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Drought Resistance



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Drought: Scarcity of moisture (soil moisture) which restricts the expression of full genetic yield potential of a plant.

Drought resistance: The ability of crop plants to grow, develop and reproduce normally under moisture stress.

Mechanisms of drought resistance

There are 4 mechanisms of drought resistance.

1. **Drought Escapes** : It is due to ability of a genotype to mature early, before occurrence of drought. Drought escape is most common in plants grown in desert region.

Eg. Early maturing varieties of sorghum, maize, bajra, wheat, rice etc; give more yield than late maturing under drought.



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2. Drought Avoidance (Dehydration avoidance) : It is due to the ability of plants to maintain favorable water balance even under stress. The plants which avoid drought retain high moisture content in their tissues and lose less water.

Drought Avoidance

This is possible either because of :

- i) Increased water uptake (due to increase in root development) plants are called water spenders.(or) ii) Reduced water loss (due to reduction in growth of aerial parts are called water savers (i.e. to avoid transpiration)

Dehydration avoidance is interpreted as the ability of genotypes to maintain high leaf water potential when grown under soil moisture stress:



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Several traits contribute to dehydration avoidance Such as :
Leaf rolling, folding and reflectance narrow leaves, increased pubescence on aerial organs , presence of awns, osmotic adjustment of stomata, cuticular wax, increased water uptake ; Reduced Transpiration, Increase in concentration of Abscisic Acid (ABA), closure of stomata, ABA plays role in reduction of leaf expansion, Promotion of root growth etc.

3. **Drought Tolerance** (Dehydration tolerance) : Ability of plants to produce higher yield even under ‘low water potential’. In cereals drought tolerance generally occur during reproductive phase. Tolerant cultivars exhibit better germination, seedling growth and photosynthesis. Drought tolerance may be due to

- i. high proline accumulation
- ii. maintenance of membrane integrity



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4. Drought Resistance : It is the sum total of avoidance and Tolerance. It refers to the genetic ability of plants to give good yield under moisture stress conditions.

Various morphological, physiological and biochemical features / parameters associated with drought resistance

a. Morphological

1. Earliness 2. Reduced tillering

3. Leaf characters : Leaf rolling , Leaf folding, Leaf shedding, Leaf reflectance 4. Reduced leaf area : Narrow leaf, Change in leaf angle 5. Hairiness (presence of hairs on leaf and other parts, lowers leaf temperature and reduce transpiration) 6. Colour of leaves 7. Wax content 8. Awns (eg. wheat and barley) 9. Root system (rooting depth and intensity)



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b. Physiological

1. Photosynthesis (efficient system like C4) under stress, photosynthetic efficiency is reduced due to chloroplast damage.
2. Reduced Transpiration and reduced respiration losses
3. Stomatal behavior (closure of stomata, also change in size and number of stomata)
4. Osmotic adjustment
5. Leaf enlargement (increase in thickness)
6. Leaf cuticle wax (increases)



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C. Biochemical

1. Accumulation of proline and betaine
2. Increase in Abscisic acid (barley) and Ethylene (maize & wheat)
3. Protein synthesis (increases under stress)
4. Nitrate – reductase activity

Sources of drought resistance

1. Cultivated varieties
2. Land (old or desi primitive varieties)
3. Wild relatives (reported in several crops)



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For example :

In Wheat *Aegilops Variabilis*, *Aegilops speltoides*, *Aegilops umbellulata*, *Aegilops squarrosa* are drought resistant

In Sugarcane *Sacharum spontaneam* is resistant to Drought & salinity

4. Transgenes :

Eg. 'Rab' (Responsive to abscisic acid) in rice

Screening / Evaluation

1. Field Env. Highly desirable
2. Green house Env. More precisely controlled than field



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Breeding Methods and Approaches

It is important that drought resistance can be incorporated in material with high genetic potential for yield.

1. Yield and yield components are best evaluated under non stress / optimal environments, while
2. Drought resistance must be evaluated under water stress.

Breeding methods :

Methods are same as for yield and other economic characters.

Breeding for drought resistance refers to breeding for yield under moisture stress, i.e. developing varieties which can give high yields under stress. The common methods are



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1. Introduction
2. Selection
3. Hybridization
4. Mutation
5. Biotechnology

Limitations :

1. Generally resistant varieties have low yield
2. Do not have much wider adaptability (as abiotic resistant is location specific)
3. Drought resistant genes may have linkage with undesirable genes.
4. Transfer of resistant genes from wild types may post problem.
5. Drought resistance is a consequence of a combination of characters and single character can be used for selection.



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6. Measurement of many drought resistant traits is difficult and problematic, since virtually all the useful drought resistant traits are under polygenic control. (So pedigree method most common). But if resistant genes is from agronomically inferior race then 1-2 backcrossing with cultivated type in made. If resistance gene is from wild species-go for backcrossing breeding. Generally selection is performed on individual plant progenies instead of individual plants (i.e. similar to line breeding)
7. Creation of controlled moisture stress Environments
8. Selection require considerable resources



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WATER LOGGING



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As per Levitt (1980 b) flooding (i.e. water logging) is the presence of water in soil excess of field capacity.

It leads to deficiency of O₂ and build up of Co₂, Ethylene and other toxic gases and this leads to reduction in aerobic respiration.

Effects of water logging:

1. Once soil becomes water logged, air space in soil is displaced with water, the O₂ in the soil is dissolved in water. i.e. O₂ decreases; Co₂ ethylene and other toxic gases increases.
2. O₂ replacement in the soil is very inefficient. Diffusion of atmospheric O₂ into the water logged soils is very inefficient (because of the slow diffusion of atmospheric O₂ to water logged soil).



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3. Root systems are suddenly plunged into an anaerobic condition. This switching from aerobic to anaerobic respiration disrupts root metabolism.

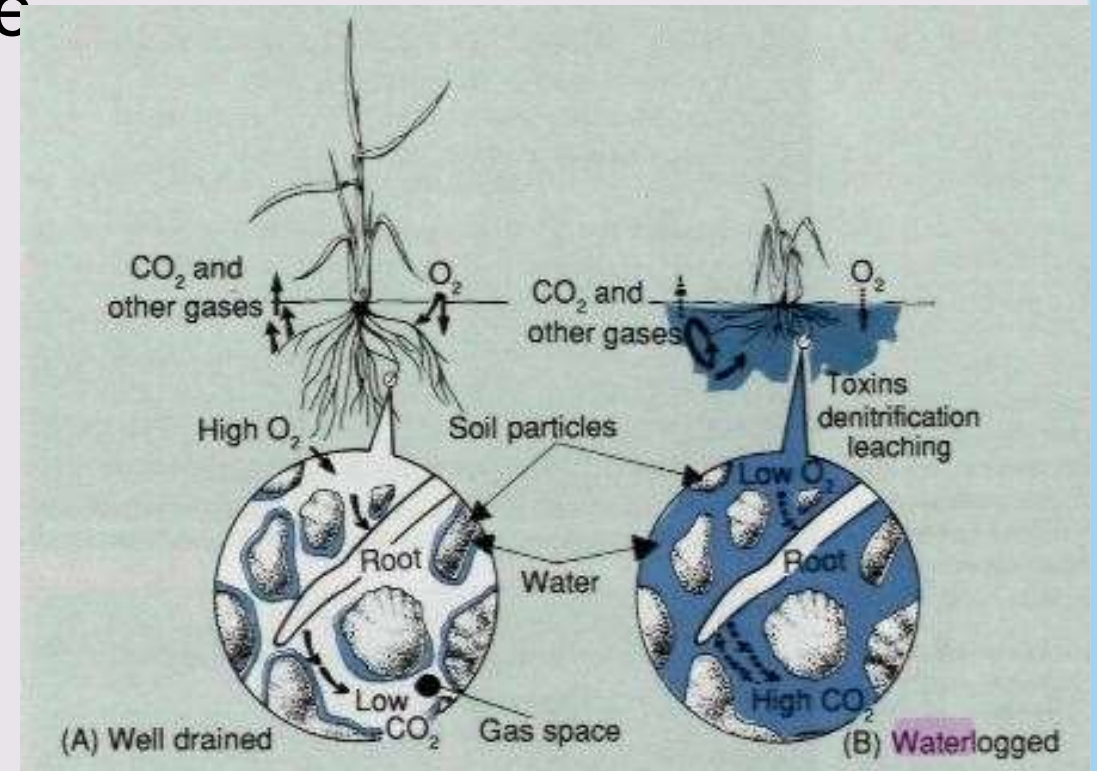
4. Carbohydrates level get depleted it is due to

a. Dissipation of metabolism

b. High water temperature

c. Low light

If air space in soil is displaced with water, the O₂ in the soil is dissolved in water. i.e. O₂ decreases





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Characteristics of plants in response to water logging stress :

1. Reduced growth / elongation.
2. Chlorosis, senescence and abscission of lower leaves
3. Wilting & leaf curling
4. Hypertrophy (increase in size of organ due to increase in cell size)
5. Epinasty (downward growth of petioles)



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Mechanisms of tolerance:

1. Adventitious root formation on lower part of stem (close to surface so that O₂ tension is quickly restored after transient water logging) eg. Tomato
2. Lenticel (i.e. raised pores in the stem of plants) formation
3. Aerenchyma formation (soft plant tissue contains air spaces found in aquatic plants) in the cortex that provide canal parallel to the axis of the root through which gases can diffuse longitudinally (eg. rice)



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4. Elongation capacity (In rice – best elongation response give 100% recovery from submergence and poorest elongation gives upto 49% recovery) Scoring for elongation can be done between booting and flowering stage after flooding the crop to varying depths.

In sugarcane, *S. spontaneum* has more tolerance to flooding. Some canes gave upto 70% of their production potential when in continuous flood for 5 months (in an east at canal point Florida, USA)



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Ideotype for flooded areas : The postulated ideotype for flooded areas should have the following characteristics.

1. Capacity to carry out functional activity at low O₂ concentration (i.e. High cytochrome activity)
2. Ability for photosynthesis under low light intensity
3. Capacity to synthesis food rapidly
4. Regeneration capacity of shoots when damaged by flood
5. Ability to withstand drought at later growth stage
6. Deep root system
7. Narrow, medium long and dark green leaves with high sugar and protein content.



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BREEDING FOR SALT TOLERANCE



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Salt Tolerance: refers to the ability of plants to prevent, reduce or overcome injurious effects of soluble salts present in their root zone.

It is a global problem as saline and alkali soils are found in almost all the countries of the world, more in Semi Arid Tropic (SAT) of world.

Problem of salinity can be overcome by two ways:

1. Soil reclamation : costly, time consuming and short lived
2. Resistant varieties : less costly, more effective, long lasting require longer period to develop.



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Behavior / characteristics of plants to salt :

1. Land races more tolerant than High yielding varieties. Tolerant plants varieties are found in salt affected areas

2. Salt tolerance capacity differs from species to species. Also genetic differences exist among cultivars for their salt tolerance capacity.

3. Different crop plants show differential response to salinity

4. Higher ploidy level crops are more tolerant than lower ploidy level crops.

Eg. Hexaploid wheat more tolerant than tetraploid

Tetraploid Brassica more tolerant than diploid Brassica

5. In rice tall, coarse grained, late maturing varieties- more tolerant



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6. In sugarcane different strains have differential tolerance;
Barley is more tolerant than wheat.

a. Highly tolerant crops: Sugabeet, sunflower, barley (grain), cotton, datepalm, asparagus

b. Moderately Tolerant crops: Barley (Forage), rye, sorghum, wheat, safflower, soybean

c. Moderately sensitive: Rice, corn, foxtail millet, cow pea, peanut, sugarcane, tomato, potato, sweet potato, radish, alfalfa, cabbage

d. Extremely sensitive: Citrus, straw berry, melon, peas, other legumes, apple, rajmabean, carrot, okra, onion (orange)



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Symptoms of plants to salt stress :

1. Retardation / cessation of growth
2. Necrosis
3. Leaf abscission
4. Loss of turgor
5. Ultimate death of plant

Mechanisms of salt tolerance :

2 types of mechanisms

1. **Salt Tolerance** : Plants respond to salinity stress by accumulating salt, generally in their cells or glands and roots etc.



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2. **Salt avoidance** : plants avoid salt stress by maintaining their cell salt concentration unchanged either by water absorption eg. Rice, chenopodiaceae family or by salt exclusion eg. Tomato, soybean, citrus, wheat grass

Glycophytes (Non-halophytes) plants owe their resistance primarily to avoidance. Eg. Barley

Hallophytes (plants that grew in salty or alkaline soils) show tolerance by ion accumulation mechanism



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Breeding methods

Breeding methods are same but breeding strategies are

1. Breeding for yield potential should have greater emphasis than breeding for salt resistance per se (As screening is done on the basis of yield reduction in stress environment as compared to non-stress Environment.).
2. Selection should be done in stresses target environments (As abiotic stress resistance is an important part of Environ. Fitness & is bound to be location specific i.e. it is related to narrow adaptation.



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Screening Techniques

Common methods are

1. Sand culture by using nutrient solution in sand & irrigation with saline water
2. Solution culture by using solution culture tanks (Hydroponic culture)
3. Microplot techniques by using small microplots

Microplot Techniques: By using small microplots of size 6 x 3 x 1 m (CSSRI, Karnal, Haryana) at central soil salinity Research Institute.

Then Multilocation Trial (MLT) conducted over seasons to get more reliable results. Genotypes which survive better under salinity are considered tolerant & tested further.



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Selection criteria

1. Germination (%) in saline medium
2. Dry matter accumulation (seedling / plant dry wt.) / Early vigour
3. Leaf senescence or death – Estimated by total dead leaf area or No. of dead leaves
4. Leaf necrosis
5. Leaf ion content
6. Osmoregulation (Determined as maintenance of turgor under stress) Measured as proline or CHO accumulation or accumulation of glycine, betaine etc.
7. Yield – Economic yield



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Problems

1. Creation of reliable controlled salinity Env.
2. Scoring for salinity resistance
3. Genetic control – it is complex & polygenic
4. Mechanisms of resistance poorly understood. Salinity may have interaction with other stresses.



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COLD TOLERANCE



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When temperatures remain above-freezing *i.e.* $>0^{\circ}\text{C}$ to $<10-15^{\circ}\text{C}$ it is called chilling

When temperature. remain below freezing *i.e.* $<0^{\circ}\text{C}$ it is called Freezing.

A. Chilling Resistance:

Chilling sensitive plants are typically tropical plants.

Temperate plants are generally tolerant to chilling injury.



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Effects of chilling stress on plants :

1. Reduced germination
2. Poor seedling establishment
3. Stunted growth
4. Wilting
5. Chlorosis
6. Necrosis
7. Pollen sterility
8. Poor fruit set / seed formation
9. Reduced root growth
10. Locked open stomato
11. ABA accumulation



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At subcellular level

12. Reduces membrane stability
13. Poor chlorophyll synthesis (affected)
14. Reduced photosynthesis & respiration
15. Toxicity due to H₂O₂ formation

Chilling Tolerance

Ability of some genotypes to survive / perform better under chilling stress than other genotypes is called chilling tolerance. It is because of chilling hardening, *i.e.* an earlier exposure to a near chilling temperature for a specified period as a result of which chilling tolerance of the concerned plants increases.



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Mechanisms of chilling tolerance:

1. Membrane lipid un-saturation
2. Reduced sensitivity of photosynthesis
3. Increased chlorophyll accumulation
4. Improved germination
5. Improved fruit / seed set
6. Pollen fertility

Sources of chilling Tolerance :

1. Late adopted breeding populations eg. maize
2. Germplasm (eg. That collected from high altitude , low temperature geographic regions)



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3. Induced mutants for cold tolerance
4. Cold tolerant somaclonal variants
5. Related wild species eg. Tomato

Selection criteria: Based on -

1. Germination test
2. Growth under stress (measured as plant dry matter accumulation)
3. Chlorophyll Loss under chilling stress eg. rice, cucumber, tomato (measured as seedling colour)
4. Membrane stability : (Assayed in terms of solute leakage from tissues)
5. Photosynthesis : Chilling injury to photosynthesis is assayed as variable chlorophyll fluorescence at 685 nm



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6. Seedling mortality

7. Seed / Fruit set

8. Pollen fertility (apply during injury at PMC)

B. Freezing Resistance

Freezing injury / Frost injury / cryo injury

Freezing Stress : Dormant state is conducive to freezing resistance, while resistance in actively growing tissue is rare : Thus Freezing resistance largely involves surviving freezing stress in such a manner as to enable subsequent regrowth when the temperature rises.

As water in plants cools below 0C, it may either

1. Freeze *i.e.* form ice or 2. Super cool without forming ice.



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Effects of freezing stress

1. Ice formation : Two types

A. Intercellular ice formation, B. Intracellular ice formation

Intercellular Ice formation: Initiation of ice formation on plant surface is sufficient to induce freezing of the internal (intercellular & xylem vessels etc.) water in most plant species. **Intracellular ice formation:** It is more lethal may be due to physical disruption of subcellular structure by ice crystal. Intracellular ice formation is the major and terminal freezing stress.

Extracellular ice formation in a cases the concentrations of extracellular solutes, there by water is withdrawn from the cells during extracellular ice formation. This creates water stress in the frozen tissue / plant.



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2. Membrane disruptions :

Freezing causes disruptions or alter the semipermeable properties of plasma membrane. Loss of solutes from the cells occur, Cells remain plasmolyzed even after thawing which is often called as frost plasmolysis. Cells may become highly effected due to uptake of excess water.

3. Supercooling :

Cooling of water below 0C without ice crystal formation is called supercooling . In plants water may cooldown to -1 to -15C in herbaceous sps and to -4 to -45C in hardy trees. This becomes possible apparently because internal ice nucleators are absence in such cases. This is regarded as an important. Mechanism of freezing avoidance



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4. Stress due to external factors : Consequent to freezing

- 1) Ice sheet formation below and above the ground causes reserve depletion anoxia etc. in plants.
- 2) Tissues killed during freeze-thaw are highly prone to pathogen attacks
- 3) Auto toxicity may occur



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Mechanism of Freezing resistance.

1. **Freezing avoidance** : The ability of plant tissues / or genes (but the whole plants) to avoid ice formation at sub zero temperature is called freezing avoidance. Supercooling is a mechanism of freezing avoidance.

It is controlled by

1. Lack of ice-nucleators
2. Small cell size
3. Little or no intercellular space
4. Low moisture content
5. Barriers against external nucleators
6. Presence of antinucleators



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2. Freezing Tolerance : Ability of plants to survive the stresses generated by extra cellular ice formation and to recover and regrow after thawing is known as freezing tolerance.

The various components of freezing tolerance are as follows:

- 1) Osmotic adjustment
- 2) Amount of bound water
- 3) Plasma membrane stability
- 4) Cell wall components properties
- 5) Cold-responsive proteins Eg. ABA



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Sources of freezing tolerance

1. Cultivated varieties
2. Germplasm lines
3. Induced Mutations
4. Related wild species Eg. Wheat *Agropyron* sps; rye, Barley – *H. jubatum*, *H.brachyantherum x H.bogdanii*, *H.jubatum x H.compressum*, Oats – *Avena sterilis*
5. Transgenes : Eg. chemical Synthesized antifreeze protein gene, ala 3, in tobacco



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Selection criteria:

Based on

1. Field survival
2. Freezing test in laboratory
3. Cryo freezing
4. Osmoregulation



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Problems in breeding for freezing tolerance

1. Freezing Tolerance is a complex trait & involves several components. So, it is not readily measurable under field conditions
2. Breeding work under field conditions is highly influenced by other environmental factors and biotic stresses
3. Due to large G X E for the trait field survival shows poor heritability
4. Freezing tolerance also shows a large GXE interaction which limits progress under selection
5. Laboratory tests are yet to be developed to screen large breeding population