Plant Responses and Adaptation to High Temperature

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High Temperature: Prediction

Among the ever changing components of environment, the constantly rising temperature is considered as one of the most detrimental stresses creating apprehension among the scientists because the global air temperature is predicted to rise by 0.2°C per decade which leads to 1.8–4.0°C higher temperature than the current level by 2100 (IPCC 2007).

Heat Stress

High temperature or heat stress results from temperatures high enough to damage plant tissues, substantially influencing the growth and metabolism of plants. Although variable for different plant species, temperatures in the range of 35–45°C produced heat stress effects on tropical plants (Hall 1992). However, the extent to which this occurs in specific climatic zones depends on the probability and period of high temperatures occurring during the day and/or at night.

Plans responses to high temperature

Plant responses to HT vary with the degree of temperature, duration and plant type. At very HT, cellular damage or cell death may occur within minutes, which may lead to a catastrophic collapse of cellular organization. However, at moderately HT, cell injury or death may occur only after long-term exposure. Indirect or slower heat injuries include inactivation of enzymes in chloroplast and mitochondria, inhibition of protein synthesis, protein degradation and loss of membrane integrity. High temperature stress impaired mitochondrial functions and resulted in induced oxidative damage.

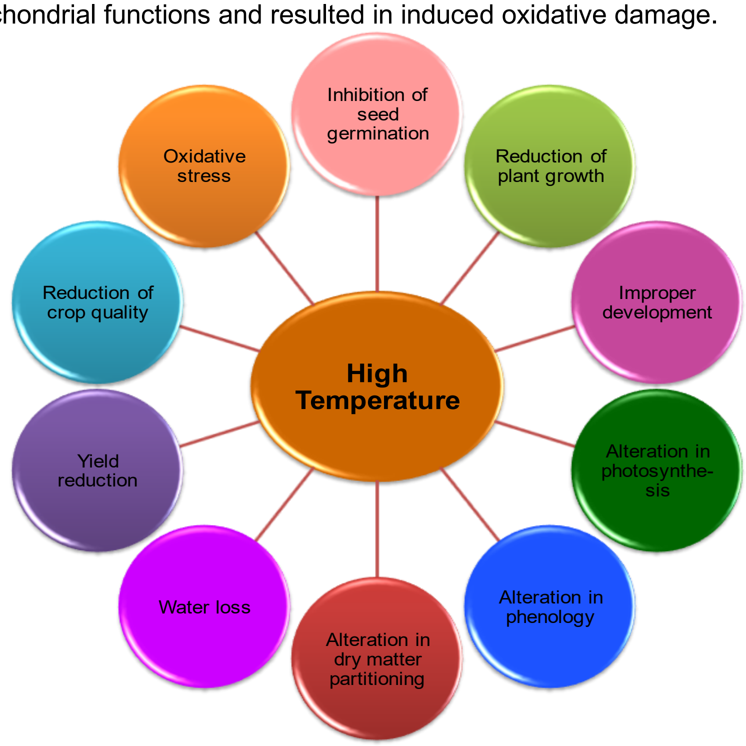


Fig. 1 Major effects of high temperature on crop plants

Seed germination and emergence

Seed germination and seedling vigor are important characteristics for obtaining a good plant stand and subsequent high yields of crop. Seed germination is highly dependent on temperature as temperature is one of the basic perquisites of this process. However, the range of temperature in which seeds perform better germination depends largely on crop species (Table 1). Soil temperature is one of the major environmental factors that influence not only the proportion of seeds that germinate, but also the rate of emergence and subsequent establishment, even under optimum soil and irrigation conditions.

Table 1. Ranges of temperatures for seed germination of different crops (Hasanuzzaman et al. 2013)

Crop species	Temperature (°C)		
	Minimum	Maximum	Optimum
Rice	10	45	20-35
Wheat	20	40	25-30
Maize	10	40	25-30
Soybean	10	35	25-30
Tomato	11	30	15-27
Cucumber	18	30	25-30
Egg plant	15	33	20-25
Peeper	15	35	20-30
Pumpkin	15	40	20-25
Water melon	15	35	25-30
Lettuce	4	25	15-20
Carrot	11	30	15-25
Cabbage	8	35	15-30
Spinach	5	30	15-20

Growth and morphology

The most observed effect of heat stress on plants is the retardation of growth. As heat stress often occur simultaneously with drought stress, the combination of drought and heat stress induce more detrimental effect on growth and productivity of crops than when each stress was applied individually. In higher plants, heat stress significantly alters cell division and cell elongation rates which affect the leaf size and weight. However, it was reported that heat stress resulted in significant increases in leaf numbers, particularly when reproductive development was arrested without any decrease in leaf photosynthetic rates. Exposure of plants to severe heat stress decreased the stem growth resulting in decreased plant height.

Photosynthesis

Like other physiological processes of plant temperature plays one of the most important roles in the rate and ability of a plant to photosynthesize effectively. In general, there is a positive correlation between change in temperature and photosynthesis. But when temperatures exceed the normal growing range (15°C to 45°C) of plants heat injury takes place and HT hurt the enzymes responsible for photosynthesis. Even in the absence of heat stress injury, photosynthesis would be expected to decline as temperature increases because photorespiration increases with temperature faster than does photosynthesis.

Water relations

Plant water status is considered as the most important variable under changing ambient temperatures. Plant water relation is more affected under the combined heat and drought stress, than the condition of heat and sufficient moisture level. High temperatures affect seedlings, first, by increasing evaporative demand and tissue damage. High temperatures induced increased transpiration and water transportation is another necessary tool for plant survival under extreme temperatures.

Dry matter partitioning

Dry matter (DM) partitioning varied widely under different temperatures and crops. Stresses like water deficit and heat slower down the assimilation process and the mineral uptake during the filling period. Assimilates those are transferred directly to kernels and remobilization of assimilates stored in vegetative plant parts both together contribute to grain yield. Sometimes under HT, it happens that the sink activity lost due to the earlier panicle senescence where the source activity still exists as the leaf senescence does not occurs. In those cases, grain filling was terminated earlier than complete leaf senescence.

Reproductive development

It is well established that the reproductive development of many crop species is damaged by heat and in such cases they produce no flowers or if they produce flowers they may set no fruit or seeds. It is notable that reproductive development in plants is more sensitive to HT because plant fertility is considerably reduced as temperatures increase.

Yield

As HT negatively affected plant establishment, growth, DM partitioning, reproductive growth and photosynthesis, it ultimately poses serious consequence on crop yield. Several lines of studies indicated the reduction of crop yield under HT which greatly varies with the degree and duration of temperature as well as genotypes of the crop.

Oxidative stress

Oxidative stress has been mentioned as a common metabolic route of different stresses, and it has been associated with genotypes tolerant to different abiotic stresses. Several recent reports indicated that under abiotic stress production of free radicles or reactive oxygen species (ROS) markedly increased. Heat stress accelerates the generation and reactions of reactive oxygen species (ROS) including singlet oxygen ($^1O_2$), superoxide radical ($O_2{\bullet}^-$), hydrogen peroxide (H_2O_2) and hydroxyl radical (OH•), thereby inducing oxidative stress. In plant cells, ROS are continuously produced as a consequence of aerobic metabolism in all the intracellular organelles, in particular in the chloroplast, mitochondria and peroxisomes. The chloroplast is the main source of ROS in plants.

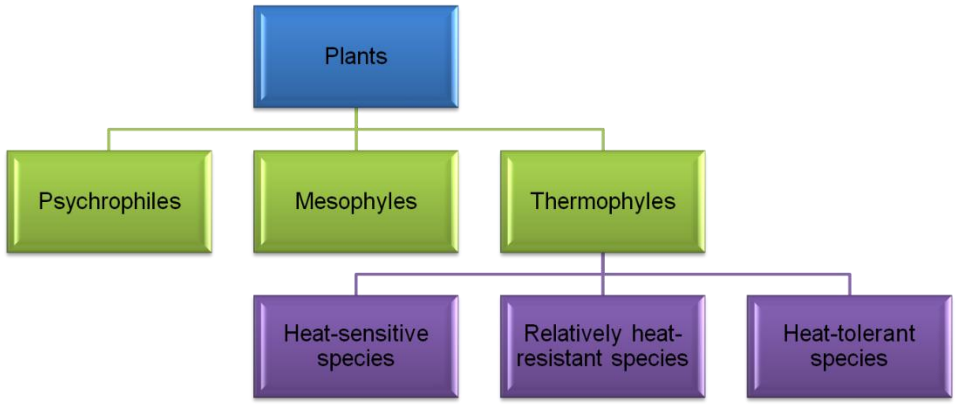
Plant adaptation to heat stress

On the basis of thermotoleranc Larcher (1995) classified all the plant species into three groups:

i) Heat-sensitive species: These species injured at 39 to 40 °C and they are mostly eucaryotic algae and submerged cormophytes, lichens in hydated state. Some soft-leaved terrestrial plants are also falls in this category.

ii) Relatively heat-resistant species: These plants can survive a 30 minutes exposure to 50 to 60 °C and may tolerate shorter exposure to temperature of up to 70 °C. They are mainly found in dry and sunny places.

iii) Heat-tolerant species: These are thermophillic procaryotes that can tolerate temperature of 75 to 90 °C. Some Archaebacteria can also survive even higher temperatures of up to 105 °C after an acclimation treatment (Trent 1996).



Survival in hot, dry environments can be achieved in a variety of ways, by combinations of adaptations. Plant adaptation to heat stress includes avoidance and tolerance mechanisms which employ a number of strategies.

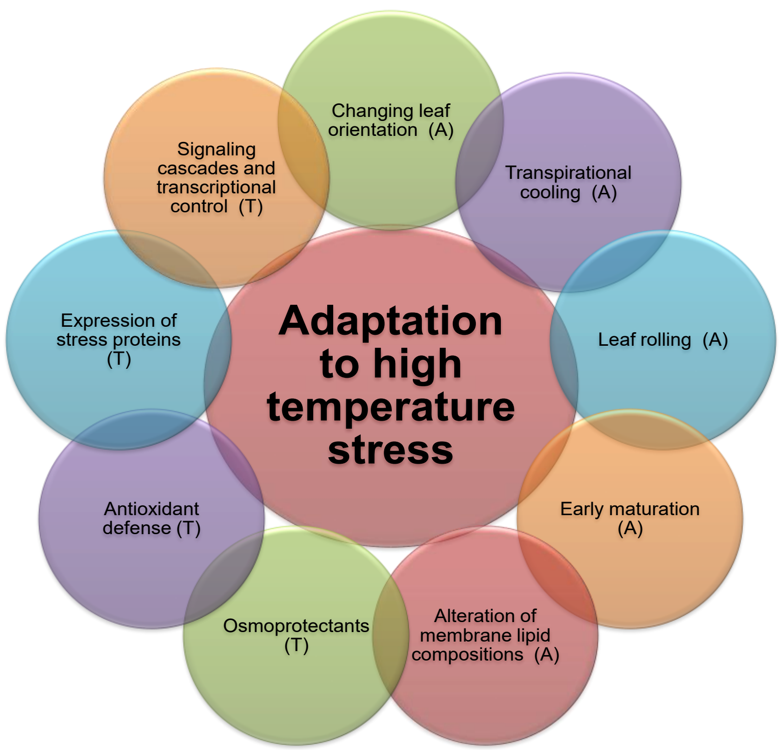


Fig. 4 Adaptive mechanisms of plants under high temperature

Avoidance mechanism

High temperature stress can also be avoided by crop management practices such as

- Management of sowing methods
- Choice of sowing date
- Choice of cultivars
- Selecting irrigation methods etc.

For instance, in subtropical zones, cool-season annuals such as lettuce when sown in the late summer may show incomplete germination and emergence due to high soil temperature. The incomplete emergence problem can be overcome by sowing the lettuce seed into dry beds during the day and then sprinkle irrigating the beds during the late afternoon.

Seed priming is another potential solution to this problem which involves placing the seed in an osmotic solution for several days at moderate temperatures and then drying them.

In temperate or subtropical climatic zones, which have seasonal variations in temperature, sowing date can be varied to increase the probability that annual crop species will escape stressfully high temperatures during subsequent sensitive stages of development.

In some cases, high temperature and intense direct solar radiation can cause damage to fruit. This can be avoided if fruit is shaded by foliage.

Tolerance mechanisms

Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under high temperatures.

This is a highly specific trait, and closely related to species, even different organs and tissues of the same plant, may vary significantly in this respect.

Plants have evolved various mechanisms for thriving under higher prevailing temperatures. They include

- Ion transporters
- Late embryogenesis abundant proteins
- Osmoprotectants
- Antioxidant defense
- Factors involved in signaling cascades and transcriptional control.