Physiological effects of abiotic stress on crop yield and quality

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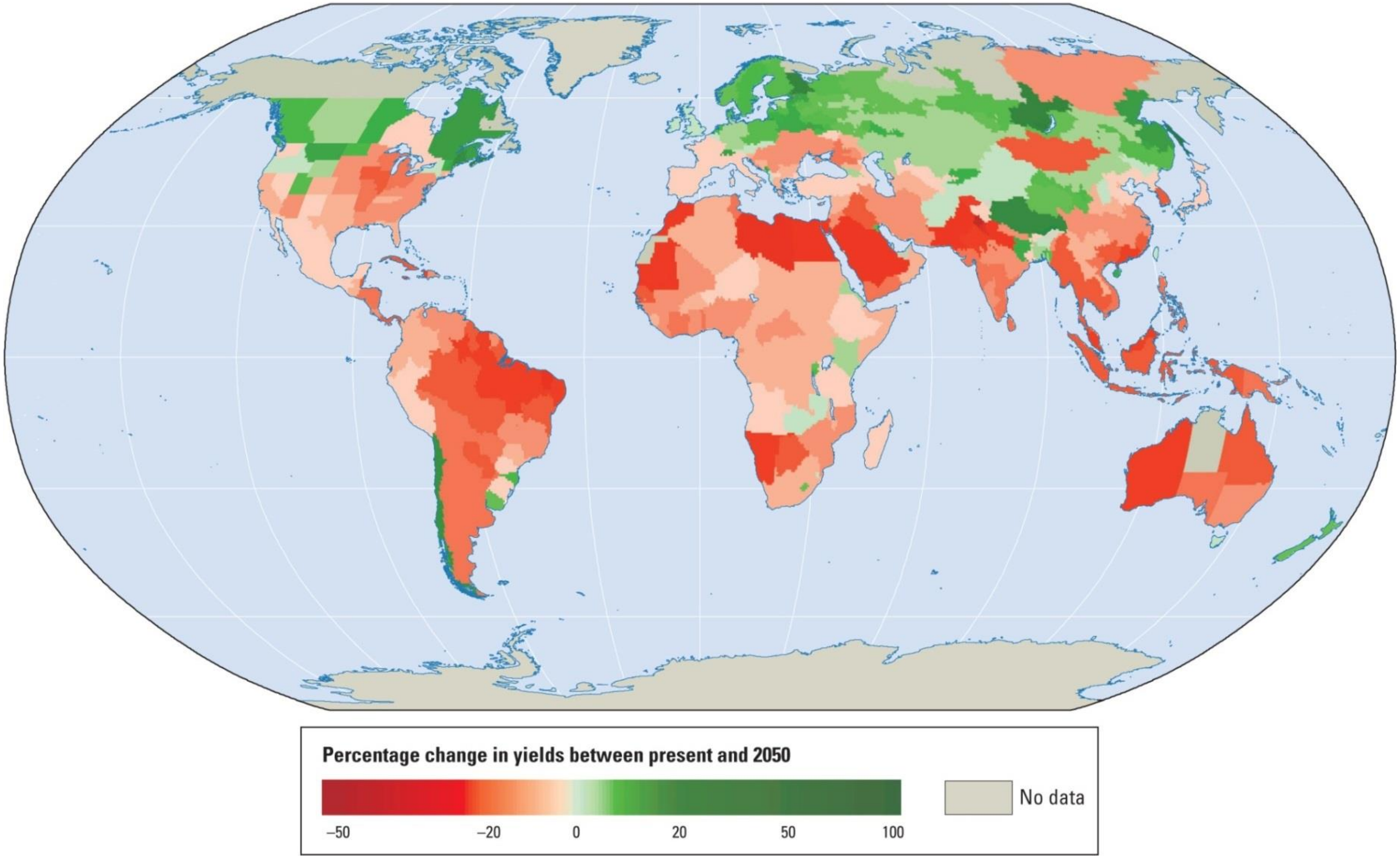
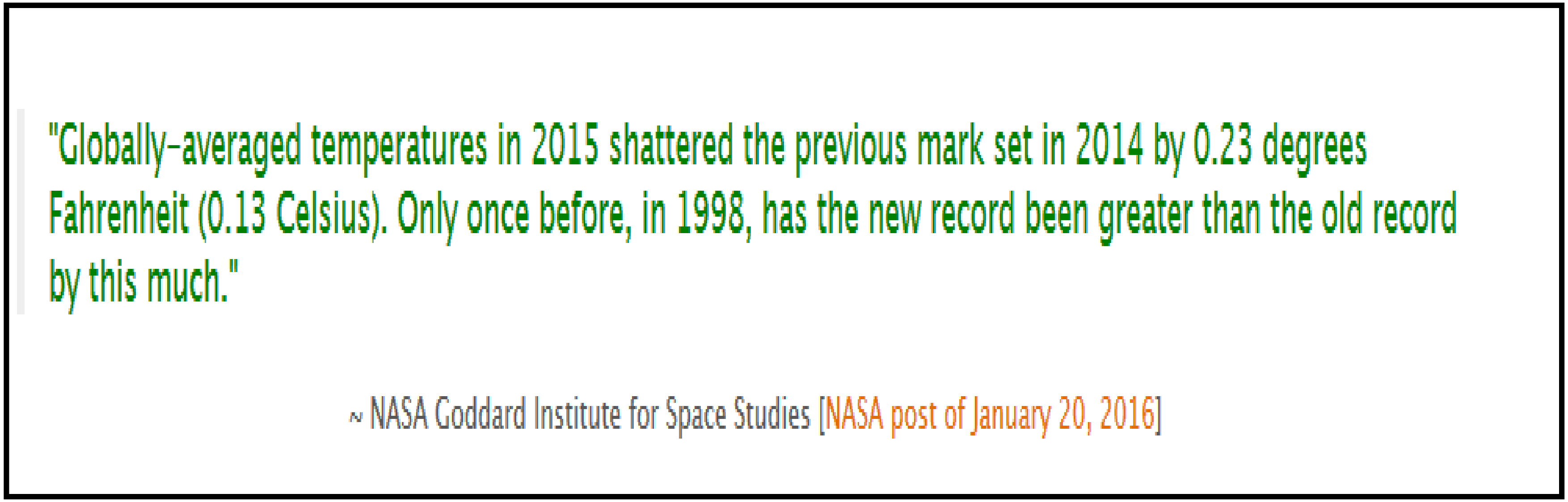
Agricultural yields are likely to decrease by 2050



World Development Report 2010

Abiotic stress: Challenging Indian Agriculture

- **Agriculture production has undergone drastic changes in recent years and is being seriously limited by various abiotic stresses**
- **More than 50% of agricultural production loss is due to abiotic stresses, their intensity and adverse impact are likely to amplify with climate change**
- **The major loss is due to high temperature (20%) followed by drought (9%), low temperature (7%), and other forms of stresses (4%).**



> "Globally-averaged temperatures in 2015 shattered the previous mark set in 2014 by 0.23 degrees Fahrenheit (0.13 Celsius). Only once before, in 1998, has the new record been greater than the old record by this much."

~ NASA Goddard Institute for Space Studies [NASA post of January 20, 2016]

Floods, droughts to be the norm

***Kamcilla Pillay** reports back from the annual briefing on climate change by India's Centre for Science and Environment in New Delhi last week.*

EXTREME weather events brought on by climate change would hit developing nations the hardest, making it imperative for them to come together to find solutions.

Floods and droughts, like the one afflicting KwaZulu-Natal, would affect food security, heighten poverty and result in deaths, said experts gathered at the annual media briefing on climate change, convened by the Centre for Science and Environment in New Delhi last week.

Emmanuel Olukayode Oladipo, who is based at the Climate Change Network in Nigeria, said in his talk on drought response and disaster management that the situation for developing nations would become more challenging.

"From 2016 to 2035, droughts, according to the Climate Change Emergency Institute, are more likely than not. There will be more record hot weather. In fact, at present, we are experiencing between one and five days of extreme heat (a year).

"As the Earth's temperature increases by 2°C, we will experience 27 of these days. As we reach 3°C, the number will increase to 62."

Southern Africa would experience an increase in temperature, general dryness and there would be "no coherent patterns" in rainfall trends. The region's problems would worsen in the coming years.

The Intergovernmental Panel on Climate Change said that droughts could intensify over the coming century in southern parts of the continent.

The Centre for Science and Environment said in a report that all types of natural disasters, including droughts, had increased from an average of 50-plus events during the 1970s to 350 in 2014.

Africa, on average, between 1970 and last year, experienced 60 natural disasters, affecting millions of people.

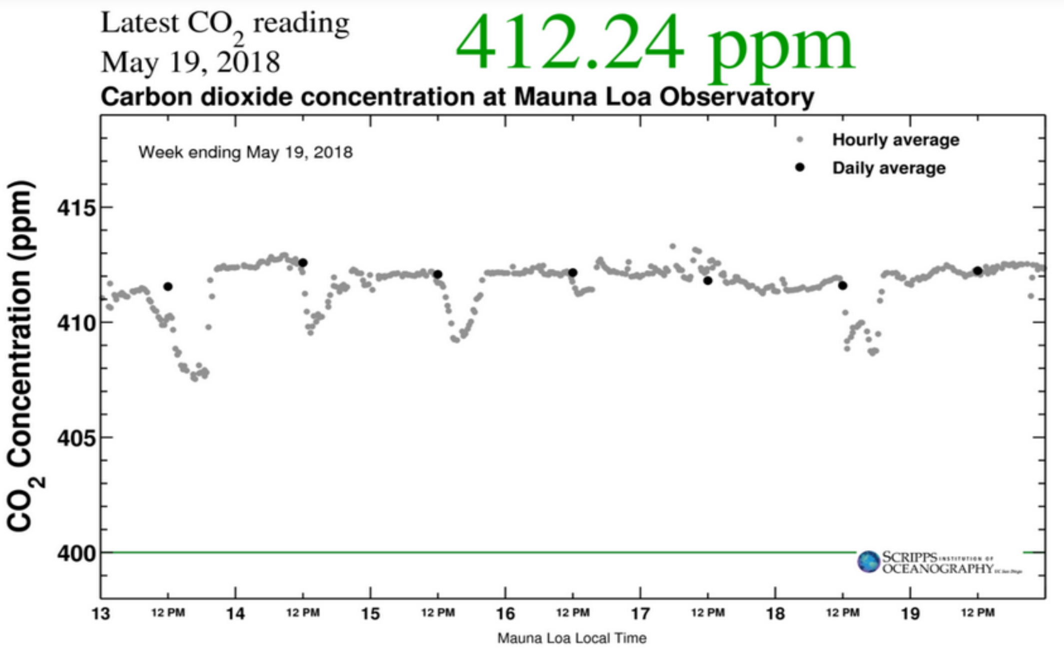
Early warning systems on the part of local governments were crucial but, Oladipo said, community-based systems such as those used in Nepal were also needed.

Rosa Perez, of the Philippine Climate Change Commission, agreed with Oladipo and said these systems worked well with broad vulnerability and risk assessments.

She said tapping into indigenous knowledge and traditional methods while honing them with scientific methods would also help communities adapt to the changing climate.

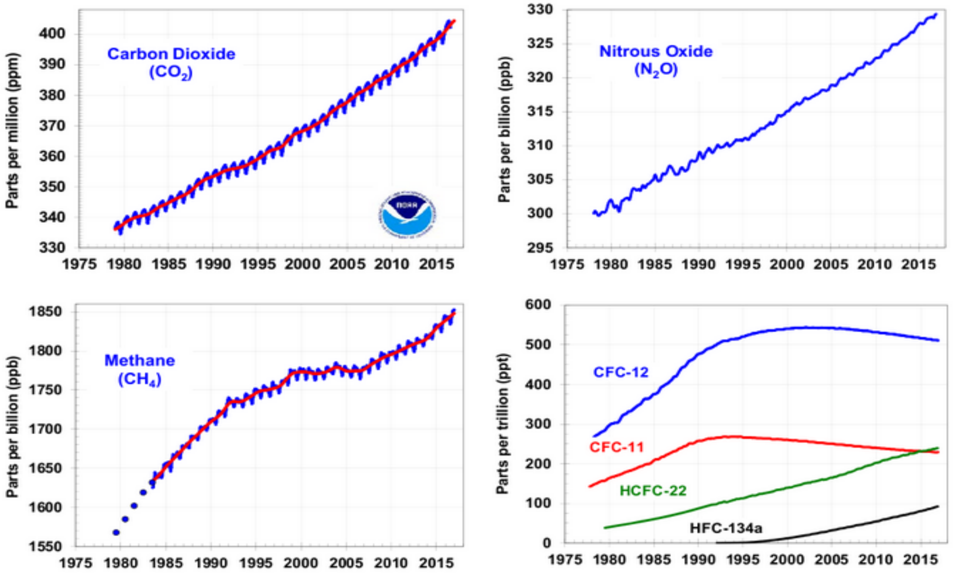
Asia would also feel the effects of climate change.

Roxy Mathew Koll, a scientist at the Indian Institute of Tropical Meteorology, said one third of the past 15 years were afflicted by droughts in South Asia and that drought frequency was expected to increase.



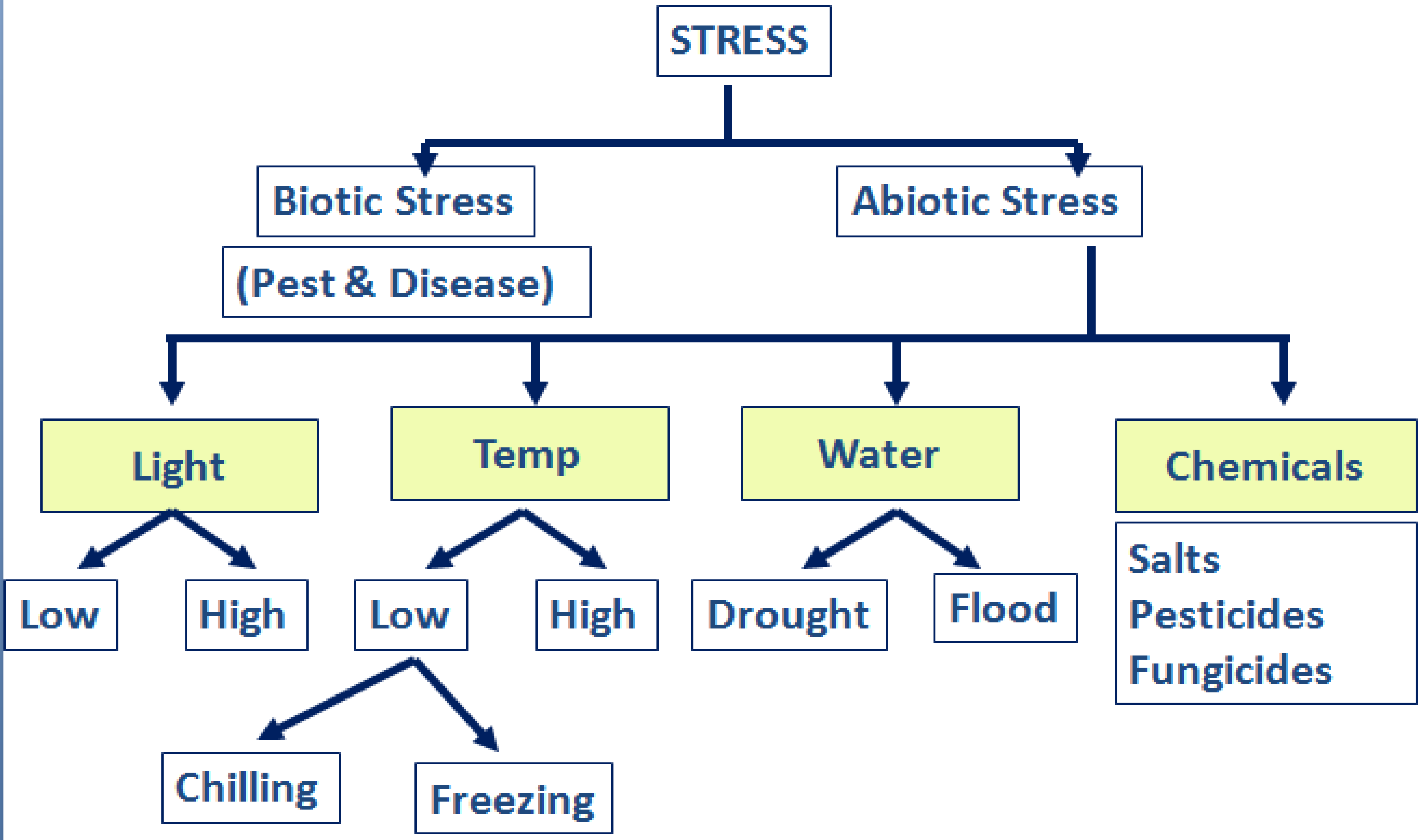
Build up of atmospheric carbon di oxide and other GHGs over years

Global Average Abundances of Major, Long-Lived Greenhouse Gases



Source Graphic NOAA Annual Greenhouse Gas Index (AGGI)

Source: National Oceanic and atmospheric administration



STRESS

Biotic Stress

(Pest & Disease)

Abiotic Stress

Light

Low

High

Temp

Low

High

Chilling

Freezing

Water

Drought

Flood

Chemicals

Salts
Pesticides
Fungicides

ABIOTIC STRESS RESPONSES OF PLANTS

GROWTH

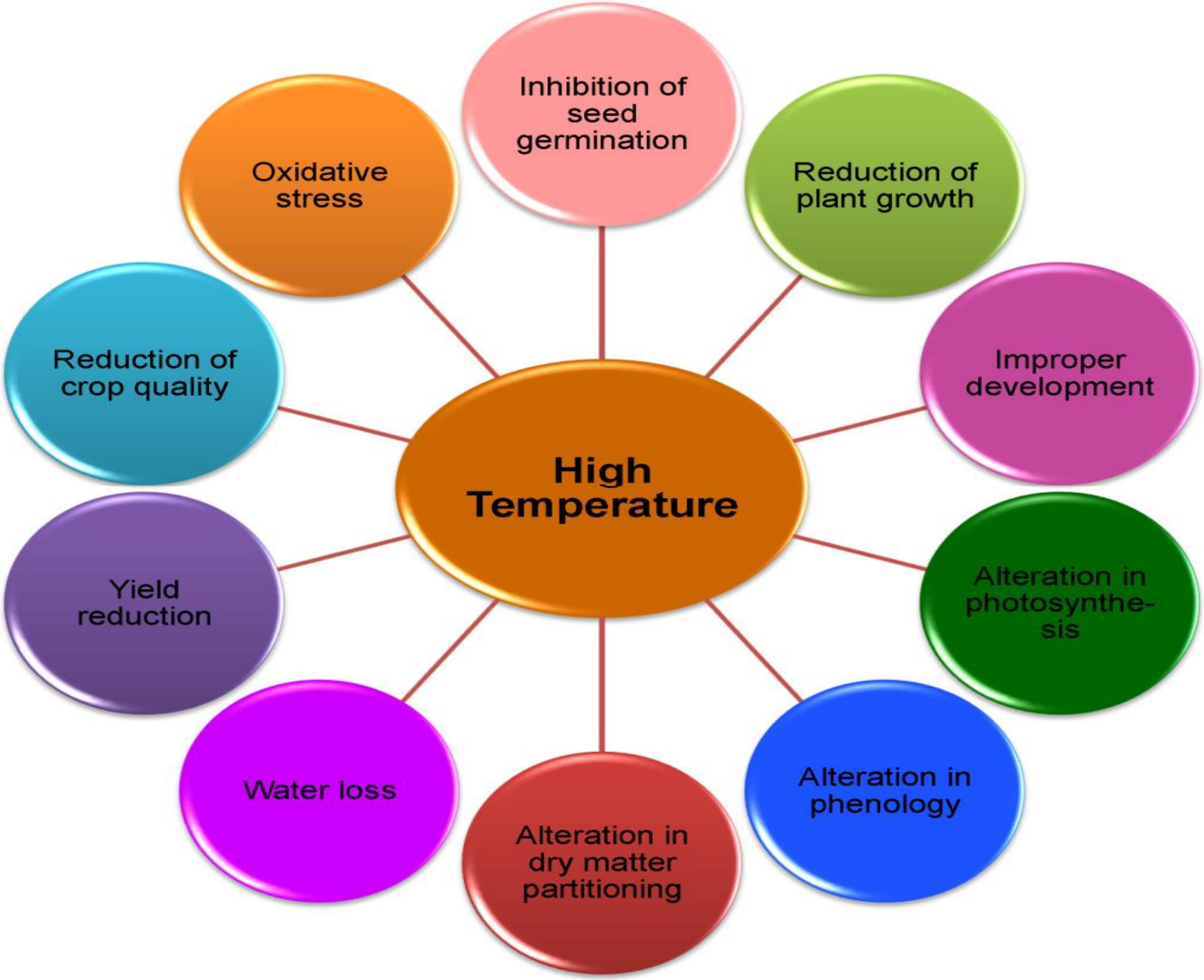
- Germination inhibitation
- Growth reduction
- Premature senescence
- Reduction in productivity

PHYSIOLOGY

- Reduction in water uptake
- Altered transpiration rate
- Reduction in Photosynthesis
- Altered respiration
- Decrease in Nitrogen assimilation
- Metabolic toxicity
- Accumulation of growth inhibitors

MOLECULAR BIOLOGY

- Altered gene expression
- Breakdown of macromolecules
- Reduced activity of vital enzymes
- Decreased protein synthesis
- Disorganization of membrane systems



High Temperature

Inhibition of seed germination

Reduction of plant growth

Improper development

Alteration in photosynthesis

Alteration in phenology

Alteration in dry matter partitioning

Water loss

Yield reduction

Reduction of crop quality

Oxidative stress

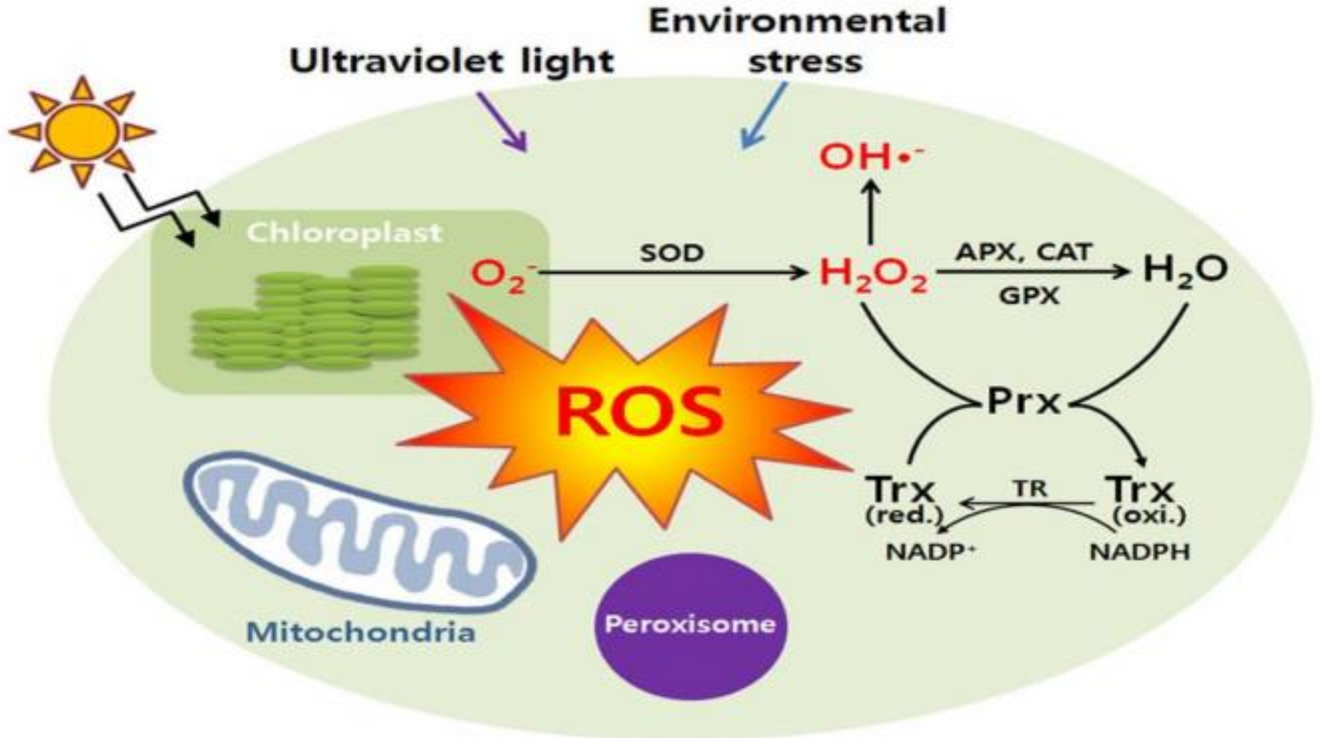
Crops	Threshold temperature (˚C)	Growth stage
Wheat	26	Post-anthesis
Corn	38	Grain filling
Cotton	45	Reproductive
Pearl millet	35	Seedling
Tomato	30	Emergence
Brassica	29	Flowering
Pulses	25	Flowering
Groundnut	34	Pollen production
Cowpea	41	Flowering
Rice	34	Grain yield

Physiological effects of high temperature

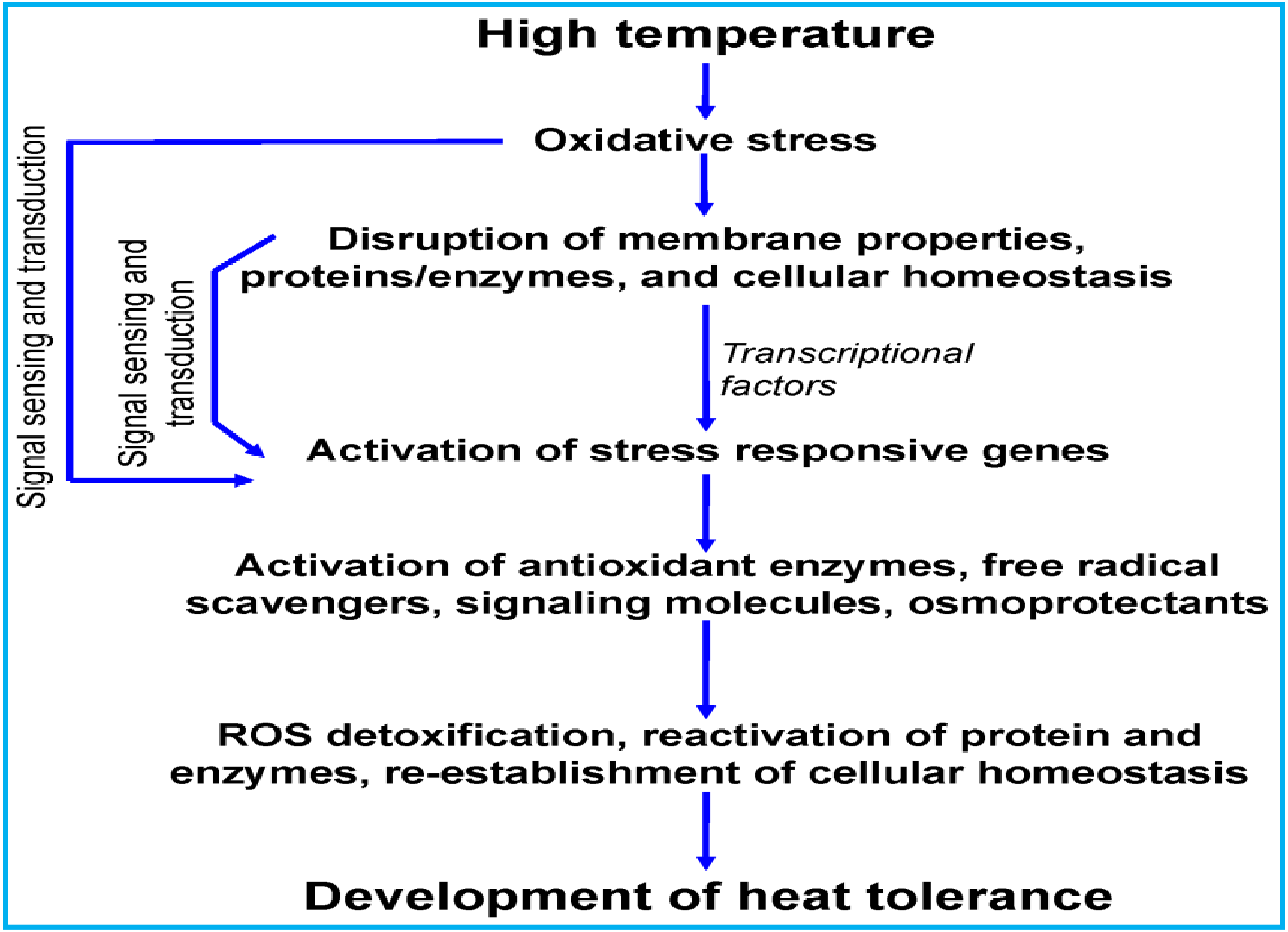
1. Inhibition of metabolic activities due to enzyme denaturing
2. Simple proteins are less susceptible than complex ones
3. Changes in membrane fluidity
4. Rubisco activase is more sensitive than Rubisco
5. Respiration increases drastically than gross Pn at higher Temp.
6. More loss of C through photorespiration (30-80%)
7. Respiration rate is doubled for every 10°C increase in tissue temperature

Accumulation of Reactive Oxygen Species (ROS) as a result of high temperature is a major cause of crop yield loss

Apel & Hirt, 2004; Mahajan & Tuteja, 2005; Tuteja, 2007, 2010; Khan & Singh, 2008; Waraich *et al*., 2012



Reactive Oxygen Species (ROS) generation in chloroplasts, Mitochondria and Peroxisomes causing oxidative damage due to abiotic stresses



High temperature

Oxidative stress

Disruption of membrane properties, proteins/enzymes, and cellular homeostasis

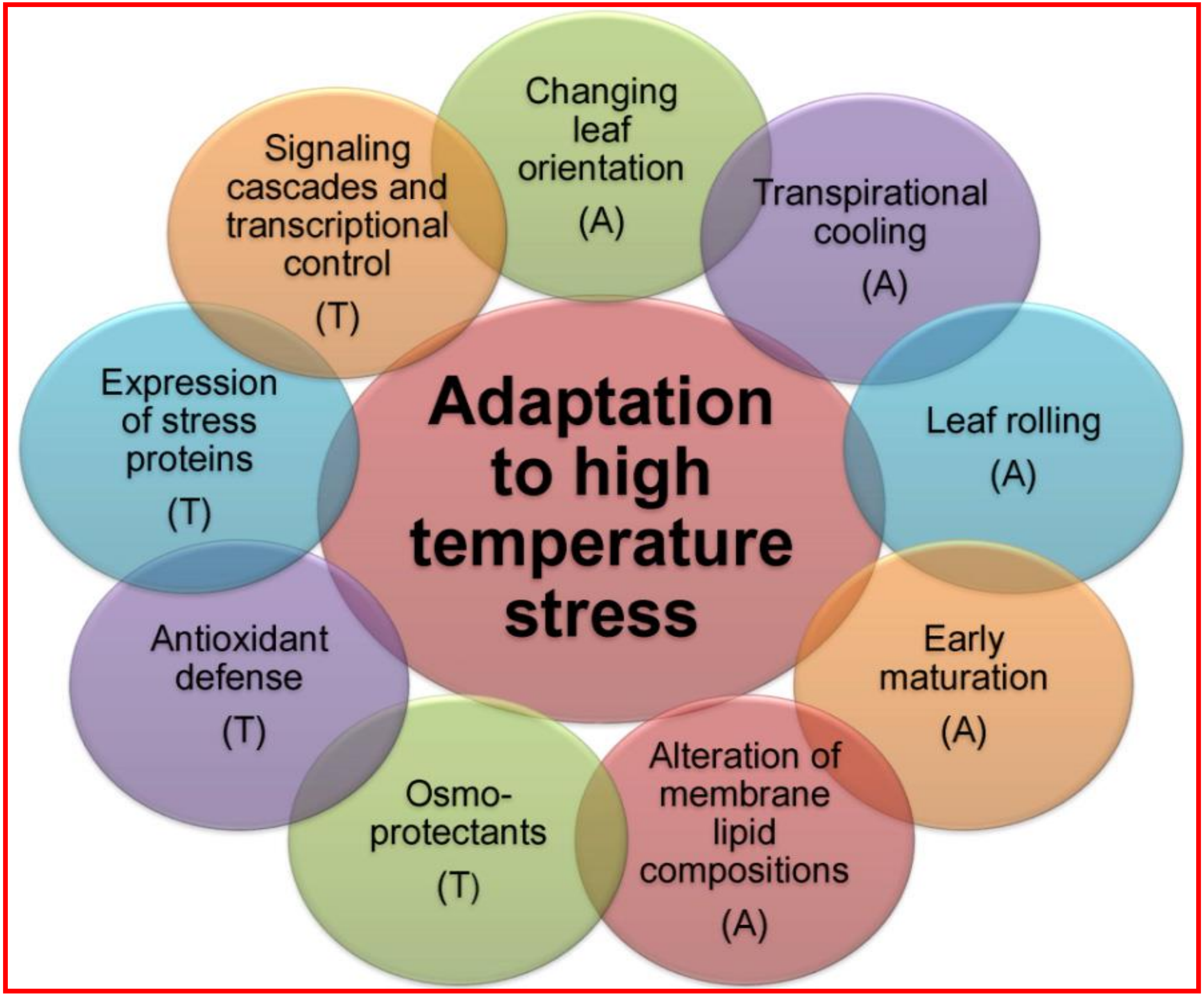
Transcriptional factors

Activation of stress responsive genes

Activation of antioxidant enzymes, free radical scavengers, signaling molecules, osmoprotectants

ROS detoxification, reactivation of protein and enzymes, re-establishment of cellular homeostasis

Development of heat tolerance



Changing leaf orientation (A)
Transpirational cooling (A)
Leaf rolling (A)
Early maturation (A)
Alteration of membrane lipid compositions (A)
Osmo-protectants (T)
Antioxidant defense (T)
Expression of stress proteins (T)
Signaling cascades and transcriptional control (T)
Adaptation to high temperature stress

Physiological traits associated with heat tolerance/ avoidance

1. CTD (Canopy cooling)
2. Photosynthetic rate
3. Cell membrane thermostability
4. Stomatal conductance
5. Cholorophyll fluorescence (Efficiency of photosystem II)
6. Leaf rolling and surface reflectance
7. Spikelets fertility
8. Pollen viability

LOW TEMPERATURE STRESS

Chilling injury

- Plants are seriously injured by temperature **above 0˚C, below 15˚C.**

Freezing injury

- As temperature decreases **below 0˚C, ice forms in the intercellular spaces of plant tissues**.
- Low temperature damages plants both by a chilling effect, leading to physiological and developmental abnormalities, and by freezing, causing cellular damage directly or via cellular dehydration

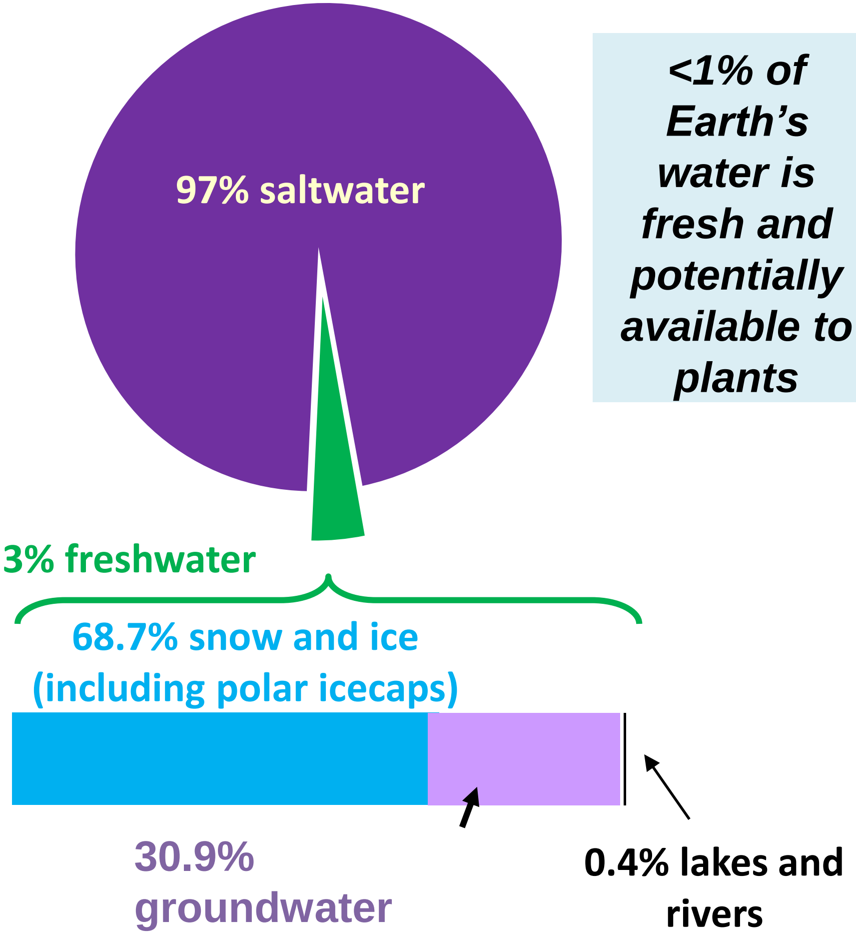
Effects of low temperature stress

- Flowering in rice are extremely sensitive to low temperatures and damage may occur at temperatures as low as 20°C.

- Visible symptoms of low-temperature injury
  - Wilting of leaves
  - Bleaching due to photo-oxidation of pigments
  - Water logging of the intercellular spaces
  - Browning
  - Leaf necrosis and plant death

WATER STRESS

The 75% of the earth's surface is with water, but most is not available to plants



97% saltwater

3% freshwater

68.7% snow and ice (including polar icecaps)

30.9% groundwater

0.4% lakes and rivers

<1% of Earth's water is fresh and potentially available to plants

NASA: Earth Observatory

Water stress and drought are not synonyms

Water stress: short term effect (minutes to hours)

- Very frequent even in well irrigated plants
- Whenever evaporative demand is higher than the xylem capacity for refilling leaves.

eg. The incidence of dry wind can cause a temporary water deficit in the leaf.

Drought: Long term effect (days to months)

- When soil water depleted partially (or) totally (due to low precipitation).
- While the evaporative demand is high, a long term imbalance is produced between water demand and supply.
- Drought is usually accompanied by high irradiance and temperature.

DROUGHT STRESS

Physiological Responses

- Recognition of root signals
- Loss of turgar and osmotic adjustment
- Reduced leaf water potential (ψ)
- Decrease in stomatal conductance to CO_2
- Reduced internal CO_2 concentration
- Decline in net photosynthesis
- Reduced growth rates

Biochemical Responses

- Transient decrease in photochemical efficiency
- Decreased efficiency of Rubisco
- Accumulation of stress matabolites like MDHA, Glutathione, Pro, Glybet, Polyamines, and ∝-tocopherol
- Increase in antioxidative enzymes like, SOD, CAT, APX, POD, GR and MDHAR
- Reduced ROS accumulation

Molecular Responses

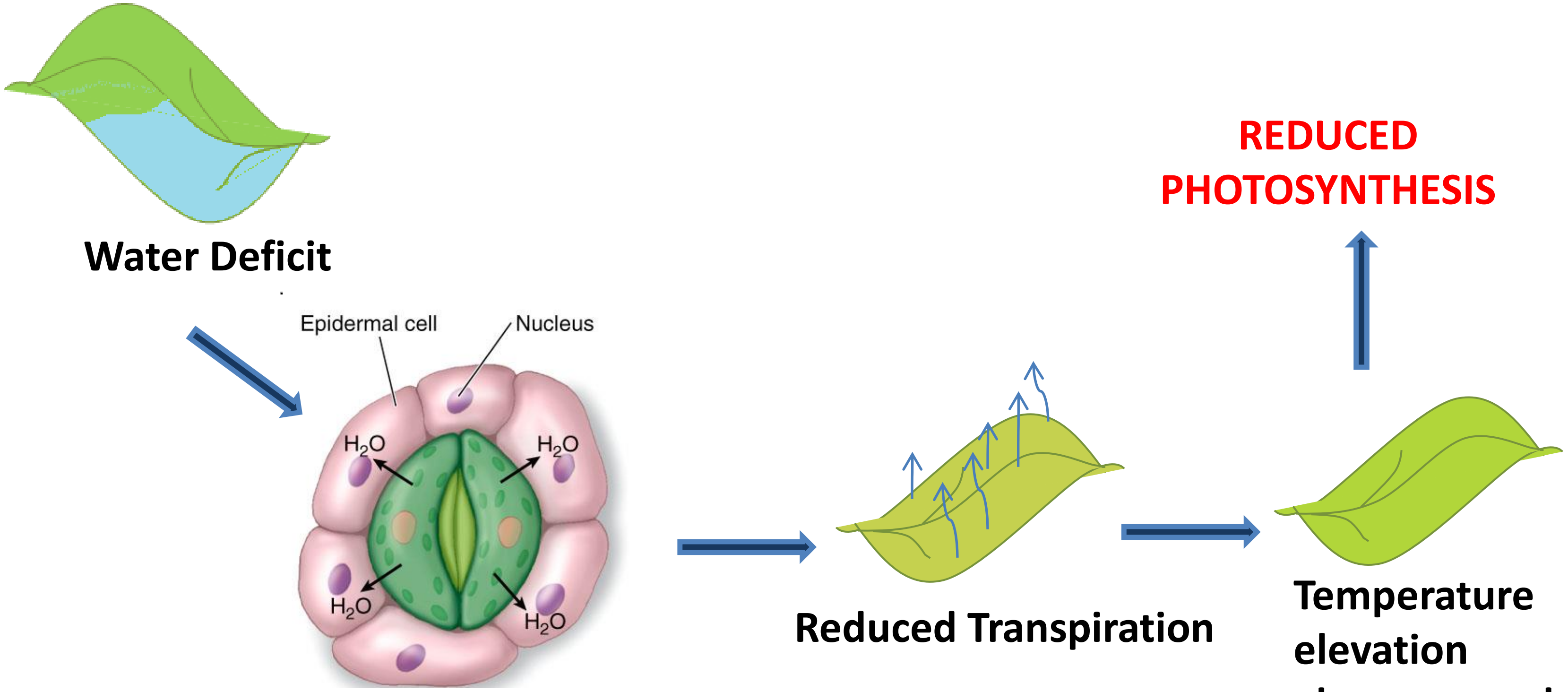
- Stress responsive gene expression
- Increased expression in ABA biosynthetic genes
- Expression of ABA responsive genes
- Synthesis of specific proteins like LEA, DSP, RAB, dehydrins
- Drought stress tolerance

Plant's response to water deficit

1. Decreases leaf area
2. Stimulates Leaf Abscission
3. Enhances Root Extension into soil
4. Stomata Closes in Response to Abscisic Acid
5. Limits Photosynthesis within the chloroplast
6. Increases Wax Deposition on the Leaf Surface
7. Alters Energy Dissipation from Leaves
8. Reduces Protein synthesis and enzyme levels
9. Reduces Nutrient uptake
10. Accumulates compatible solutes

How Water Deficit is related to Leaf Energy Balance ?

When water deficit develops slowly enough to allow changes in developmental processes, water stress has several effects on growth.



Water Deficit

Stomatal Closure

Reduced Transpiration

Temperature elevation above normal

REDUCED PHOTOSYNTHESIS

Effect of drought intensity on photosynthesis

- **Mild stress**
- **Leaf Pn / stomatal conductance is reduced**
- **Stomata close to maintain high WUE by inhibiting transpiration**

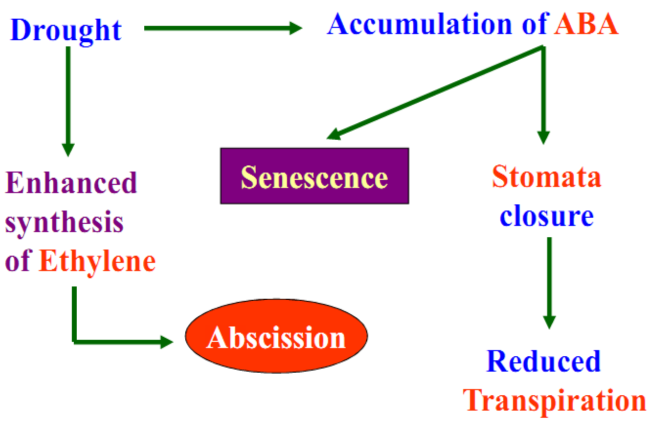
- **Severe stress**
- **Dehydration of mesophyll cells**
- **Inhibit Pn, mesophyll metabolisms impaired, WUE decreases**
- **Effects are more on stomatal conductance than Pn**

Table I. Economic yield reduction by drought stress in some representative field crops.

Crop	Growth stage	Yield reduction	References
Barley	Seed filling	49–57%	Samarah (2005)
Maize	Grain filling	79–81%	Monneveux et al. (2005)
Maize	Reproductive	63–87%	Kamara et al. (2003)
Maize	Reproductive	70–47%	Chapman and Edmeades (1999)
Maize	Vegetative	25–60%	Atteya et al. (2003)
Maize	Reproductive	32–92%	Atteya et al. (2003)
Rice	Reproductive (mild stress)	53–92%	Lafitte et al. (2007)
Rice	Reproductive (severe stress)	48–94%	Lafitte et al. (2007)
Rice	Grain filling (mild stress)	30–55%	Basnayake et al. (2006)
Rice	Grain filling (severe stress)	60%	Basnayake et al. (2006)
Rice	Reproductive	24–84%	Venuprasad et al. (2007)
Chickpea	Reproductive	45–69%	Nayyar et al. (2006)
Pigeonpea	Reproductive	40–55%	Nam et al. (2001)
Common beans	Reproductive	58–87%	Martínez et al. (2007)
Soybean	Reproductive	46–71%	Samarah et al. (2006)
Cowpea	Reproductive	60–11%	Ogbonnaya et al. (2003)
Sunflower	Reproductive	60%	Mazahery-Laghab et al. (2003)
Canola	Reproductive	30%	Sinaki et al. (2007)
Potato	Flowering	13%	Kawakami et al. (2006)

Accumulation of hormones- ABA and ethylene

ABA closes stomata during water stress



Drought

Accumulation of ABA

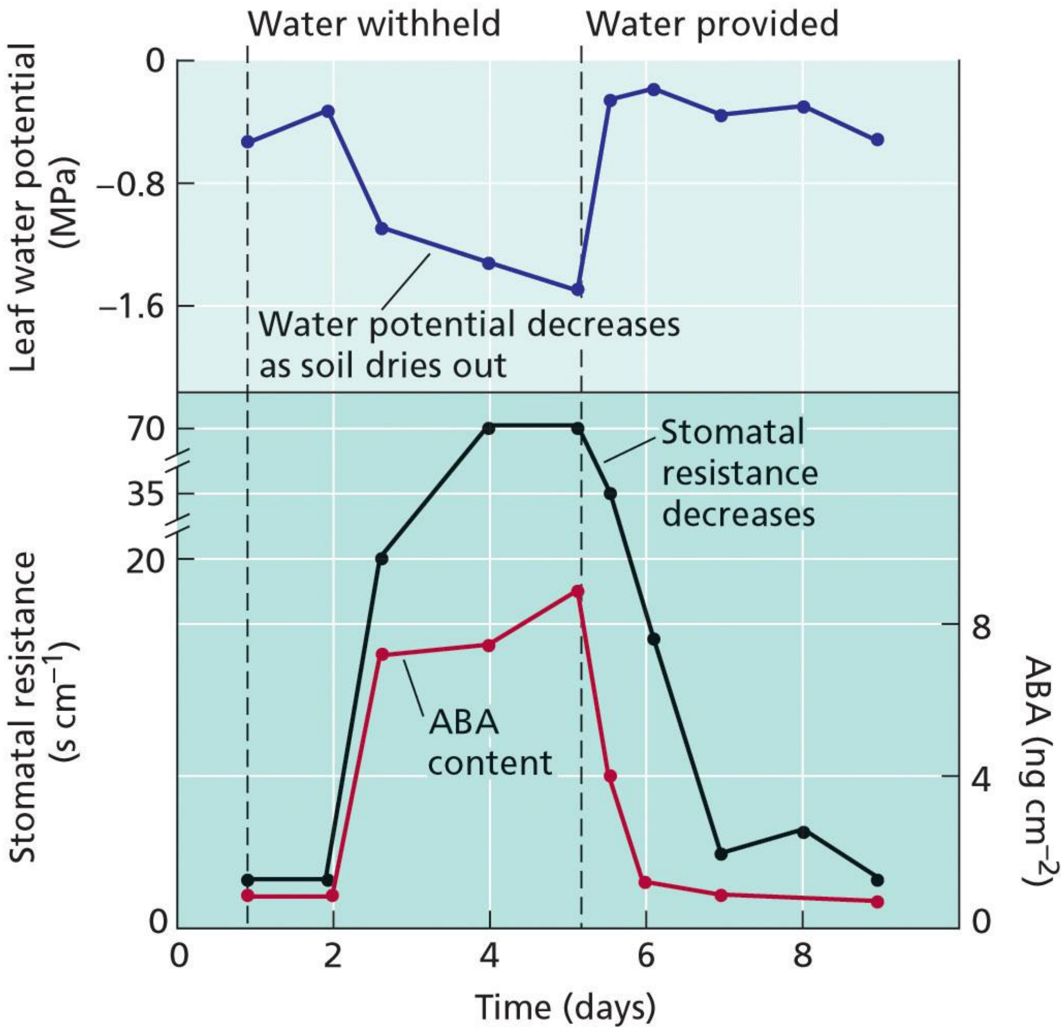
Enhanced synthesis of Ethylene

Senescence

Stomata closure

Abscission

Reduced Transpiration



Plant adaptations to drought

1. Resistance
2. Adaptation

Resistance

Plants express pre-existing programme and able to maintain, more or less original growth and development eg. Increased ABA and reduced growth promoters

Changes in phytohormones directly proportional to severity of stress and inversely to resistance ability

Adaptation

Initiate new developmental programme. Once adapted, growth recover even up to non stress condition.

ANTIOXIDANT SYSTEMS UNDER STRESS

Plants subjected to abiotic stresses produce ROS

- superoxide (O^{2-})
- hydrogen peroxide (H_2O_2)
- hydroxyl radicals (·OH)
- singlet oxygen ($_1O^2$)

These ROS may initiate destructive oxidative processes

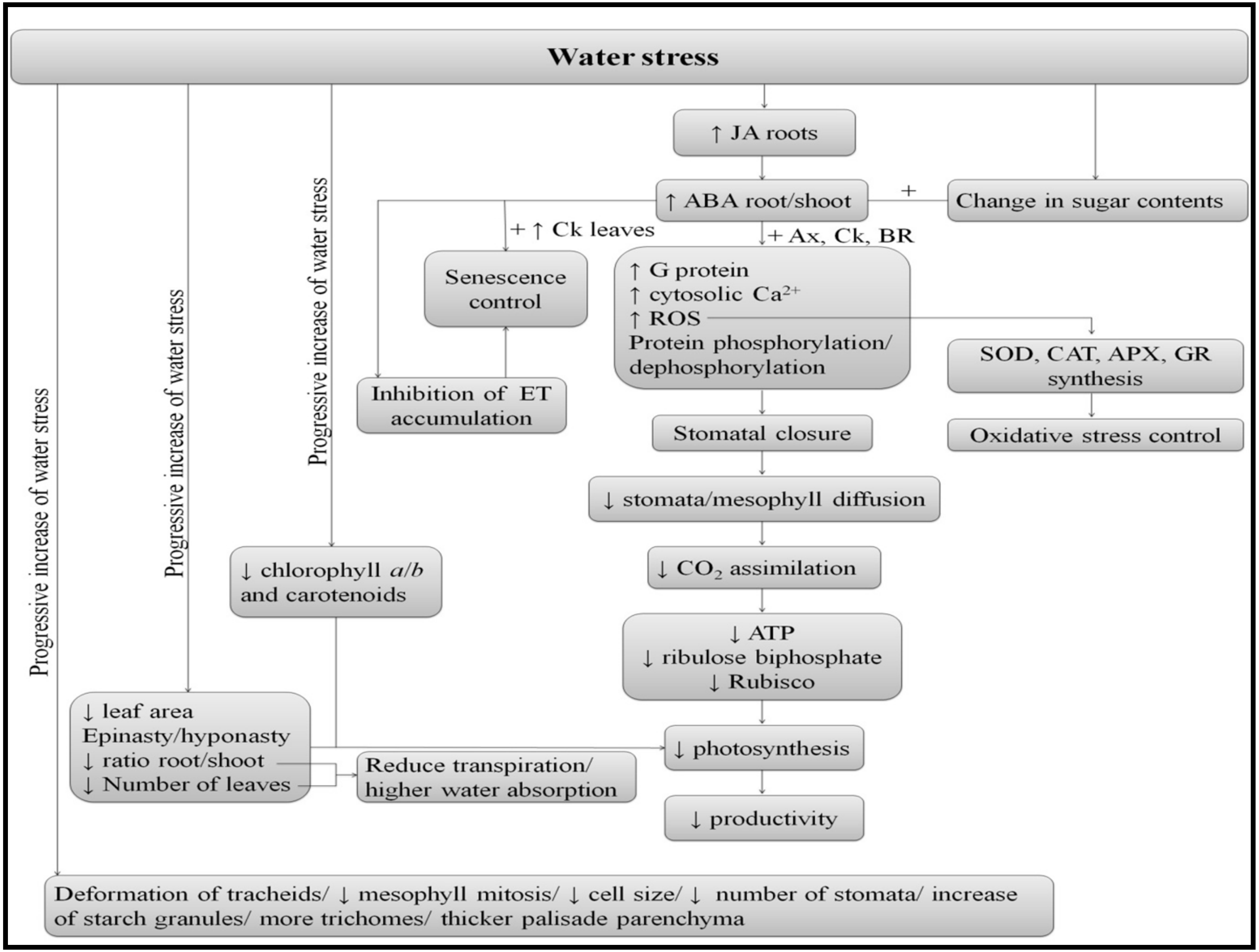
- lipid peroxidation
- chlorophyll bleaching
- protein oxidation
- damage to nucleic acids

Antioxidant enzymes

- Superoxide dismutase (SOD)
- glutathione reductase (GR)
- Catalase
- Peroxidase

Low-molecular antioxidants

- ascorbic acid
- glutathione
- α-tocopherol, flavonoids and carotenoids play a key role in scavenging those activated species


Water stress
↑ JA roots
↑ ABA root/shoot
+
Change in sugar contents
+ ↑ Ck leaves
+ Ax, Ck, BR
Senescence control
↑ G protein
↑ cytosolic Ca^{2+}
↑ ROS
Protein phosphorylation/ dephosphorylation
SOD, CAT, APX, GR synthesis
Oxidative stress control
Inhibition of ET accumulation
Stomatal closure
↓ stomata/mesophyll diffusion
↓ CO_2 assimilation
↓ ATP
↓ ribulose biphosphate
↓ Rubisco
↓ photosynthesis
↓ productivity
Progressive increase of water stress
Progressive increase of water stress
Progressive increase of water stress
↓ chlorophyll *a*/*b* and carotenoids
↓ leaf area
Epinasty/hyponasty
↓ ratio root/shoot
↓ Number of leaves
Reduce transpiration/ higher water absorption
Deformation of tracheids/ ↓ mesophyll mitosis/ ↓ cell size/ ↓ number of stomata/ increase of starch granules/ more trichomes/ thicker palisade parenchyma

SUBMERGENCE STRESS

- In rainfed lowland areas, submergence is a major problem during the monsoon periods
- ≈9% of global rice area is flood-prone
- Total area affected due to submergence in Tamil Nadu – 5 lakh hectares of paddy with a production loss of Rs. 950 crores in samba and thaladi seasons
- Nagapattinam and Tiruvarur districts - 1.34 lakh hectares each, Thanjavur district - 1.26 lakh hectares

Flooding

Flash flood

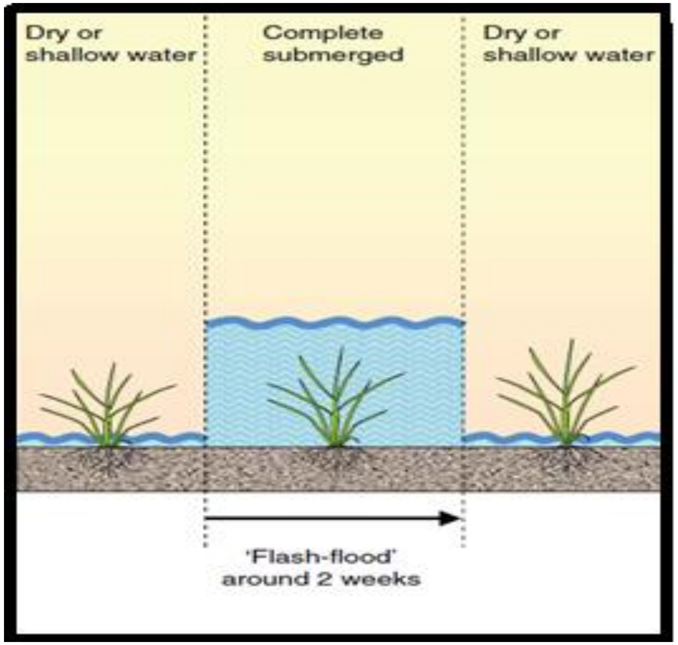
Short duration over a few weeks (2 weeks) and not very deep. Water level can reach 50 cm

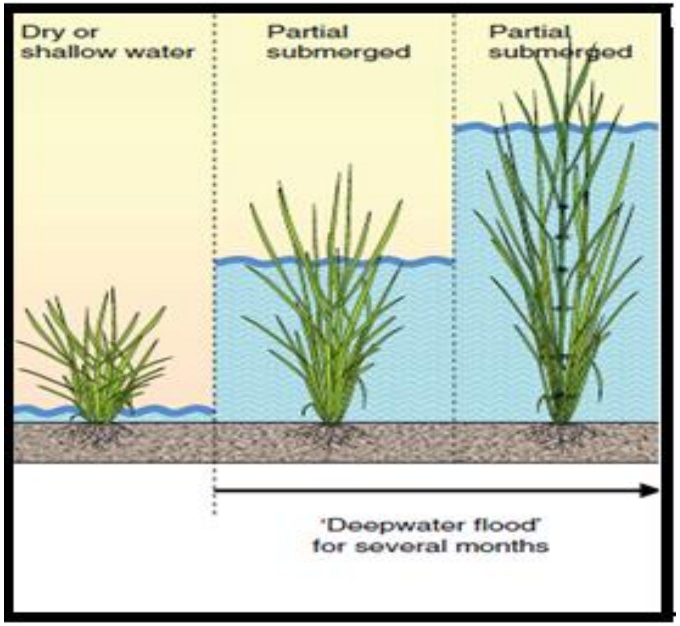
Deep flooding

Lasts for a long time (several months).

Submergence tolerance

The ability of a rice plant to survive 10–14 d of complete submergence and renew its growth when the water subsides





Hattori *et al.*, 2011

Impact of flooding

- Reduced movement of gases to and away from plant surfaces
- Reduced O_2 supply that limits respiration
- Reduced CO_2 supply that limits photosynthesis
- Reduced ethylene diffusion away from the plant which triggers chlorosis and excessive leaf elongation of intolerant cultivars
- Poor plant growth and survival during submergence

(Ella *et al*., 2003)

Alcoholic Fermentation

- Submergence can shift aerobic respiration to the less efficient anaerobic fermentation pathway

- This pathway depends on continued supply of substrate (glucose) and the two key enzymes, alcohol dehydrogenase (ADH) and pyruvate decarboxylase (PDC).

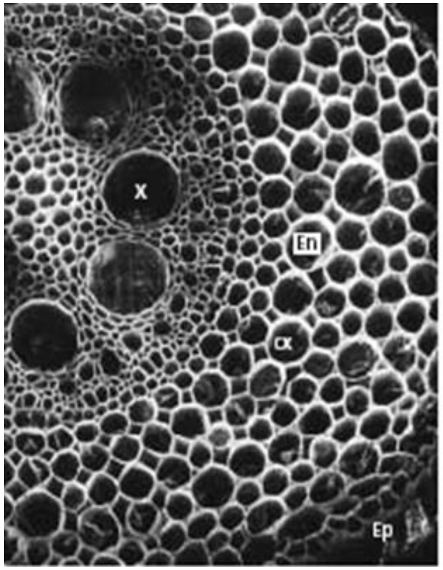
- Alcoholic fermentation is the key catalytic pathway for recycling NAD to maintain glycolysis and substrate level phosphorylation in the absence of oxygen.

- Increased alcoholic fermentation is a way to alleviate the effect of anoxia on reduced production of energy for growth and maintenance

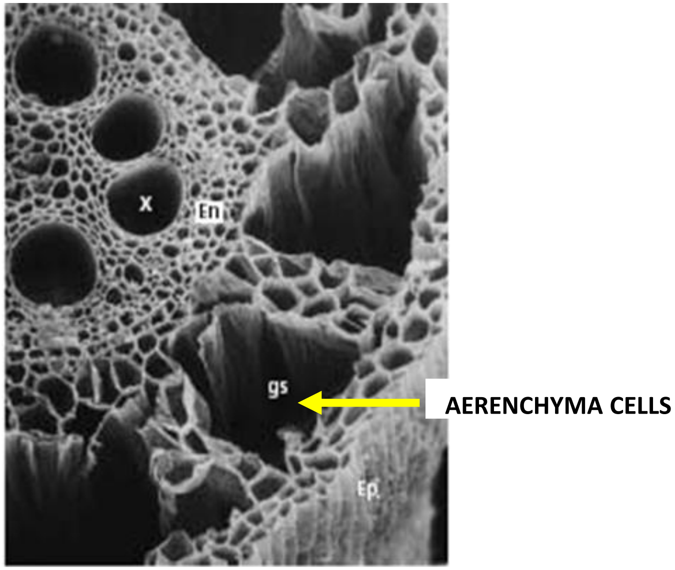
Adaptations for Submergence Tolerance

- The presence of gas filled spaces, known as aerenchyma, in roots of numerous plant species is considered to be an important anatomical adaptation for survival under flooded conditions.

- Aerenchyma provides a diffusion path for the transport of oxygen from aerial plant parts to roots or rhizomes.



CONTROL ROOTS



OXYGEN DEFICIET ROOTS

Physiology of submergence tolerance

Energy maintenance

- Conservation of carbohydrate during submergence
- Sustained sugar supply and energy metabolism
- Quick regeneration following submergence
- Efficient ROS scavenging

Submergence mediated by plant hormones

- Ethylene, GA and ABA play important roles
- Under anaerobic conditions, ethylene concentration increases in plant tissue because of both increased synthesis and entrapment
- Susceptible genotypes show a reduction in ABA concentration with a concomitant increase in GA resulting in enhanced shoot elongation

SALINITY

The presence of excessive amounts of soluble salts hinder or affect the normal functions of plant growth.

- 10% of global arable land - affected by salinity or sodicity
- Out of 1.5 billion ha of global cultivated land:

  23 % - salinity and 37% - sodicity
- Salinity: Higher accumulation of Ca, Mg, Na and their SO_4, NO_3, CO_3, HCO_3 and Cl salts.
- Sodicity: Higher concentration of Na.

EFFECTS OF SALINITY ON CROP PLANTS

Osmotic effect or water deficit

Reduces the plant's ability to take up water leading to slower growth

Salt specific effect or Ion Excess

Salts enter the transpiration stream and eventually injure cells in the transpiring leaves, further reducing growth.

High salt concentration in the plant cause

Chlorophyll degradation

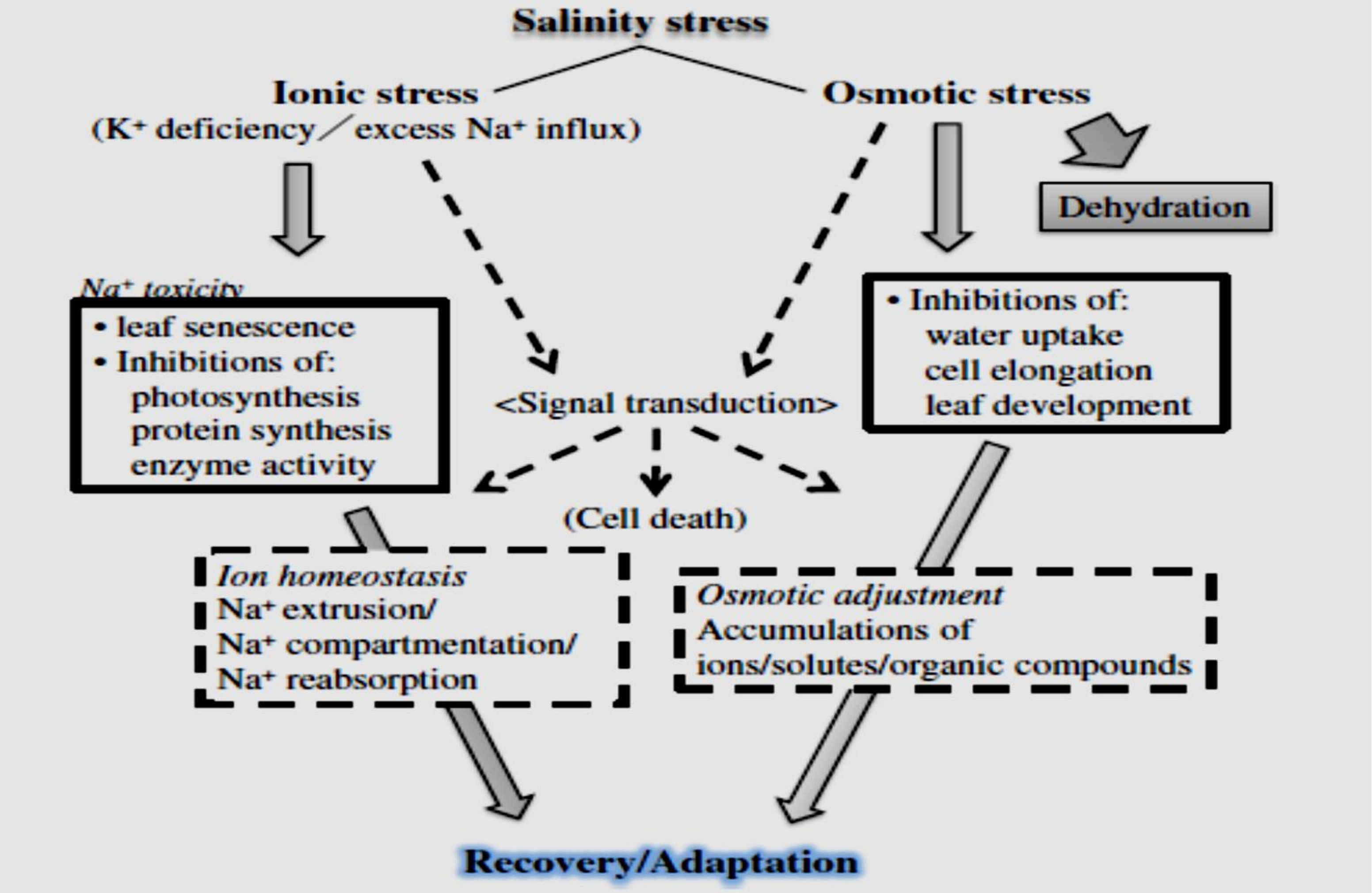
Leaf edge burns

Necrotic spots on the leaf

Cell poisoning

Death of the plant

EVENTS THAT TAKE PLACE UNDER SALT STRESS AND PLANT RESPONSES



(Horie *et al.*, 2012)

EFFECTS OF SALINITY ON CROP PLANTS

- Increased respiration
- Ion toxicity
- Changes in plant growth
- Mineral distribution
- Membrane permeability
- Decreased efficiency of photosynthesis
- Increased production of reactive oxygen species

Effects on growth and development

- Reduction in the rate of leaf surface expansion.
- Clear stunting of plants
- Decrease in the fresh and dry weights of leaves, stems, and roots.
- Sterility and lower seed set.
- Increased the number of sterile florets and
- Viability of pollen becoming more pronounced with increased salinity

Effects on leaf anatomy

- Epidermal thickness
- Mesophyll thickness
- Palisade cell length
- Palisade diameter
- spongy cell diameter

Increases

- Reduces intercellular spaces in leaves

MECHANISM OF SALT TOLERANCE

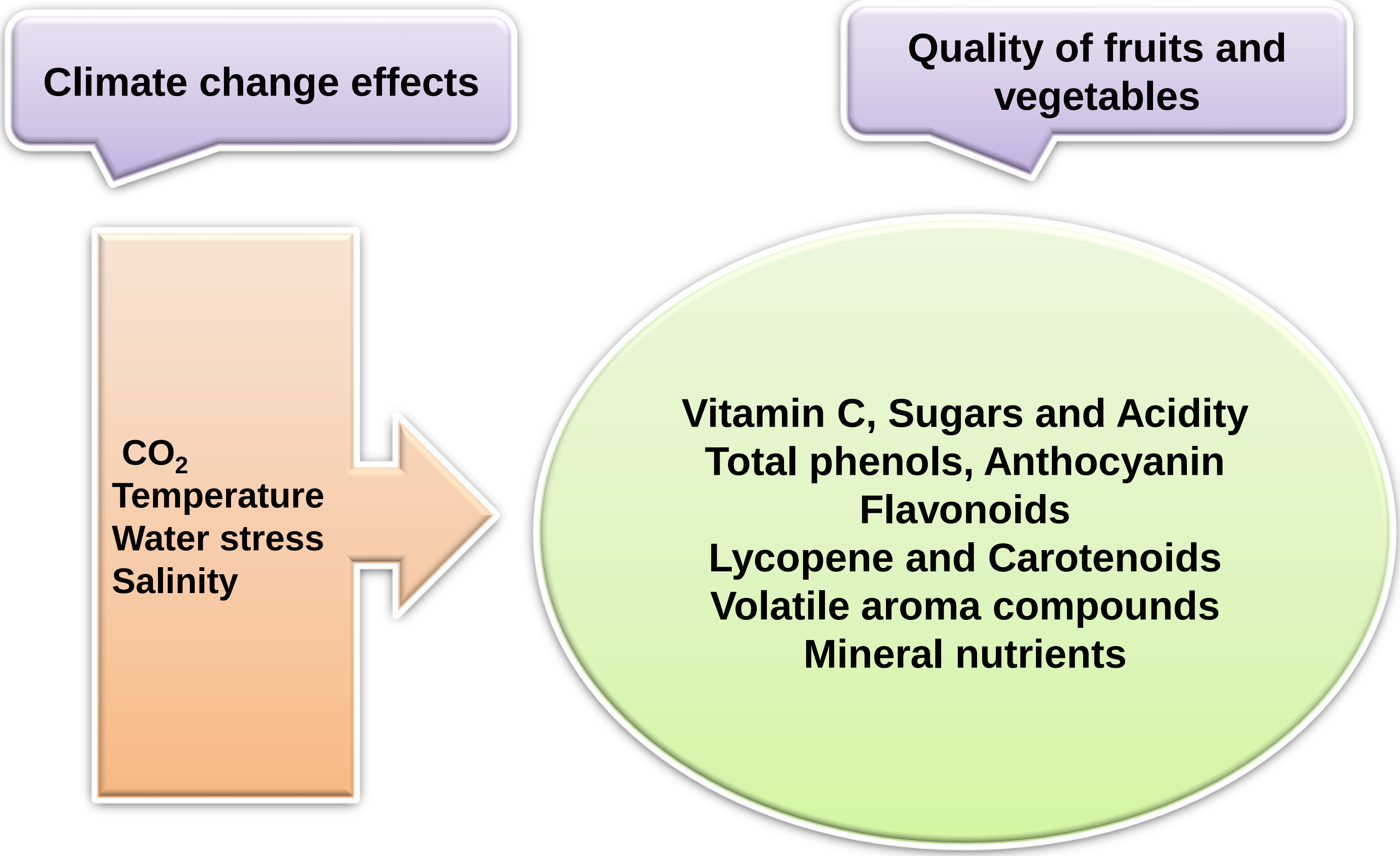
Avoidance

- Salt Exclusion
- Salt Extrusion
- Salt Dilution
- Compartmentation of ions

Tolerance

- Osmotic adjustment
- Hormone synthesis – ABA hardens plants against excess salts
- Homeostasis
- Detoxification
- Growth control

Consequences on postharvest produce quality



Climate change effects

Quality of fruits and vegetables

CO_2
Temperature
Water stress
Salinity

Vitamin C, Sugars and Acidity
Total phenols, Anthocyanin
Flavonoids
Lycopene and Carotenoids
Volatile aroma compounds
Mineral nutrients

Elevated CO_2 affect the mineral composition of fruits and vegetables.

Significant reduction of minerals like N, Ca, Fe, S, Mg and Zn (15–25%) is seen in many herbaceous and woody plants under high CO_2 concentrations

(Loladze 2002)

Initial reduction in protein and mineral content could be overcome in long-term exposures to elevated CO_2 by the enhanced root growth and hence may maintain the quality of fruits and vegetables

(Idso and Idso 2001)

High temperature reduce Starch, Vitamin C, Sugars, Acidity, Phenolics, Flavonoid

High temperatures reduce colour development. Night temperatures are more critical for the anthocyanin content than the day temperatures

(Kentaro Mori *et al*., 2005).

- Increased day and night temperatures (30°C/25°C) reduced the **soluble sugars, starch, AA and proteins** in apple (Hsiao-hua Pan *et al.,* 2007).
- Citrus fruits grown in hot tropical areas have lower levels of **vitamin C** compared to areas of cool nights (Njoku *et al*., 2011) .

Many fruit crops are widely cultivated in semi-arid climates

Water stress affects the sugar content of fruits to a greater extent than other quality parameters. In fruits, water **stress reduces the juiciness, thereby increasing the sugar content**

(Romero *et al.*, 2006).

Deficit irrigation treatment is used in some of the fruit crops to **increase the sugar** content by imposing the treatment at **later stages of fruit maturation.**

Carotenoids, the naturally occurring isoprenoids with antioxidant properties, are the major pigments in many fruits and vegetables – influenced by water stress

Salinity

Lycopene and Carotenoids

- Antioxidants like lycopene, carotenoids and ascorbic acid accumulated in tomato fruits during salt stress (D'Amico *et al.,* 2003)*.*

- However, in leaves of *Lycopersicon esculentum* plants **under salt-stress condition shows a decreased expression of carotenoid biosynthetic genes** (Merlene Ann Babu *et al.*, 2011).

Phenols, Flavonoids and Anthocyanins

- The response of strawberry plants under salt-stress conditions revealed that the phenylpropanoids and flavonoid pathways are still intact and functioning, as indicated by **higher contents of antioxidants**

  (Neocleous and Vasilakakis 2007**)**.

Approaches to improve abiotic stress tolerance

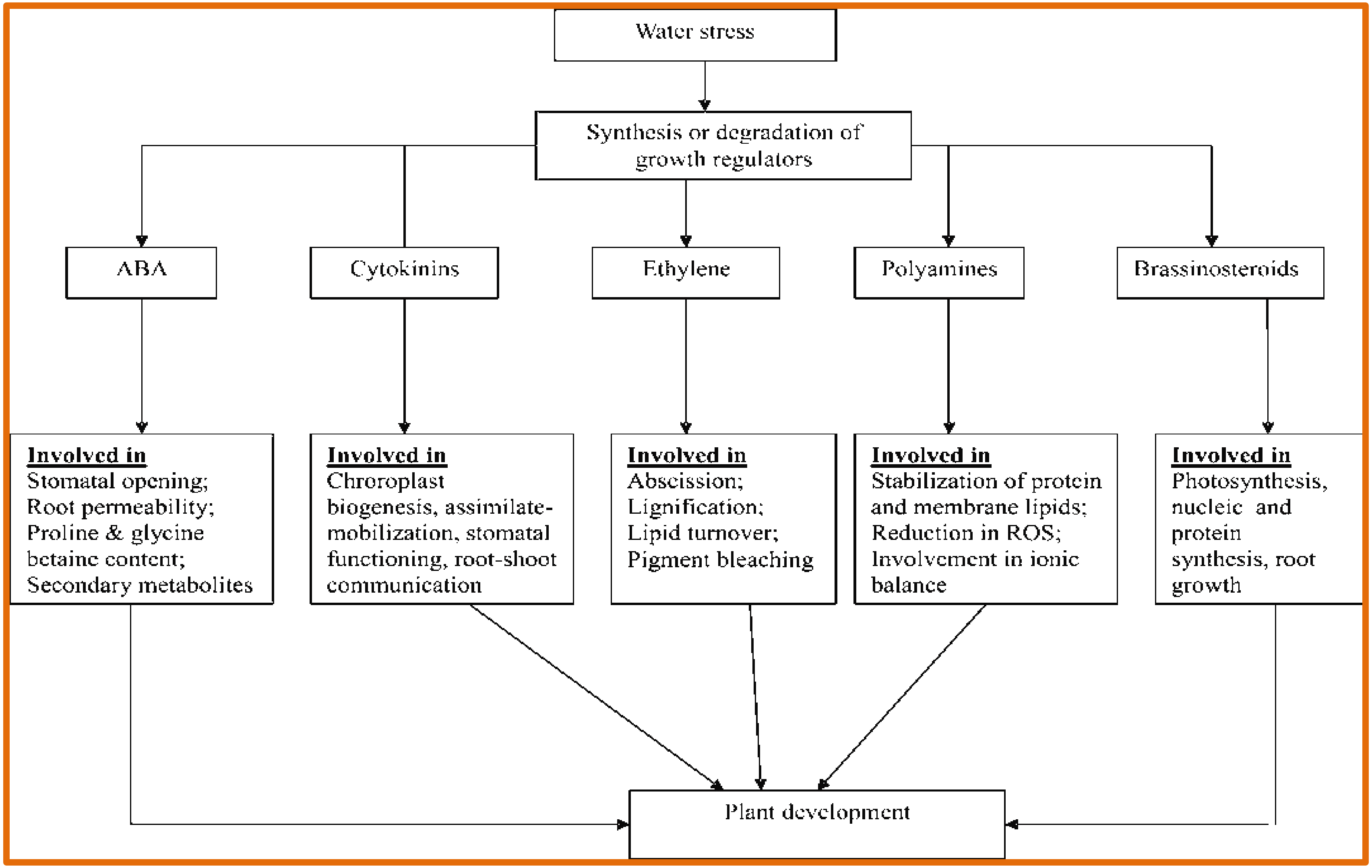
1. GERMPLASM IMPROVEMENT
2. IMPROVEMENT OF STRESS TOLERANCE THROUGH CONVENTIONAL BREEDING
3. IMPROVEMENT OF STRESS TOLERANCE THROUGH MARKER ASSISTED BACKCROSS BREEDING
4. IMPROVEMENT OF STRESS TOLERANCE THROUGH PLANT GENETIC ENGINEERING
5. HORMONAL REGULATION OF STRESS TOLERANCE
6. BIOSTIMULANTS AND BIOINCOLUNATS

Endogenous hormonal balance and adaptation to stress

- Hormonal balance is important than conc. of individual hormone
- Stress induces production of high ABA, low CK and Auxin and alter GA and ethylene level
- Increase in CK level- exceeding the pre stressed level cause improvement in yield
- Increased ABA during drought: induce cross tolerance.

  eg. salinity/cold tolerance
- Resistance to stress is linked with ability of plant to maintain the existing hormonal balance

Physiological role of PGRs in stress management



Water stress

Synthesis or degradation of growth regulators

ABA

Cytokinins

Ethylene

Polyamines

Brassinosteroids

Involved in
Stomatal opening;
Root permeability;
Proline & glycine betaine content;
Secondary metabolites

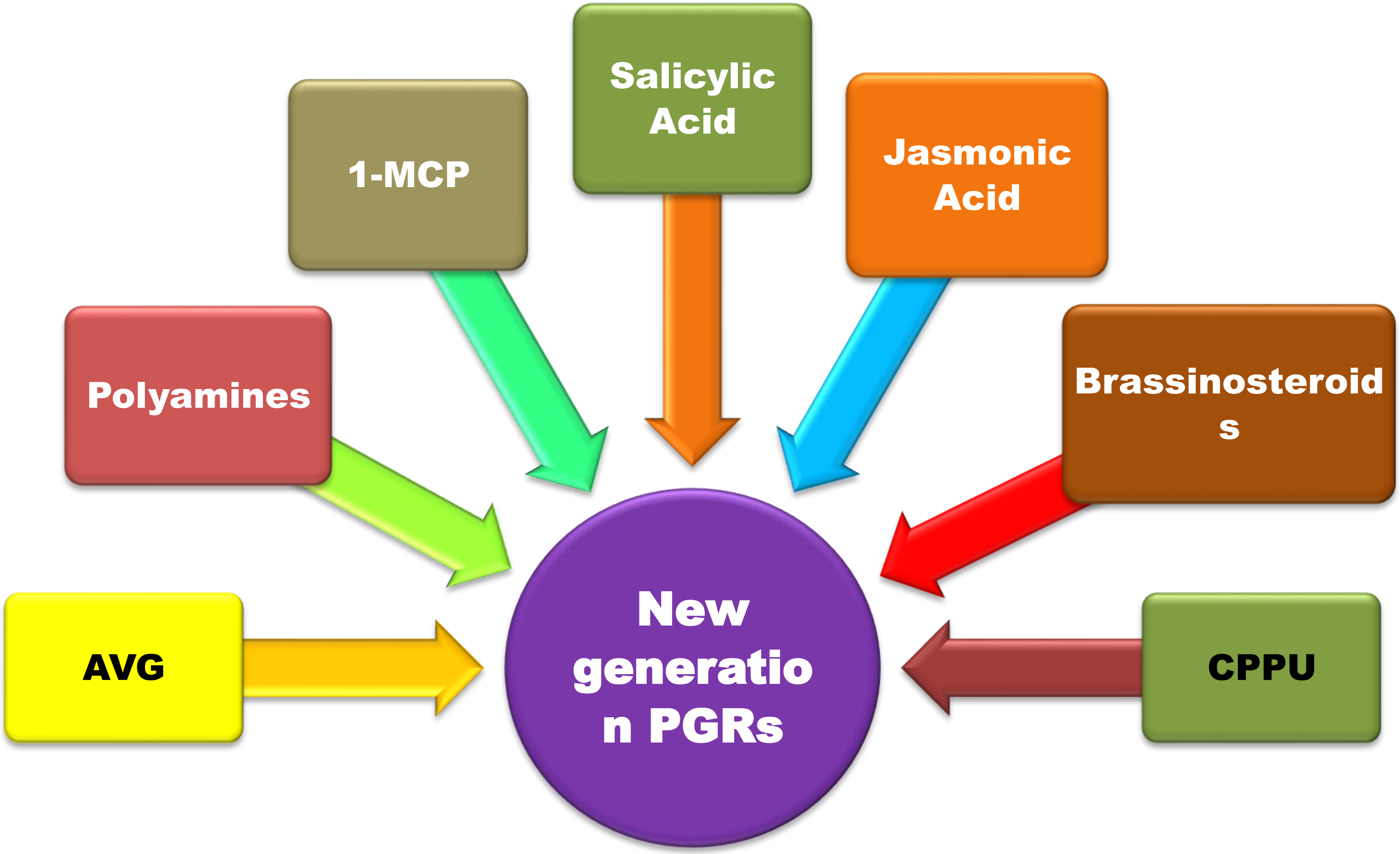
Involved in
Chroroplast biogenesis, assimilate-mobilization, stomatal functioning, root-shoot communication

Involved in
Abscission;
Lignification;
Lipid turnover;
Pigment bleaching

Involved in
Stabilization of protein and membrane lipids;
Reduction in ROS;
Involvement in ionic balance

Involved in
Photosynthesis, nucleic and protein synthesis, root growth

Plant development



1-MCP

Salicylic Acid

Jasmonic Acid

Polyamines

Brassinosteroids

AVG

New generation PGRs

CPPU

SALICYLIC ACID

- SA is a phenolic phytohormone with high potential for stress tolerance
- Lower level of SA alleviate abiotic stress ; at higher level it induces oxidative stress

- Induce drought tolerance with an enhanced antioxidant system
- Inhibits ethylene synthesis and antagonistic to Jasmonic acid

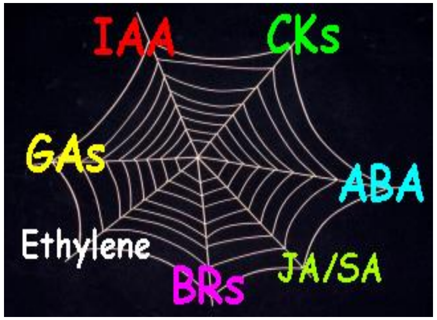
- Triggers systemic acquired response (SAR)
- Induces the pathogenesis related proteins PR-1, PR-2, PR-5
- Improves stomatal regulation, maintains leaf chlorophyll content, increases WUE, and stimulates root growth

Anosheh *et al*., 2012

JASMONIC ACID

- **Jasmonic acid** (**JA**) is an organic compound found in several plants
- Cyclopentanone derivative synthesized from linolenic acid
- Induces storage proteins, osmotin, thionin (antifungal) and defensin.
- The major function of JA and its various metabolites is regulating plant responses to abiotic and biotic stresses.
- It has an important role in response to wounding of plants and systemic acquired resistance

Interaction of Ethylene, Jasmonic Acid & Salicylic acid with reference to stress condition



- Pathways do not function independently.
- Involved in a complex signaling network in different pathways influence positive and negative regulatory interactions.
- Hormones may interact with one another in regulating stress signaling and plant stress tolerance.
- Ethylene enhance ABA action in seeds (Gazzarrini and McCourt, 2001) but may counteract ABA effects in vegetative tissues under drought stress (Spollen *et al.*, 2000).
- *A. thaliana* provide evidence for cross talk among the SA, JA and ET signaling pathways.

BRASSINOSTEROIDS

- Brassinosteroids - sixth group of phytohormones
- Significant growth promoting effects and essential for many processes in plant growth and development
- Participate in the processes of gene expression, transcription and translation in normal and stressed plants

- Induce the expression of antioxidant genes and enhance the activities of antioxidant enzymes
- Brassinosteroid-1µM alleviates drought induced oxidative stress

(Behnamnia, 2009)

BRASSINOSTEROIDS

Water stress, Thermal stress, Heavy metal stress, Salt stress

1. Enhances the activities of superoxidase dimutase, catalase , ascorbate peroxidase and glutathione reductase
2. Enhances the level of ascorbic acid and carotenoids
3. Enhances the net photosynthetic rate
4. Enhances the level of ABA, proline and other osmolytes
5. Enhances the Glutathione and phytochelatins
6. Stimulates nitrogen metabolism
7. Enhances the level of heat shock proteins
8. Improves the pigment levels and nitrate reductase

POLYAMINES

- Polyamines are small, positively charged, organic molecules that are ubiquitous in all living organisms.

- Three types: Putrescine, spermidine, hermospermine according to structure, universal distribution in cellular compartments, and involvement in physiological activities.

- Water stress leads to accumulation of free or conjugated polyamines. Differences in polyamine metabolism under stress depend upon plant species/cultivar, duration of stress, developmental stage, etc.

- Polyamines have antioxidative, free radical scavenging effects and ABA synthesis and membrane stabilizing properties.

Liu *et al*, 2007

CCC/ CC/ MC and Paclobutrazol

Tolerance to water stress in many plant species

- Increased production of ABA by inhibiting gibberellin synthesis
- Increased ABA helps in plant water balance, growth reduction and increased antioxidant content/activity
- **Combination of triazole and strobilurins** help in abiotic stress tolerance

Effect of 1-MCP on Antioxidant Enzymes, Membrane Leakage and Protein Content

- 1-MCP increase the activity of glutathione reductase and superoxide dismutase in water stressed plants
- These effects significantly increased protein concentration and maintained cell membrane integrity
- Provide protection against ROS produced by plants under stress condition - *Eduardo M. Kawakami ,2007*

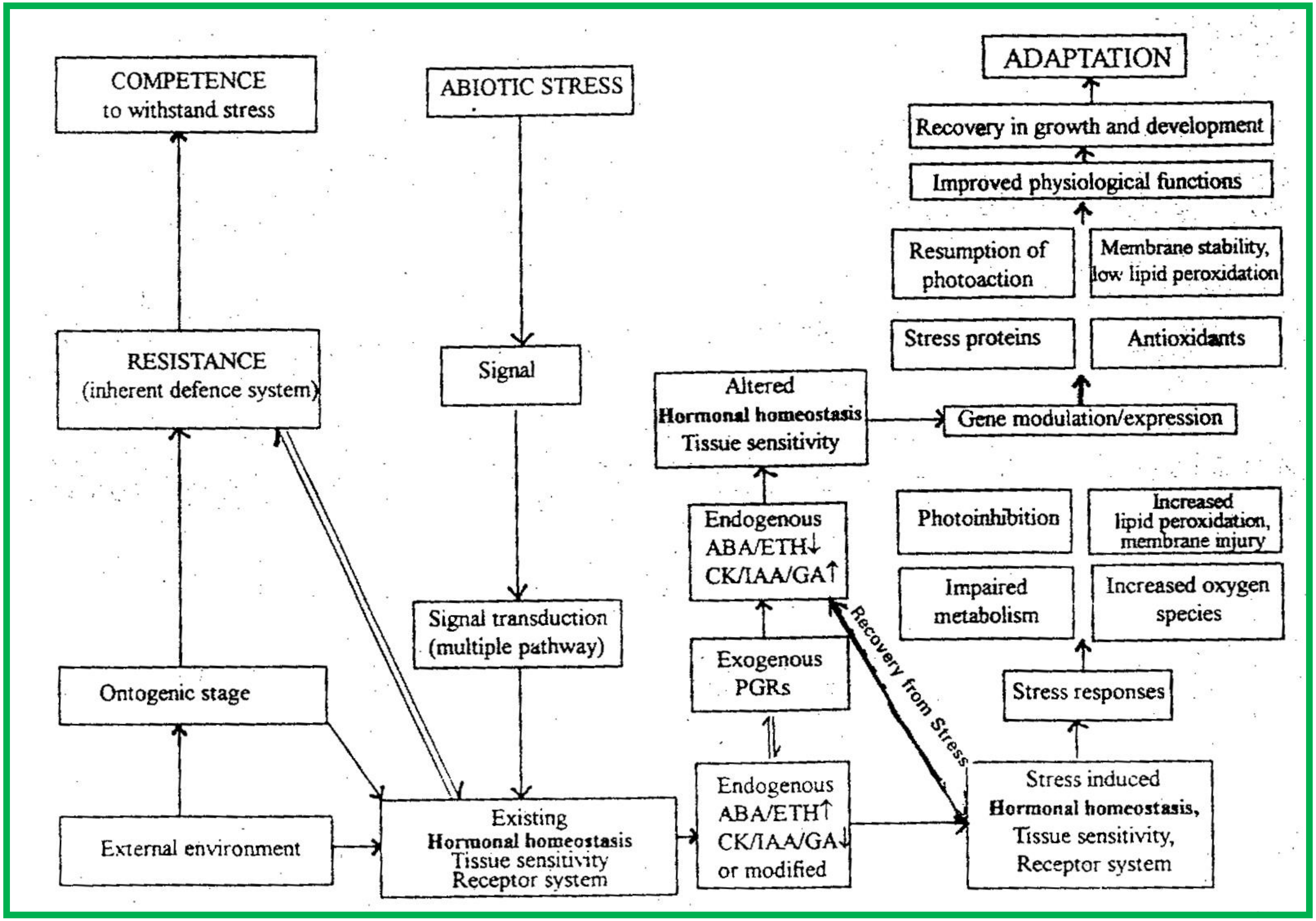
Effect of Ethrel and 1-MCP on Antioxidants in Mango

Postharvest loss due to high temperature

Accelerated ripening affects the quality and nutritional contents of fleshy fruits.

- 1-MCP is applied to delay ripening while ethrel is used to accelerate ripening of climacteric fruits.
- 1-MCP decreased H_2O_2 and lipid peroxidation with increased activities of CAT and SOD while ethrel behaved just opposite
- Activity of ascorbate peroxidase (APX) increased in the presence of Ethrel while 1-MCP led to marginal increase in APX.

Hypothetical scheme for adaptation to stressful environment



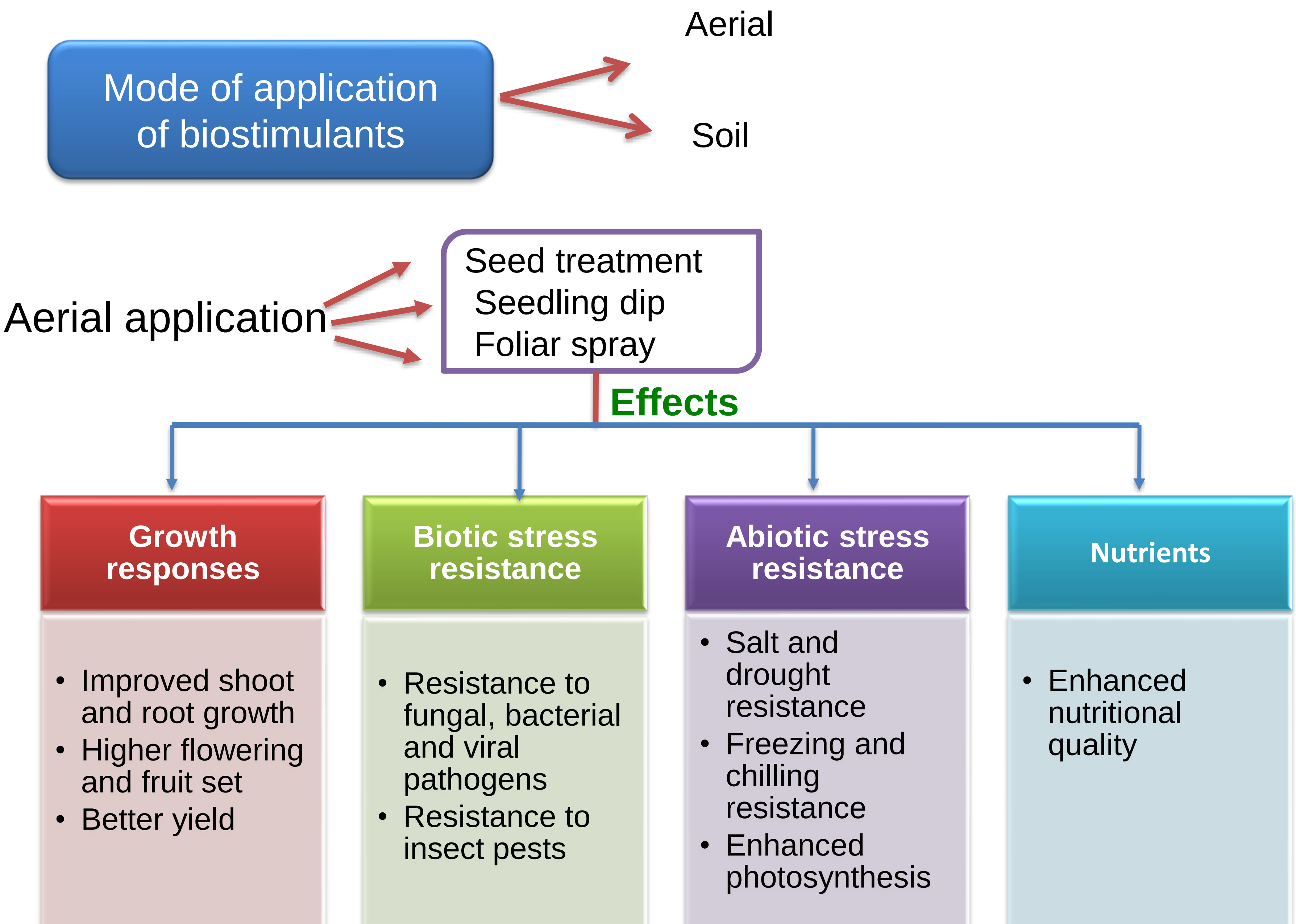
CROPS	PGR	DOSE AND STAGE	BENEFITS
Sunflower	Salicylic acid	200mg L^{-1} Seed treatment	Increased germination percentage and vigour index
Wheat	Strobilurin	250g/L Vegetative stage	Increased water use efficiency , chlorophyll content and yield
Mustard	GA3	100 ppm	Increase in chlorophyll, proline content in leaves, and yield
Barley	Salicylic acid and potassium nitrate	0.5mM SA and 10 mM KNO3 After three weeks	Low MDA contents and decreased Na+/K+ ratio in leaves.
Wheat	Strigolactone and salicylic acid	1 mM and 10 mM Tillering and anthesis stages	Lower electrolyte leakage, higher relative water content, membrane stability index and antioxidants

CROPS	PGR	DOSE AND STAGE	BENEFITS
Apple	Paclobutrazol	250ppm	Reduced water loss, ethylene production and polyamines
Brassica	Epibrassinolide	1 µM at seedling stage	Enhanced seedling tolerance to drought
French bean	Epibrassinolide	1 µm Prior to stress	Increased root nodulation in French bean, due to induction in CK synthesis and nitrogenase
Rice	Putrescine, spermidine, spermine	10 µM Four leaf stage	Improved net photosynthesis, water use efficiency, proline, anthocyanins and CMI
Cotton	GA3	200ppm Vegetative stage	Increased the net photosynthetic rate, stomatal conductance and transpiration rate

Biostimulants and bioinoculants in stress mitigation

Categories

- Humic substances
- Seaweed extracts
- Protein hydrolysates and amino acids
- Chitosan
- Beneficial bacteria
- Beneficial fungi



Mode of application of biostimulants

- Aerial
- Soil

Aerial application

- Seed treatment
- Seedling dip
- Foliar spray

Effects

Growth responses

- Improved shoot and root growth
- Higher flowering and fruit set
- Better yield

Biotic stress resistance

- Resistance to fungal, bacterial and viral pathogens
- Resistance to insect pests

Abiotic stress resistance

- Salt and drought resistance
- Freezing and chilling resistance
- Enhanced photosynthesis

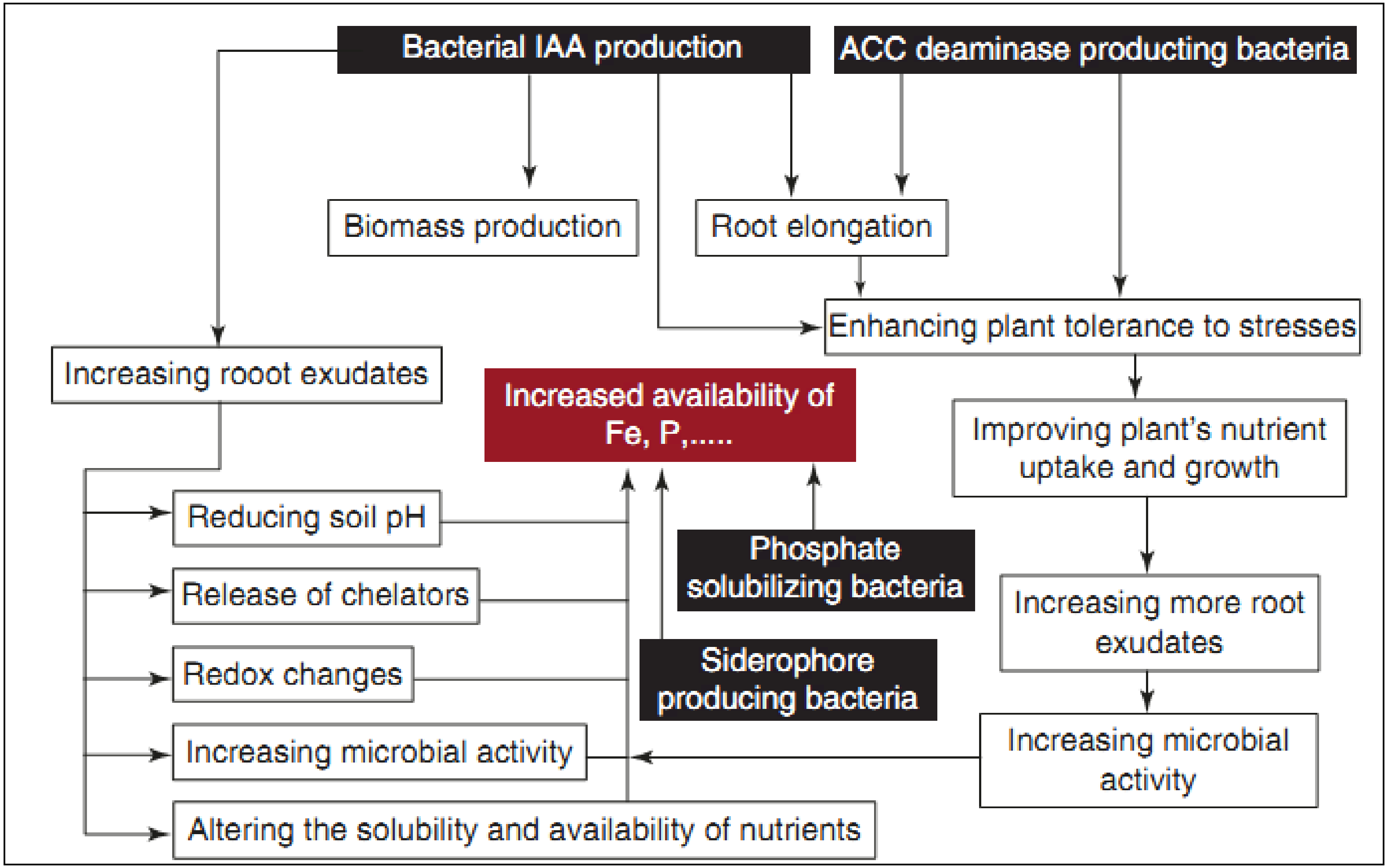
Nutrients

- Enhanced nutritional quality

Beneficial bacteria (PGPR)

- *Pseudomonas*
- *Azospirillum*
- *Anthrobacter*
- *Azotobacter*
- *klebsiella*
- *Burkholderia*
- *Enterobacter*
- *Bacillus*

Schematic representation of mechanisms by which PGPR affect nutrient availability in the rhizosphere (Etesami *et al.* 2015)



Bacterial IAA production

ACC deaminase producing bacteria

Biomass production

Root elongation

Enhancing plant tolerance to stresses

Increasing rooot exudates

Increased availability of Fe, P,.....

Improving plant's nutrient uptake and growth

Reducing soil pH

Phosphate solubilizing bacteria

Release of chelators

Increasing more root exudates

Siderophore producing bacteria

Redox changes

Increasing microbial activity

Increasing microbial activity

Altering the solubility and availability of nutrients

Conclusion

- The concept of abiotic stress is not new to agriculture
- The benefits of modern agriculture rarely reached ecologically challenged regions and that have huge potential for sustaining agricultural productivity
- The current mitigation and adaptation options are insufficient to face the challenges for food security
- There is a need to change the strategy for addressing abiotic stress in agriculture through research, management, capacity building and policy changes to promote innovative and rewarding technologies

Thank you