Abiotic Stresses and Plant Adaptation,

Annisa Firdaus Winta Damarsya

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- Chilling and freezing stress
- Salinity stress
- Oxygen deficiency

Plant response to abiotic stress

- arising from an excess or deficit in the physical or chemical environment

- Stresses trigger a wide range of plant responses, such as:
  - altered gene expression
  - cellular metabolism
  - Morphological adaptation

Stresses arise from an excess or deficit in the physical or chemical environment. It triggers a wide range of responses in plant, such as alters gene expression, cellular metabolism and morphological adaptation.

Two magic words

- **Acclimation:** An increase in the stress tolerance of an individual plant as a result of exposure to prior stress. Non-heritable.

- **Adaptation:** genetically determined resistance acquired over generations by selection. Heritable.

Here I have two magic words that we have to distinguish and remember: Acclimation and Adaptation.

Acclimation means an increase in the stress tolerance of a plant as a result of exposure to prior stress. It's non-heritable.

Adaptation is genetically determined resistance acquired over generations by selection. In contrast with acclimation, it's heritable.

Chilling and Freezing

- **Chilling injury**

Occurs at temperatures that are too low for normal growth but above freezing.

- **Freezing injury**

Occurs at temperatures below the freezing point of water.

http://www.extension.umn.edu/garden/diagnose/plant/vegetable/eggplant/plantstunted.html

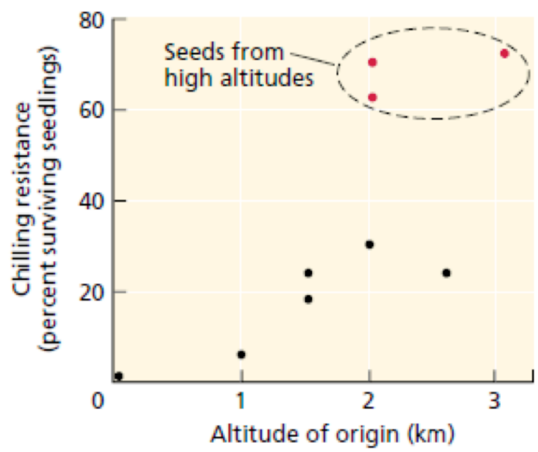
The first kind of abiotic stress I want to talk are chilling and freezing.

Under this kind of abiotic stress, plant may experience these two conditions: chilling injury and freezing injury.

Chilling injury: occurs when the temperatures are too low for normal growth, but still above freezing temperature. The symptoms are: growth is slowed, discoloration or lesions appear in the leaves, foliage looks soggy, and the roots may wilt.

Freezing injury occurs when temperatures are below the freezing point of water.

Genetics adaptation to the colder temperatures associated with high altitude can improve chilling resistance



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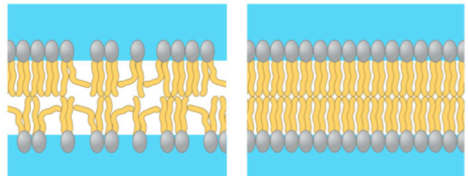
This diagram shows the survival at low temperature of seedlings of different populations of tomato collected from different altitudes in South America. Seed was collected from wild tomato and grown in the same greenhouse at 18-25 degree C. All seedlings were then chilled for 7 days at 0 C and then kept for 7 d in a warm growth room, after which in the number of survivors was counted. Seedlings from some of the seed collected from high altitudes show greater resistance to chilling than those collected from lower altitudes.

From this experiment, it can be concluded that genetics adaptation to the colder temperatures associated with high altitude can improve chilling resistance.

Membrane properties change in response to chilling injury



http://www.aasd.k12.wi.us/

TABLE 25.5
Fatty acid composition of mitochondria isolated from chilling-resistant and chilling-sensitive species

	Percent weight of total fatty acid content					
	Chilling-resistant species			Chilling-sensitive species		
Major fatty acids[a]	Cauliflower bud	Turnip root	Pea shoot	Bean shoot	Sweet potato	Maize shoot
Palmitic (16:0)	21.3	19.0	12.8	24.0	24.9	28.3
Stearic (18:0)	1.9	1.1	2.9	2.2	2.6	1.6
Oleic (18:0)	7.0	12.2	3.1	3.8	0.6	4.6
Linoleic (18:2)	16.4	20.6	61.9	43.6	50.8	54.6
Linolenic (18:3)	49.4	44.9	13.2	24.3	10.6	6.8
Ratio of unsaturated to saturated fatty acids	3.2	3.9	3.8	2.8	1.7	2.1

[a] Shown in parentheses are the number of carbon atoms in the fatty acid chain and the number of double bonds.
Source: After Lyons et al. 1964.

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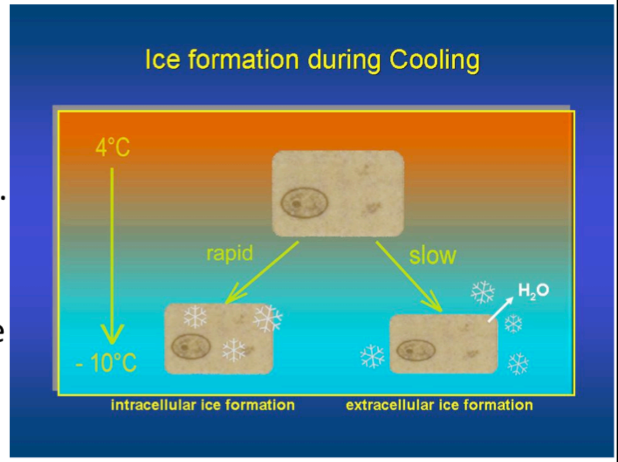
This table shows us the comparison of fatty acid composition among plants. Membrane lipids of chilling-resistant plants often have a greater proportion of unsaturated fatty acids than those of chilling-sensitive plants. Greater proportion of unsaturated fatty acids helps plant to lower the temperature at which membrane lipid begin to crystallize and allows membranes to remain fluid at lower temperature.

Ice crystal formation is a problem for plants

Ice crystal formation and protoplast dehydration kill cells

- **Intercellular ice formation:** caused by slow cooling, extended freezing causes dehydration.
- **Intracellular ice formation:** caused by rapid cooling, ice nucleation, causes extensive damage to the cell.



http://cryopreservation.ch/Cryoinjury.htm

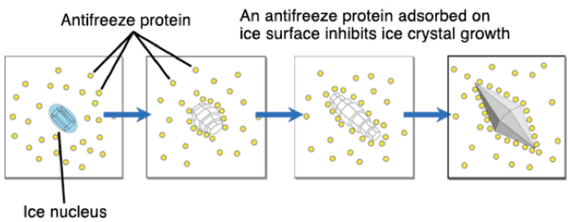
Freezing injury is highly related with ice crystal formation. There are two types of ice crystal formation: intercellular and intracellular.

Intercellular ice formation is caused by slow cooling and extended freezing. The size of ice crystal is usually forms first in xylem. This is not lethal to hardy plants. However, if tissue exposed to extended freezing temperature, the growth of ice crystal results in the movement of water from the protoplast and causes excessive dehydration.

Intracellular ice formation: occurs under rapid cooling. Begin with a process called ice nucleation in which water molecules in the protoplast start to form stable ice crystals. Some large polysaccharide and proteins facilitate ice crystal formation and are called ice nucleators. This process can lead to extensive damage to the cell.

Limitation of ice formation contributes to freezing tolerance

- Cold temperatures induce antifreeze proteins which prevent or slow further crystal growth.
- Sucrose and some of the cold-induced proteins are suspected to have cryoprotective effects.



http://www.spring8.or.jp/en/news_publications/press_release/2012/120529/

http://www.accuweather.com/en/weather-news/moisture-reaches-part-of-winte/3460544

Some plants are tolerant to low temperature. Some of them have these cold-induced proteins in their cells. E.g. winter wheat.

This picture (left) shows how antifreeze protein prevents ice nucleation. Antifreeze protein adsorbed on ice surface, cover it and inhibits the growth of ice nucleation.

Moreover, sugars and some of the cold-induced proteins are suspected to have cryoprotective effects. They stabilize membranes and proteins during dehydration induced by low temperatures.

Cold stress, ABA, and protein synthesis

- Acclimation to freezing involves ABA and protein synthesis. ABA appears to have a role in inducing freezing tolerance.
- Osmotic stress effect leads to the activation of osmotic stress-related signaling pathways.
- Cold-specific, non-osmotic stress-related genes are also activated.

Now I'm talking about relationship between cold stress, ABA, and protein synthesis.

Acclimation to freezing involves ABA and protein synthesis. An it appears that ABA have a role in inducing freezing tolerance.

Cold stress reduces water activity and leads to osmotic stress within the cells. This leads to the activation of osmotic stress-related signaling pathways.

And last, under cold stress condition, cold-specific, non-osmotic stress-related genes are also activated.

Salinity Stress

Words to remember:

- **Sodicity**

High concentration of Sodium ion.

- **Salinity**

High concentration of total salts.

TABLE 25.6
Properties of seawater and of good quality irrigation water

Property	Seawater	Irrigation water
Concentration of ions (m*M*)		
Na^+	457	<2.0
K^+	9.7	<1.0
Ca^{2+}	10	0.5–2.5
Mg^{2+}	56	0.25–1.0
Cl^-	536	<2.0
SO_4^{2-}	28	0.25–2.5
HCO_3^-	2.3	<1.5
Osmotic potential (MPa)	−2.4	−0.039
Total dissolved salts (mg L^{-1} or ppm)	32,000	500

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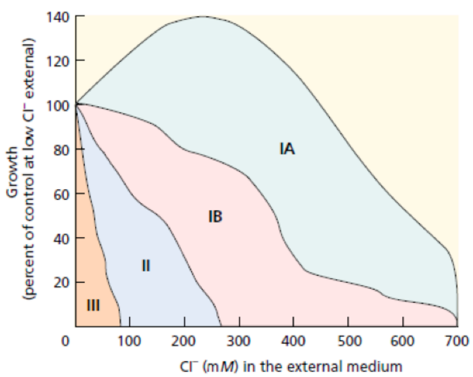
Salinity stress occurs when irrigation water contains a high concentration of solutes and where there is no opportunity to flush out accumulated salts to drainage system, salts can quickly reach levels that are injurous to salt-sensitive species, especially crops.

Again, there are two words to remember: sodicity, which means high concentration of sodium ion, and salinity, means high concentration of total salts.

This table shows properties of seawater and of good quality of irrigation water. If concentration of ions in irrigation water exceed its normal concentration, the plants may suffer from salinity stress.

Plants show great diversity for salt tolerance



Group IA (halophytes) includes sea blite (*Suaeda maritima*) and salt bush (*Atriplex nummularia*). These species show growth stimulation with Cl⁻ levels below 400 n*M*.

Group IB (halophytes) includes Townsend's cordgrass (*Spartina x townsendii*) and sugar beet (*Beta vulgaris*).These plants tolerate salt, but their growth is retarded.

Group II (halophytes and nonhalophytes) includes salt-tolerant halophytic grasses that lack salt glands, such as *Festuca rubra* subsp. red fescue (*littoralis*) and *Puccinellia peisonis*, and nonhalophytes, such as cotton (*Gossypium* spp.) and barley (*Hordeum vulgare*). All are inhibited by high salt concentrations. Within this group, tomato (*Lycopersicon esculentum*) is intermediate, and common bean (*Phaseolus vulgaris*) and soybean (*Glycine max*) are sensitive.

The species in **Group III (very salt-sensitive nonhalophytes)** are severely inhibited or killed by low salt concentrations. Included are many fruit trees, such as citrus, avocado, and stone fruit.

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This diagram shows four groups of plant based on their ability to tolerate

Group IA and IB consist of halophytes which are native to saline soils and complete their life cycles in that environment.

Group II consists of both halophytes and nonhalophytes. All are inhibited by high concentration of salt. The example of intermediate in this group is tomato. Whereas bean and soybean are categorized as sensitive.

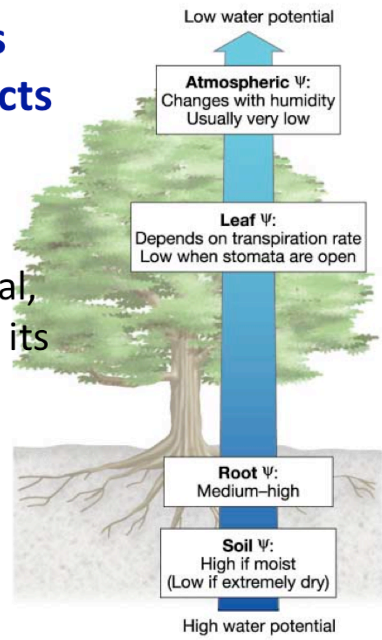
Very salt-sensitive nonhalophytes plants are categorized in group III. They are severely inhibited or killed by low salt concentrations.

Salt stress causes multiple injury effects

Osmotic effects

Reduce soil water potential, so plants have to lowered its water potential. Affects general water balance.

http://www.uic.edu/classes/bios/bios100/lecturesf04am/lect19.htm



Water moves from higher potential to lower potential. Salinity stress reduces water potential, so plants have to lowered its water potential by taking more ions. This affects general water balance.

Salt stress causes multiple injury effects

Ion toxicity
High concentration of Na+ disturbs ion homeostasis.

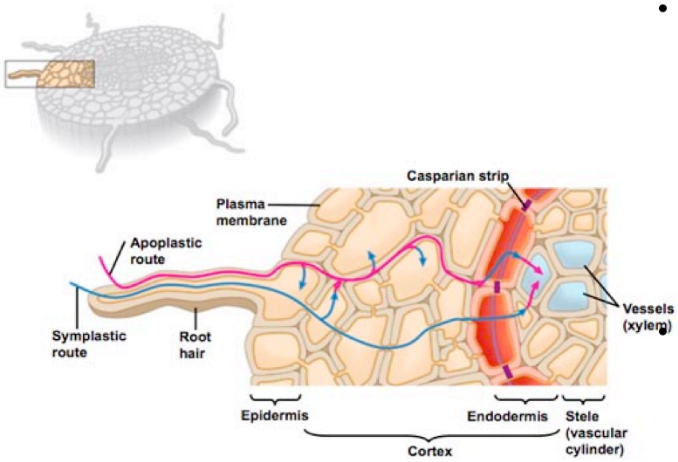
Accumulated Na+ and/or Cl- in chloroplast inhibit photosynthesis.

Secondary effects
e.g. disruption of cell membrane integrity and metabolism, production of reactive oxygen species.

The second effect is ion toxicity. Greater uptake of ions leads to high concentration of Na+, which disturbs ion homeostasis. It is not only injures plants but also degrades the soil structure, decreasing porosity and permeability. Moreover, accumulated Na+ and/or Cl- in chloroplast inhibit photosynthesis.

There are also some secondary effects caused by salinity stress, such as disruption of membrane integrity and metabolism, and production of reactive oxygen species which might harm the plant.

Plants use multiple strategies to reduce salt stress



- Reducing salt exposure of meristems and leaves that are actively growing and photosynthesizing.
- Restricts salt movement with Casparian strip.

http://www.pleasanton.k12.ca.us/avhsweb/thiel/apbio/labs/plant_transport.html

Plants responses under salt stress are similar to those of plants under water deficit. To reduce salt stress, plants use multiple strategies such as: reducing salt exposure of meristems and leaves that are actively growing and photosynthesizing and restricts salt movement with casparian strip.

Plants use multiple strategies to reduce salt stress

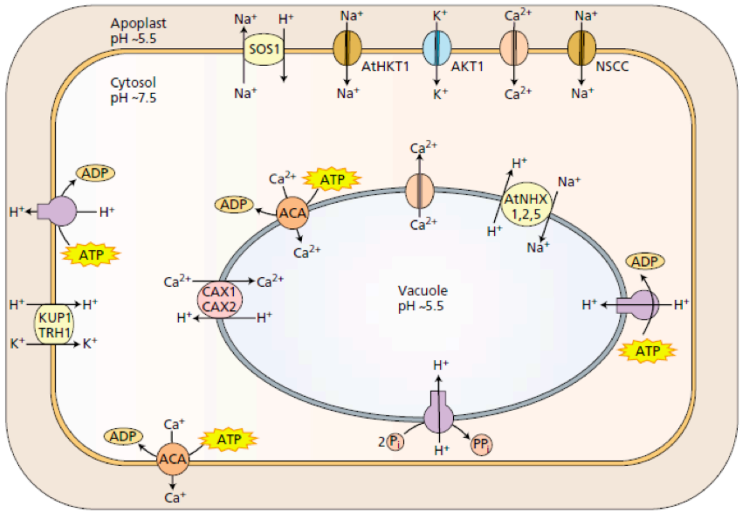
http://www.asknature.org/strategy/0ef4cce98e84127a384ff963259e4724#.VF8ctzSUeSo

- Salt glands in some halophytes.
- Osmotic adjustment. Compatible solutes (osmolytes): betaine, proline, sorbitol, mannitol, pinitol, and sucrose.
- Reduce leaf area and/or drop leaves via leaf abscission.

Some halophytes also have salt glands. This is the picture of salt glands in mangrove leaf.

Some others do osmotic adjustment with compatible solutes, some reduce leaf area and or drop leaves via leaf abscission.

Membrane transport proteins mediating sodium, potassium, and calcium transport



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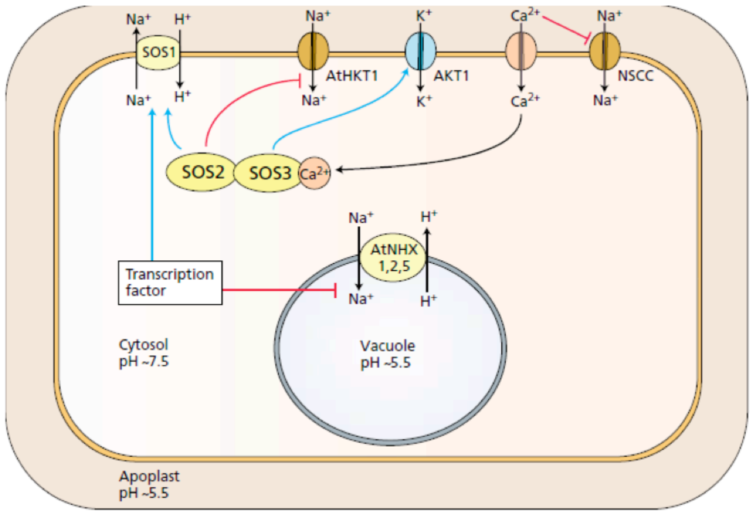
The regulation of homeostasis by the SOS signal transduction pathway, salinity stress, and calcium levels



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Plant adaptations to toxic trace elements

- **Exclusion**: by maintaining toxic elements concentration below a toxic threshold value in plants.
- **Internal tolerance**: various biochemical adaptations allow the plant to tolerate elevated concentration of those elements. Extreme strategy: **hyperaccumulation**.

http://eol.org/pages/1114455/overview

http://www.zimbabweflora.co.zw/1

Plants adapt to toxic trace elements by two strategies: exclusion-by maintaining toxic elements concentration below its threshold value, and internal tolerance-by allowing the plant to tolerate elevated concentration of those elements. The extreme strategy of internal tolerance is hyperaccumulation.

Toxic elements include As, Cd, Cu, Ni, Ze, and Se.

Example of hyperaccumulation:

Pistia stratiotes (right): Hyperaccumulator for Cadmium.

Barley (*Hordium vulgare,* left): hyperaccumulator for Aluminum. 1000 mg/kg dry weight

Oxygen deficiency

- Typical of flooded or waterlogged soils.
- **Flooding-sensitive plants** are severely damaged by 24 hours of anoxia.
- **Flooding-tolerant plants** can withstand anoxia temporarily, but not for period more than a few days.

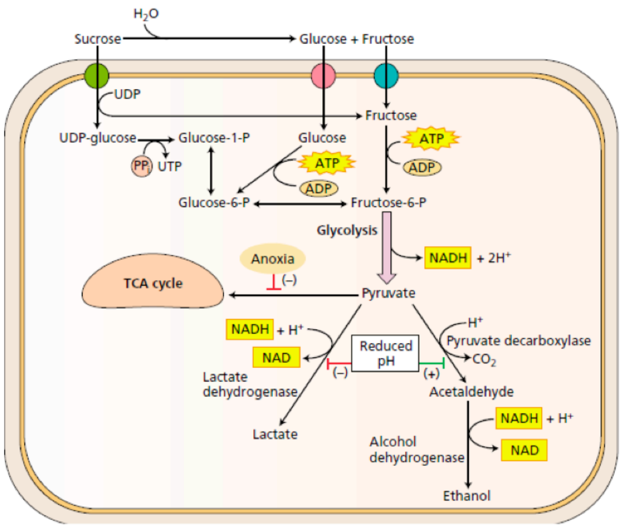
http://wartaaceh.com/2012/11/13709/450-hektare-tanaman-jagung-di-aceh-tengah-selatan-akibat-banjir/

Oxygen deficiency is typical of flooded or waterlogged soils. Water fills the pores and blocks the diffusion of O2 in the gaseous phase.

Plants are divided into two types based on its tolerance to flood: flooding-sensitive plants (which are severely damaged by 24 hours of anoxia, such as maize and garden pea) and flooding-tolerant plants (which can withstand anoxia temporarily but not for period more than few days).

Picture of flooded maize field in Aceh.

Roots are damaged in anoxic environments



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Injury to root metabolism by O_2 deficiency originates from a lack of ATP to drive essential metabolic processes.

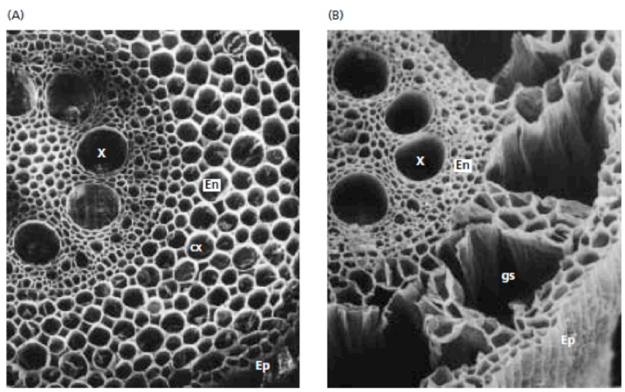
Damaged O_2-deficiency roots injure shoots.

Roots are damaged in anoxic environments. In the absence of O2: TCA cycle cannot operate: ATP is produced by lactate fermentation→net yield of fermentation is only 2 ATPs→insufficient to drive essential metabolic processes.

This causes injury to root.

Anoxic/hypoxic roots lack energy to support physiological processes on which the shoots depend. Thus, damaged anoxic roots can injure shoots.

Submerged organs can acquire O2 through specialized structures



Ethylene stimulates cell elongation of petiole.

http://flora.nhm-wien.ac.at/Seiten-Arten/Nymphoides-peltata.htm

Aerenchyma

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Submerged organs wetland vegetation is well adapted to grow for extended periods in water-saturated soil. They show no stress.

Water lily (right): submergence traps ethylene→stimulates elongation of the petiole.

Some plants like maize have a prominent, gas-filled spaces that form a tissue called aerenchyma→develop independently of enviromental stimuli. However, in a few nonwetland plants (including monocots and dicots), oxygen deficiency induces the formation of aerenchyma in the stem base and newly developing roots.

In the picture: A (under oxygenated condition), B (under deoxygenated condition)

Summary (1)

- Plant response to abiotic stress arising from an excess or deficit in the physical or chemical environment.
- Chilling injury occurs at low temperature, but above the freezing temperature. Its primary cause is the changes in membrane fluidity. Freezing injury is associated with damage caused by ice crystals formed within cells and organs.
- ABA and protein synthesis are involved in plant response to cold stress.

Summary (2)

- Salinity stress results from salt accumulation in the soil. Salt injury ensues from a decrease in water potential, makes soil water less available, and from toxicity of some accumulated ions.
- Plant responses to salt injury are similar to those of plants under water deficit.
- Oxygen deficiency is typical of flooded and waterlogged soils. Oxygen deficiency depresses growth and survival of many species. In contrast, some plants are well adapted to this condition.

Reference

- Plant Physiology, 3rd edition by Lincoln Taiz and Eduardo Zeiger