# Abiotic Stress in Crop Plants

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## Stress

Stress is usually defined as an external factor that negatively influences the plant. Plants are frequently exposed to environmental stresses in both natural and agricultural conditions. The complex nature of the environment, along with its unpredictable conditions and global climate change, is increasing gradually, creating a more adverse situation. Several abnormal environmental parameters are collectively termed abiotic stress. Plant stress is the adverse reaction of plants to environmental conditions that are unfavorable to growth.

## Stressor

A stressor is a chemical or biological agent, environmental condition, external stimulus or event that causes stress to an organism.

## Strain

Strain is the biological changes of plants under the influence of plant stress. Strain can be elastic or plastic depending on the degree and lasting time of stress.

- Elastic strain: Up to a point, a strain may be completely reversible and when the stress is relieved, the plant becomes normal.
- Plastic strain: Beyond the elastic strain, the strain may be irreversible or partially reversible irreversible, called plastic strain or permanent set.

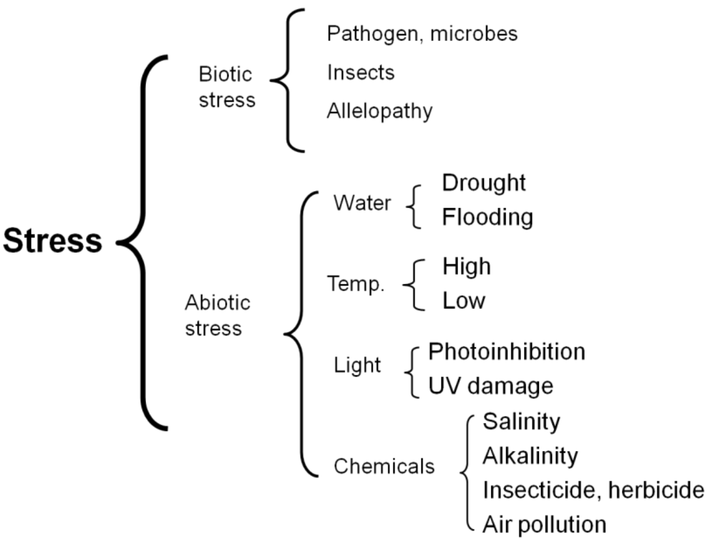



**Fig. 1. Various stresses in plants**



## Abiotic stress

Abiotic stress is defined as the negative impact of non-living factors on the living organisms in a specific environment. Plants are frequently exposed to unfavorable or even adverse environmental conditions, termed abiotic stresses (such as salinity, drought, heat, cold, flooding, heavy metals, ozone, UV radiation, etc.). Thus they pose severe threats to the sustainability of crop yield. Abiotic stresses remain the greatest constraint to crop production worldwide. It has been estimated that more than 50% of yield reduction directly results from abiotic stresses. Abiotic stress leads to morphological, physiological, biochemical, and molecular changes that adversely affect plant growth and productivity.

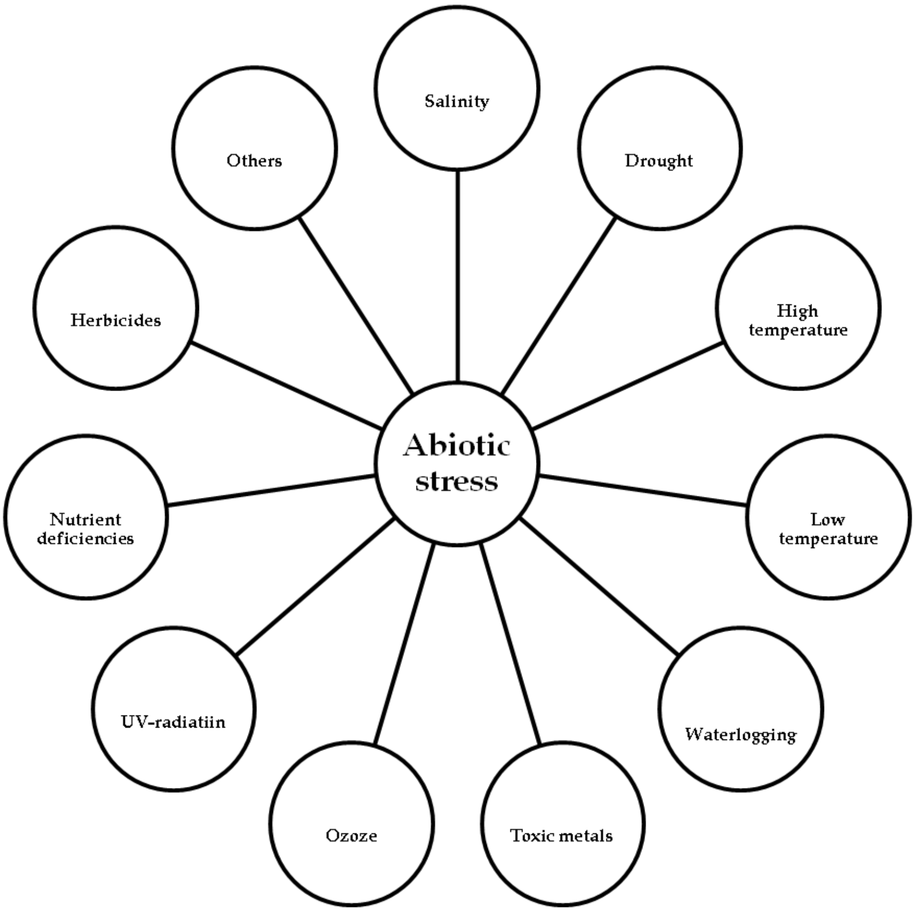



**Fig. 2. Various types of abiotic stress**

## Abiotic stress responses in plants

Abiotic stresses modify plant metabolism, damaging growth, development, and productivity. If the stress becomes very high and/or continues for an extended period, it may lead to an intolerable metabolic load on cells, reducing growth and, in severe cases, resulting in plant death. However, plant stress may vary depending on the types of the stressor and on the prevailing period. In nature, plants may not be completely free from abiotic stresses. They are expected to experience some degree of stress by any factor(s).

Some environmental factors, such as air temperature, can become stressful in just a few minutes; others, such as soil water content, may take days to weeks, and factors such as soil mineral deficiencies can take months to become stressful. In addition, stress plays a major role in determining how soil and climate limit the distribution of plant species. Thus, understanding the physiological processes that underlie stress injury and the adaptation and acclimation mechanisms of plants to environmental stress is of immense importance to both agriculture and the environment.

Due to global warming, and potential climate abnormalities associated with it, crops typically encounter an increased number of abiotic and biotic stress combinations, which severely affect their growth and yield. Concurrent occurrence of abiotic stresses such as drought and heat is more destructive to crop production than these stresses occurring separately at different crop growth stages.

**Table 1. Physiological and biochemical perturbations in plants caused by fluctuations in the abiotic environment**

| Environmental factor | Primary effects | Secondary effects |
|---|---|---|
| Salinity | • Water potential reduction<br>• Cellular dehydration<br>• Ion cytotoxicity | • Reduced cell/leaf expansion<br>• Reduced cellular and metabolic activities<br>• Stomatal closure<br>• Photosynthesis inhibition<br>• Leaf abscission<br>• Membrane and protein destabilization<br>• Ion cytotoxicity<br>• Cell death |
| Water deficit | • Water potential reduction<br>• Cellular dehydration | • Reduced cell/leaf expansion<br>• Reduced cellular and metabolic activities<br>• Stomatal closure<br>• Photosynthesis inhibition<br>• Leaf abscission<br>• Membrane and protein destabilization<br>• Cell death |
| Flooding | • Hypoxia<br>• Anoxia | • Reduced respiration<br>• Fermentative metabolism<br>• Inadequate ATP production<br>• Reactive oxygen species (ROS) production<br>• Stomatal closure |
| High temperature | • Membrane and protein destabilization | • Photosynthesis and respiration inhibition<br>• ROS production<br>• Cell death |
| Low temperature | • Membrane destabilization<br>• Water potential reduction<br>• Cellular dehydration<br>• Ice crystal formation in cells | • Reduced cell/leaf expansion<br>• Reduced cellular and metabolic activities<br>• Stomatal closure<br>• Photosynthesis inhibition<br>• Leaf abscission<br>• Membrane and protein destabilization<br>• Ion cytotoxicity<br>• Cell death<br>• Physical destruction |
| Metal toxicity | • Damage in protein and DNA<br>• ROS production | • Disruption in metabolism |
| All stress | • Excess generation of reactive oxygen species leading to oxidative stress.<br>• Reduction of growth and yield<br>• Loss of crop quality | |

**Role and Impact of Abiotic Limitations to Crop Yield**

The general scheme proposed in Figure 1 describes the plant response to abiotic stress with given features (duration, severity, etc.). The stress acts on a crop with given phenotypic characters to result in the final effects on growth, development, and mortality rate. The basic scheme of Figure 3 results from a complex causal chain, which involves plant hormones and acts at the molecular and physiological levels. The knowledge of this causal chain is substantially increasing thanks to transcriptomics, metabolomics, proteomics, and other integrated research approaches.

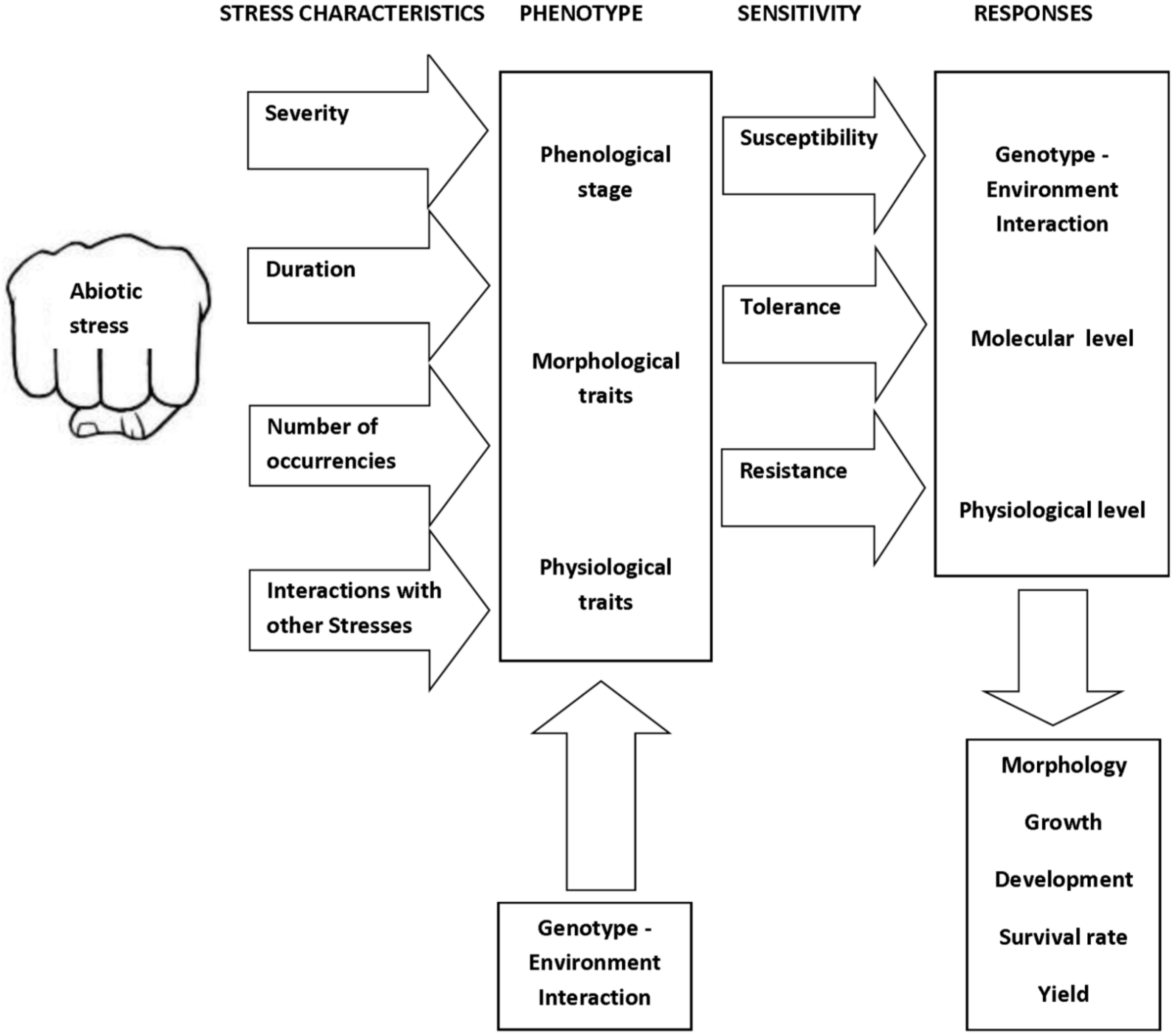



**Fig. 3. Scheme of factors that determines the crop responses to abiotic stress.**

**Secondary effects of abiotic stress**

Abiotic stress conditions such as drought, high and low temperature, and salinity influence the occurrence and spread of pathogens, insects, and weeds. They can also result in minor pests becoming potential threats in the future. Additionally, abiotic stress conditions such as drought enhance competitive interactions of weeds on crops as several weeds exhibit enhanced water use efficiency than crops.

**Stress combination**

Plants tailor their responses to combined stress factors and exhibit several unique responses, along with other common responses. Therefore, to fully recognize the impact of combined abiotic and biotic stresses on plants, it is important to understand the nature of such interactions. Mittler and colleagues (2006) developed a "stress matrix" to compile the interactions among various abiotic and biotic stresses on plant growth and productivity (Fig. 4). This matrix illustrates that the stress combinations can have negative as well as positive effects on plants. Therefore, developing plants with enhanced tolerance to combined abiotic and biotic stresses involves identifying physio-morphological traits that are affected by combined stresses.

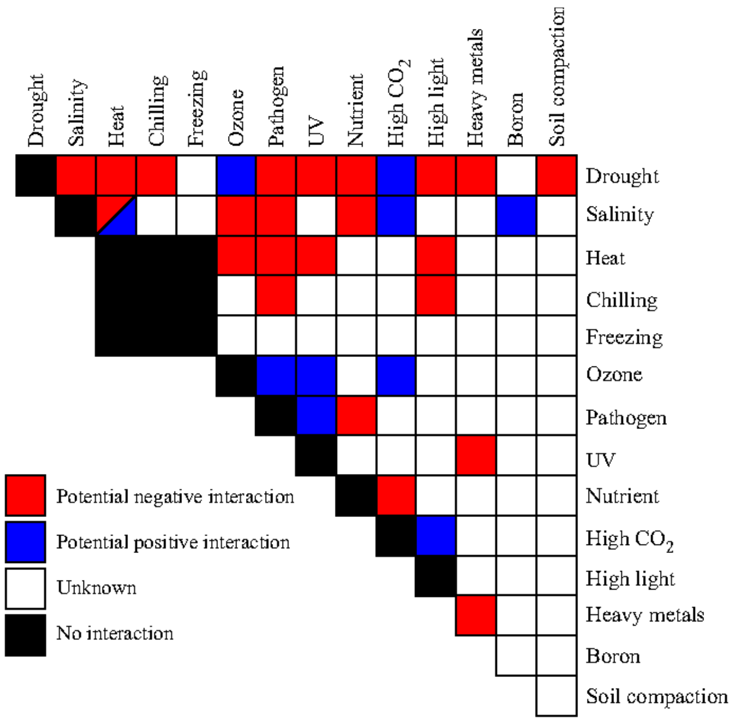



Fig. 4 The stress matrix. Different combinations of potential environmental stresses that can affect crops in the field are shown in the form of a matrix. The matrix is color-coded to indicate stress combinations studied with a range of crops and their overall effect on plant growth and yield.

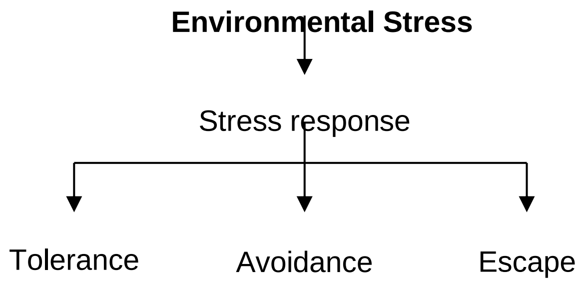
**Stress tolerance**

In the literature, stress *resistance* is often used interchangeably with *stress tolerance*, although the latter term is preferred. If tolerance increases due to exposure to prior stress, the plant is said to be acclimated (or hardened). Acclimation can be distinguished from *adaptation*, which usually refers to a *genetically* determined level of resistance acquired by selection over many generations. Unfortunately, the term *adaptation* is sometimes used in the literature to indicate acclimation. And to add to the complexity, we will see later that gene expression plays a vital role in acclimation.

Adaptation and acclimation to environmental stresses result from integrated events occurring at all levels of the organization, from the anatomical and morphological level to the cellular, biochemical, and molecular levels. For example, the wilting of leaves in response to water deficit reduces both water loss from the leaf and exposure to incident light, thereby reducing heat stress on leaves.

Cellular responses to stress include changes in the cell cycle and cell division, changes in the endomembrane system and vacuolization of cells, and changes in cell wall architecture, all leading to enhanced stress tolerance of cells. Plants alter metabolism in various ways to accommodate environmental stresses at the biochemical level.

**Plants Adaptation to Stress**




**Stress Escape**

Plant avoids the injury of stress by regulating their life cycle to avoid meeting stress. e.g., some short-lived, desert ephemeral plants germinate, grow, and flower very quickly following seasonal rains. They thus complete their life cycle during a period of adequate moisture and form dormant seeds before the onset of the dry season.

**Stress avoidance**

Plants avoid the injury of stress by building up a barrier to prevent stress factors from entering the plant. e.g., alfalfa survives dry habitats by sending down deep root systems that penetrate the water table. Salt-secretion halophytes secrete the salts from the leaf, thus reducing salt content in the leaf.

**Stress tolerance**

Plants adapt to the stressful environment by regulating their metabolism and repairing the damage caused by stress. e.g., highly salt tolerant halophytes such as *Suaeda salsa* survive salty habitats by many strategies such as high ROS scavenging ability, high osmotic adjustment ability, high ion compartmentalization ability, and so on.

**Adaptation vs. Acclimation**

- Adaptation and acclimation are means of tolerance to particular stress.
- Adaptation refers to heritable modifications in structure or function that increase the fitness of the organism in a stressful environment. e.g., CAM plants to the desert.
- Acclimation refers to nonheritable physiological modifications that occur over the life of an individual. These modifications are induced by gradual exposure to stress. e.g., slow drying increases the drought resistance of plants. The process of acclimation is known as hardening.