

Terminal heat stress

in wheat and its mitigation options through agronomic interventions

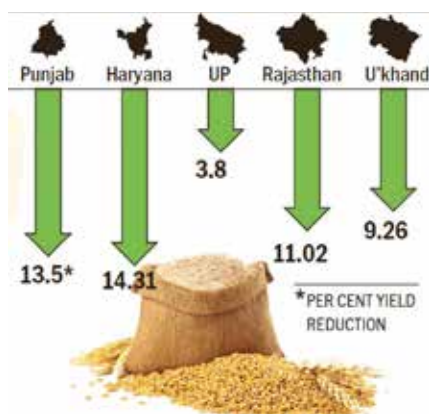
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Since the beginning of century, the ambient temperature has increased and is predicted to rise further under prevailing climate change. Heat stress is the rigorous threat to wheat particularly during reproductive and grain filling stages which results into yield losses. At flowering stage, heat stress causes sterility of pollen and anther leading to underdeveloped embryo which in turn reduces grain number, while heat stress during grain filling stage leads to reduced grain filling rate and in turn reduces grain weight and overall yield. There are various strategies for yield improvement under high temperature stress during reproductive phases in wheat but agronomic measures like timely sowing of wheat, retaining rice residue in field, irrigation during stress period, providing enough nutrition to the plants and spraying osmoprotectants can all help to reduce this stress.

Keywords: Heat stress, Osmoprotectants, Reproductive, Wheat

WHEAT (*Triticum aestivum* L.) is an important crop of rabi (winter) season covering an area of 31.6 million hectares in Indian subcontinent. Being a winter cereal, it requires particular temperature condition for better emergence, growth and flowering, and is more vulnerable if exposed to high temperatures during reproductive stages. The temperature stress, that develops throughout the reproductive development phases, during the period from heading to maturity, is denoted as “terminal heat stress”. The early commencements of significantly higher temperature during wheat grain filling are quite common especially in Indo-Gangetic plains (IGP) leading reduction in yields. Last year, in the month of February, the government forecasted that wheat production could have been a record 111.32 million tonnes but high temperature in the month of March drastically declined the production to 106.84 million tonnes. The impact of heat stress was more evident in key wheat growing states



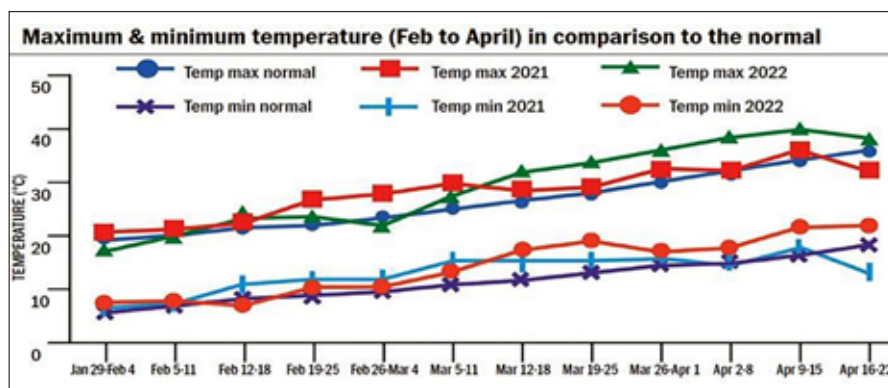
Reduction in wheat yields (2021–22) as compared to 2020–21 in 5 states
Source: Hari Ram and S S Gosal, PAU Ludhiana

Punjab, Haryana, Uttar Pradesh, Uttarakhand and Rajasthan. The wheat productivity in Punjab during 2021–22 (42.11 quintals/hectare) was reduced by 13.5% than the productivity in 2020–21.

The major reason for this reduction is the sudden rise of 2.1–6.6°C in the minimum temperature and 2.6–6°C in the maximum temperature in March, became unfavourable for the crop.

Effects of terminal heat stress on wheat crop

Terminal heat stress in wheat



Temperature variations as compared to normal for February to April, 2022
Source: Hari Ram and S S Gosal, PAU Ludhiana

Table 1. Optimal temperature requirements of wheat at different growth stages

Stage	Optimum temperature (°C)	Minimum temperature (°C)	Maximum temperature (°C)
Terminal spikelet	16.0 ± 2.30	2.50 ± 0.49	20.0 ± 1.60
Anthesis	23.0 ± 1.75	10.0 ± 1.12	26.0 ± 1.01
Grain filling duration	26.0 ± 1.53	13.0 ± 1.45	30.0 ± 2.13

Source: Khan et al. 2021

occurs when mean temperature during grain filling stage goes above 31°C. The optimal temperature requirement for wheat crop is given in Table 1. In a study it was found that even a rise of 1°C in the mean temperature in month of March-April leads to reduction in the duration of wheat crop by seven days and yield by about 400 kg/ha. Heat stress reduces plant photosynthetic capacity through metabolic limitations and oxidative damage to chloroplasts, with concomitant reductions in dry-matter accumulation and grain yield. At flowering stage, heat stress causes sterility of pollen and anther leading to underdeveloped embryo which in turn reduces grain number, while heat stress during grain filling stage leads to reduced grain filling rate and in turn reduces grain weight and overall yield. Moreover, when temperatures rise during grain filling, development speeds up, resulting in a shorter grain-filling period. Similarly, post-anthesis heat stress increased wheat grain protein content while decreasing the glutenin/gliadin ratio, which has a negative influence on flour quality.

It means that if no mitigation efforts are taken to lessen the emission of greenhouse gases, crop production will be negatively affected to a great extent. Hence, adaptation strategies are urgently required to minimize climate change impacts and some of the agronomic interventions to reduce impact of terminal heat stress on wheat are mentioned as:

Mitigation strategies for terminal heat stress

Sowing time: Sowing timing is a non-monitory element that helps to mitigate the negative effects of heat stress in wheat crop. First of all, do not prefer long duration paddy varieties as they mature late which further delays the wheat sowing.

To mitigate the terminal heat stress, wheat sowing should be started from 25th of October and completed up to 15th November. Early sowing avoids the hot, desiccating wind that occurs during flowering and grain filling period which ultimately determines crop performance. In general, late sowing wheat varieties faces severe temperature stress shortens the heading and maturity duration, ultimately affecting final yield and grain quality. Wheat productivity is reduced by around 1.50 quintals per week if planted after mid-November. Early planted crops generate considerably greater tiller count, plant height, leaf area index and dry-matter production, resulting in increased yield, and yield attributes. Therefore, maintaining appropriate planting time is one of the most important agronomic practices for getting optimum plant growth and yield of wheat under heat-stressed environment.

Irrigation management: High temperatures primarily promote plant transpiration. As a result, as long as the plants meet the greater transpiration requirement, they are not vulnerable to heat stress. Heat stress is commonly associated with water stress. Water stressed plants conserve water by closing their stomata, which results in less evaporative cooling and a pause in photosynthesis, which results in a reduction in other metabolic activity. As a result, water management is crucial during heat stress because appropriate moisture availability in the field can mitigate the harmful effects of high temperatures. Depending upon the rainfall, irrigate the timely sown crop up to the end of March to avoid the harmful effect of unusual rise in temperature at grain filling/formation stage. Care should be taken not to irrigate the crop on windy days to avoid lodging.

Tillage and residue management:

Under high-temperature stress, conservation agricultural (CA) methods based on sustaining soil moisture looks like viable alternatives. Researchers observed that keeping rice residue in an IGP rice-wheat system lowered canopy temperature in wheat by 1–4°C relative to ambient temperature between 138–153 days after sowing (DAS). Nowadays, wheat is sown by using different methods such as happy seeder, super seeder, and smart seeder, surface seeding, by which the straw of the proceeding crop is retained either by incorporation or as mulch. Mulching insulating the soil surface, consequently reduces the solar energy reaching the soil and, finally, reduces temperature increases during warm condition. The second reason for lower soil temperature under mulched field is higher water storage as compared to non-mulched field. Therefore, as compared to no mulching, paddy straw mulching conserved more water during the post-anthesis period, which results in enhanced grain production. In addition, the availability of soil moisture can help wheat plants to minimize canopy temperature through transpiration cooling and avoid heat stress.

Adequate nutrition: Efficient nutrient management is one way to reduce the impact of heat stress and sustain crop productivity. Optimization of nitrogen



Foliar application of potassium nitrate to mitigate terminal heat stress

supply sustained the wheat yield by increasing the stomatal conductance, chlorophyll contents and photosynthetic rate under elevated temperature. Phosphate is associated with supply of energy for plant processes to achieve good grain size of wheat. Potassium help in movement of nutrients in plants for redistribution of minerals to the ear potassium levels, extend the grain filling period leading to improvement in grain weight. Potassium deficient plants are found poor in regulating transpiration leading to heat stress and wilting. Adequate supply of magnesium (Mg) was identified as an effective nutritional strategy to minimize heat stress-related losses in wheat production. Zinc (Zn) deficiency and heat stress also affect the wheat productivity by reducing kernel growth and chloroplast function. Optimum supply of Zn through foliar fertilization can maintain membrane integrity and activity of SOD enzymes thus imparting heat stress resilience in wheat. Thus balanced amount of N, P, K, Mg, and Zn based upon soil test basis is essentially required for attaining the potential yield of wheat.

Spray of osmoprotectants: The osmoprotectants are nontoxic, highly soluble, compactable solutes occurring in all organisms from archaebacteria to higher plants. Exogenous application of these osmoprotectants stimulates photosynthesis machinery and hence improved yield and quality of crops. Foliar treatments of potassium nitrate, salicylic acid, thio-urea and sodium nitroprusside have been shown to improve wheat productivity in unfavourable environmental circumstances (Table 2).

Potassium Nitrate: Potassium has substantial effect on enzyme activation, protein synthesis, photosynthesis, stomatal movement and water relation (turgor regulation and osmotic adjustment) in plants. Increased application of K^+ has been shown to enhance photosynthetic rate, plant growth, yield and drought resistance in different crops under abiotic stress conditions.

Table 2. Increase in wheat grain yield by application of osmoprotectants

Osmoprotectant rate	Increased in grain yield
Sodium nitroprusside 400 µg/ml (two spray after anthesis)	18.8%
2% KNO_3 (Two spray after anthesis)	17.9%
Thio-urea 20 mM (Two spray after anthesis)	14.9%

Source: Suryavanshi P (2016).

Under draught or heat stress, the photosynthesis efficiency of plants is reduced drastically as a consequence of chloroplast dehydration. The chloroplasts lose large amount of K^+ with a simultaneous decrease in photosynthesis. Hence, application of K^+ is necessary to maintain photosynthetic ability in wheat during heat stress. Application of two sprays of 2% Potassium nitrate (13: 0: 45) by dissolving 4 kg potassium nitrate in 200 litres of water at boot leaf and anthesis stages results in combating the terminal heat stress and helps in enhancing the grain yield

Salicylic acid: Salicylic acid (SA) is a common phenolic compound that promotes photosynthesis under heat stress by influencing various physiological and biochemical process. Salicylic acid can also exert various (both activating and inhibiting) influence on the activity of peroxidase, participating in the regulation of hydrogen peroxide pool and in the generation of superoxide anion radical on the conditions of presence of surplus of reductants. The ethylene formation was restricted by application of salicylic acid which resulted in delayed senescence, retention of stay green trait and increased yield. Two sprays of salicylic acid by dissolving 15 g salicylic acid in 450 ml of ethyl alcohol using 200 litres of water per acre at boot leaf and early milk

stages can be applied to mitigate the effect of high temperature at grain filling and enhance the wheat yield.

Calcium: Under heat stress, Ca^{2+} is required for maintenance of antioxidant activity in some cool season grasses. Calcium application in the form of $CaCl_2$ increased the Malondialdehyde (MDA) content (lipid peroxidation product) and stimulated the activities of SOD and catalase, which could be the reason for the induction of heat tolerance. Calcium plays an essential role in processes that preserve the structural and functional integrity of plant membranes, stabilize cell wall structures, regulate ion transport and selectivity, and control ion-exchange behaviour as well as cell wall enzyme activities.

Zinc and Silicon: Zinc is known to have a stabilizing and protective effect on biomembranes against oxidative and peroxidative damage, and loss of plasma membrane integrity, as well as on membrane permeability alteration. Zinc ions bind to ligands containing sulfur, nitrogen, and to a lesser extent oxygen, and preferentially bind to the membrane proteins. The balance between free radical generation and free radical defence determines the survival of the system. Therefore, Zn may have a role in modulating free radicals and their related damaging effects by enhancing plant's antioxidant systems. Silicon under



Inspection of wheat crop regarding the terminal heat stress

heat or draught stress maintains plant water balance, photosynthetic efficiency and erectness of leaves and structure of xylem vessels under high transpiration rate. It increases the number and mass grain production of wheat by stimulating shoot and root biomass under water stressed conditions.

Microorganisms: Microorganisms could play an important role in adaptation strategies and increase of tolerance to abiotic stresses in agricultural plants. Plant-growth-promoting rhizobacteria (PGPR) mitigate the impact of heat stress on different plants through the production of exopolysaccharides (EPS) and biofilm formation. PGPR mitigate the impact of drought on plants through a process called induced systemic tolerance (IST), which includes: a) bacterial production of cytokinins; b) production of antioxidants and; c) degradation of the ethylene precursor ACC by bacterial ACC

deaminase. Symbiotic fungi (arbuscular mycorrhizal fungi) and dual symbiotic systems (endophytic rhizospheric bacteria and symbiotic fungi) also tend to mitigate the high temperature stress in plants. Some bacterial species and strains affect plant tolerance to high temperature.

SUMMARY

Terminal stress is a major environmental issue limiting wheat production in the majority of wheat-growing regions across the world. The term "terminal heat stress" generally refers to a rise in temperature (>30°C) after anthesis and during grain development which impairs the process of grain filling in wheat. Rising temperatures shorten the vegetative and reproductive periods of the wheat crop, but the reproductive stage is more vulnerable than the vegetative. Numerous researchers have observed that

terminal heat stress affects wheat phenology and all yield-related parameters in all major wheat-growing regions. Hence, adaptation strategies are urgently required to minimize climate change impacts. Some of the agronomic interventions to reduce impact of terminal heat stress on wheat are heat-resistant wheat cultivars, time of sowing, adoption of conservation agriculture approaches (zero tillage, happy seeder, residue retention, mulching), altering sowing dates and irrigation schedule management. The use of osmoprotectants like potassium nitrate, salicylic acid, calcium chloride, zinc and silicon also have substantial effect on various physiological and biochemical process in plants thus helps in combating the terminal heat stress in wheat crop.

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HANDBOOK OF INTEGRATED PEST MANAGEMENT

To reverse the loss of environmental resources and also to reduce biodiversity loss, the Government of India has Integrated Pest Management (IPM) as part of the National Agricultural Policy. Integrated Pest Management emphasizes the growth of a health crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms. IPM is not new – mechanical, cultural and biological tactics were used by farmers for hundreds of years before chemical pesticides became available. Besides, there are IPM techniques that have been developed more recently and are effective in suppressing pests without adversely affecting the environment.



The task of spreading the message of IPM across is tough due to poor awareness about the subject among people in line-departments as also among the farmers. The information on integrated pest management as a whole is scattered. This *Handbook* comprehensively deals with all the aspects of integrated pest management in field crops, horticultural crops under traditional, protected systems. Information on basic strategies and tactics of different methods of management including mass production of biocontrol agents, IPM policy and pesticide registration is provided in comprehensive form.

The *Handbook of Integrated Pest Management* comprises 82 chapters which are well written in lucid language with crispy sentences by the renowned scientists. The role of IPM is elucidated with different pests like *Trichogramma*, *Bacillus thuringiensis*, *Nomuraea rileyi* etc. and agricultural crops like rice, wheat, maize, sorghum, pearl millet, pulses, soybean, rapeseed mustard, groundnut, minor-oilseed crops, sugarcane, cotton, jute and mesta, potato, vegetable crops, fruits, grapes, citrus, banana, pomegranate, coconut etc. This *Handbook* will provide information of available useful technologies to educate on how to reduce or judiciously use chemical pesticides, safeguard ourselves from chronic poisoning, save the National environment while also reducing input costs and raise farmers' income. This compilation will be useful to teachers, students, trainers, line-department personnel and policy makers.

TECHNICAL SPECIFICATIONS

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