience by maintaining soil moisture and structure, which increases wheat's resistance to terminal heat and guarantees higher yields.

4. Irrigation Management

A key factor in reducing the impact of terminal heat on wheat is irrigation management. By preserving sufficient soil moisture, timely irrigation, especially during crucial phases like grain filling, helps protect the crop from heat stress. During times of high warmth, this guarantees that the plants have adequate water to maintain grain development. In order to keep the soil's moisture content constant and shield the crop from drought stress, light, frequent irrigations work better than heavy, infrequent ones. During times of heat stress, proper irrigation can greatly lower production loss and enhance the general quality of wheat.

5. Foliar Sprays

Salicylic acid or potassium nitrate (KNO_3) foliar treatments can greatly increase wheat's resistance to terminal heat stress. By strengthening the plant's stress resistance systems, these sprays help increase its capacity to tolerate extreme temperatures. Salicylic acid functions as a signaling molecule that fortifies the plant's defense mechanisms, while potassium nitrate helps to maintain cell activity and water regulation. Both treatments aid in maintaining photosynthetic activity, which guarantees the plant will continue to produce energy, and they postpone senescence, which enables the wheat to more successfully finish its grain filling period. When heat stress is present, these foliar treatments can increase overall yield and quality.

6. Use of Growth Regulators or Antioxidants

Wheat oxidative damage from terminal heat stress can be lessened by using growth regulators or antioxidants such as cytokinins, ascorbic acid, and thiourea. These compounds function by strengthening the plant's defenses against the damaging effects of heat-induced oxidative stress, which can destroy cells and interfere with regular physiological processes. Ascorbic acid functions as an antioxidant, guarding against cellular damage, cytokinins encourage cell division and proliferation, and thiourea reduces oxidative stress by scavenging free radicals. During times of heat stress, foliar application of these growth regulators can strengthen plant resistance, maintain cellular integrity, and eventually contribute to improved yield and quality.

7. Plant Nutrition

For wheat to withstand terminal heat stress, proper plant nutrition is essential. In particular, potassium strengthens cell walls, regulates water better, and increases stress tolerance, all of which increase a plant's resistance to heat. Under stressful circumstances, it guarantees improved nutrient transfer, lessens wilting, and aids in the plant's maintenance of turgor pressure. Furthermore, healthy root and shoot development is encouraged by balanced fertilization, which supplies vital nutrients including phosphorus, nitrogen, and trace elements. By doing this, the plant will be able to better control its uptake of water, sustain development in the face of heat stress, and aid in grain filling, all of which will increase production and quality during times of high temperature.

8. Breeding and Biotechnology Prospects

One long-term method of increasing resistance to high temperatures is to manage terminal heat stress in wheat by concentrating on creating heat-tolerant cultivars through genetic improvement. To find and add heat-tolerant features to wheat varieties, modern breeding methods like genomic tools and marker-assisted selection are being used. These instruments speed up the breeding process by enabling the accurate selection of genetic markers linked to heat resistance.

Furthermore, to identify promising cultivars, vast populations are screened for heat tolerance using sophisticated phenotyping platforms like infrared thermography and chlorophyll fluorescence. Breeding wheat varieties that can flourish in increasingly heat-stressed environments is made possible by the combination of genetic tools and cutting-edge screening techniques.

i. Conventional Breeding

Selecting heat-tolerant genotypes by phenotypic screening in hot climates is the foundation of conventional wheat breeding for heat tolerance. The use of recurrent selection to increase tolerance over several generations and early generation selection under hot, late-planted conditions to discover plants with superior heat resilience are important techniques in traditional breeding. Heat resistance and desired yield qualities can also be combined by crossing heat-tolerant lines with high-yielding types. Nevertheless, this method has drawbacks, such as being labor- and time-intensive. Additionally, it is environment-dependent, making it difficult to forecast performance in various settings because weather differences might affect how heat tolerance traits manifest.

ii. Marker-Assisted Selection (MAS)

A contemporary breeding method called Marker-Assisted Selection (MAS) makes use of DNA markers associated with particular heat tolerance features to select heat-resistant wheat varieties more quickly and accurately. One of the main advantages of MAS is that it makes it possible to screen at the seedling stage without requiring field testing, which greatly increases the speed and efficiency of selection. QTLs for canopy temperature depression (CTD) and stay-green characteristics, which support photosynthesis in plants under heat stress, are two examples of quantitative trait loci (QTLs) linked to heat tolerance. Furthermore, MAS can be used to identify and select for genes that regulate antioxidant enzymes and heat shock proteins (HSPs), which are essential for shielding plants from heat-induced damage.

iii. Genomic Selection (GS)

Genomic Selection (GS) is a sophisticated breeding method that more precisely and effectively selects individuals with desired features by using genome-wide markers to forecast plant performance. The capacity of GS to detect small-effect genes that affect complex traits—like heat tolerance—that are frequently challenging to detect using conventional techniques is one of its main advantages. Heat-tolerant wheat varieties can be developed more quickly thanks to GS's ability to drastically cut breeding cycles by utilizing genetic data. When several genes contribute to the overall expression of a polygenic trait, such as grain filling under heat stress, this approach is especially helpful. While guaranteeing that the most advantageous genetic features are included in future cultivars, GS speeds up the breeding process.

iv. Biotechnology and Genetic Engineering

Novel approaches to improving heat resilience are being investigated, including the direct insertion of particular genes for heat tolerance in wheat using sophisticated instruments. One strategy is to introduce Heat Shock Protein (HSP) genes, which stabilize cellular structures under stress and aid plants in surviving heat-induced damage. Furthermore, because they are essential for controlling heat stress reactions, transcription factors like DREB (Dehydration Responsive Element-Binding) and Hsf (Heat Stress Factors) are being targeted for alteration.

CRISPR/Cas9 gene editing, which enables precise alterations of the wheat genome to boost heat tolerance, is another innovative technique under investigation. Although it is still in its infancy because of regulatory obstacles, CRISPR/Cas9 has enormous promise for creating wheat cultivars that are more resistant to terminal heat stress, providing a quicker and more precise manner than conventional breeding techniques.

v. Use of Wild Relatives and Landraces

Breeding wheat with wild relatives and landraces is a good way to increase heat tolerance. Local landraces and wild wheat species, like Triticum dicoccoides, are rich genetic resources because they frequently have innate resilience to heat stress. In order to introduce beneficial genes for heat tolerance into elite, high-yielding wheat varieties, pre-breeding programs use these wild relatives. Breeders can create new cultivars that are more tolerant to terminal heat by combining these resilient features from landraces and wild species. This would guarantee bigger yields and better quality under demanding environmental conditions. This strategy increases the genetic diversity of contemporary wheat cultivars and improves their climate-adaptability.

vi. High-Throughput Phenotyping (HTP)

High-Throughput Phenotyping (HTP) is a novel method that effectively measures important characteristics including Canopy Temperature Depression (CTD), Normalized Difference Vegetation Index (NDVI), and canopy vigor in wheat using cutting-edge technologies like drones, sensors, and infrared cameras. When compared to previous procedures, these technologies enable the rapid, non-destructive assessment of plants, allowing for the evaluation of enormous breeding populations in a fraction of the time. By offering accurate and comprehensive information on how wheat plants react to heat stress, HTP speeds up the screening process and makes it simpler to choose heat-tolerant cultivars. By improving breeding programs' speed and effectiveness, this technology aids in the creation of wheat cultivars that are more hardy.