Salinity stress in date palm (*Phoenix dactylifera* L.): tolerance, mechanisms & mitigation

Horticulture, Environment, and Biotechnology

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Introduction

- **Salinization** of soil and irrigation water is becoming an increasingly serious constraint for the cultivation of fruit crops, especially in arid and semiarid areas.

- **Water scarcity**: pushes decision-makers to adopt water supplies from non-conventional sources: saline water & wastewater.

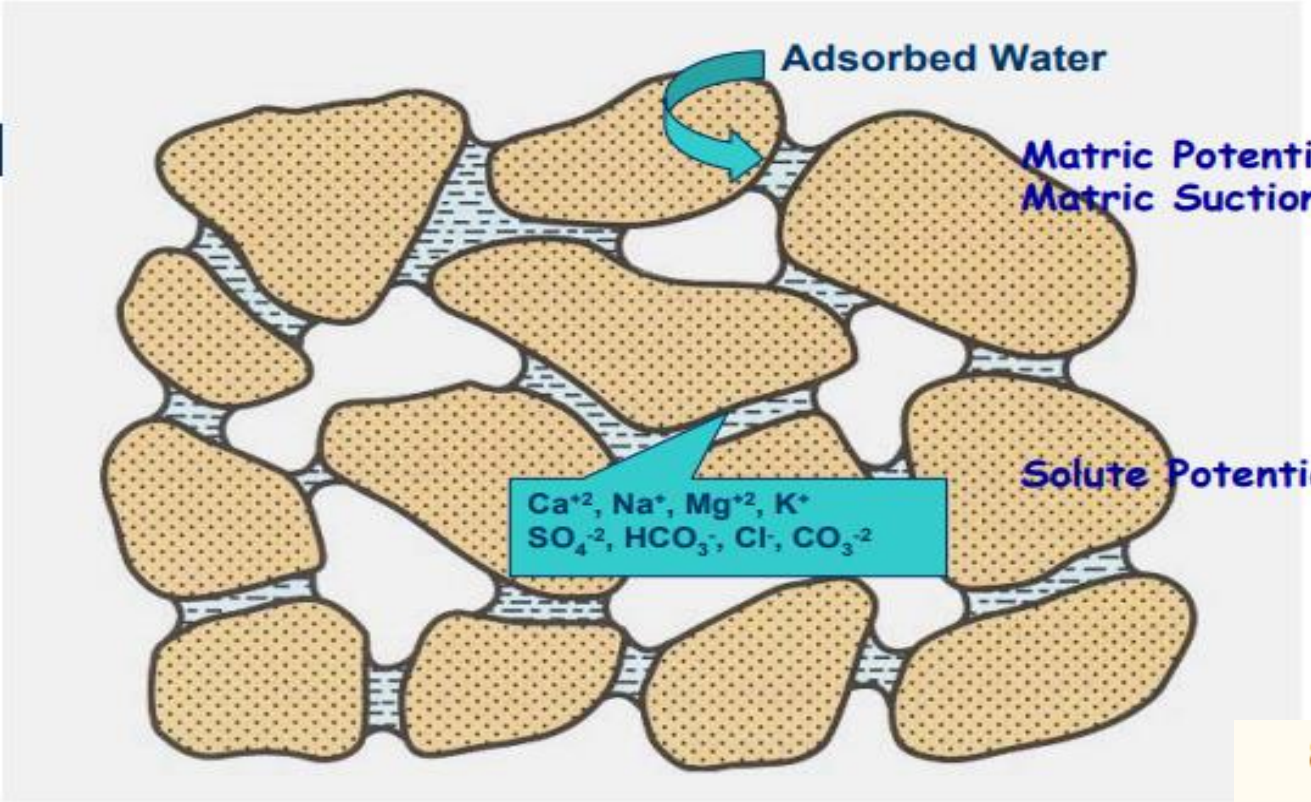
- Use of saline water is one of the alternative sources of irrigation water in Jordan and other Mediterranean countries.

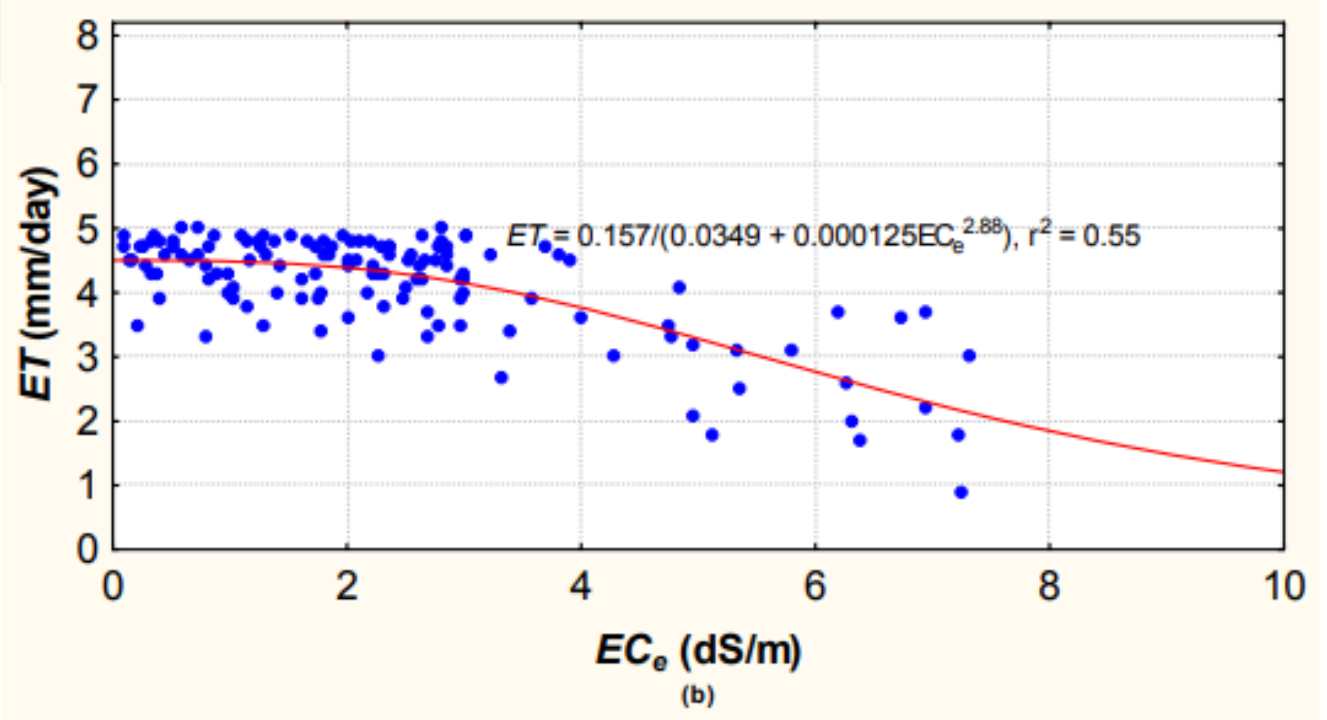
- **Principal criteria of water suitability for irrigation**:

- **Sodicity**
- **Salinity**
- **Alkalinity**
- **Specific ion toxicity.**

- **Effect of salinity of different ionic compositions** on date palm growth and tolerance **is based on:**

➢ Type of salt stress
➢ Stage of growth and development
➢ Osmotic effect
➢ Specific ion toxicity
➢ Nutritional imbalance.


Adsorbed Water
Matric Potential or
Matric Suction
Solute Potential
Ca^{+2}, Na^{+}, Mg^{+2}, K^{+}
SO_4^{-2}, HCO_3^{-}, Cl^{-}, CO_3^{-2}


$ET_c = 0.157/(0.0349 + 0.000125EC_e^{2.88})$, $r^2 = 0.55$
ET (mm/day)
EC_e (dS/m)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
(b)

Classes of irrigation water quality

Class	Ecw (dS/m)	Salinity Level
1	0 - 0.28	Low
2	0.28 - 0.8	Medium
3	0.8 - 2.3	High
4	2.3 - 5.5	Very High
5	>5.5	Extremely High

Salt tolerance

- **Date palm** is classified as a relatively tolerant tree crop
- The extent of tolerance mechanisms in date palm is strongly cultivar-specific.
- **The cyclic use of** saline water and good quality water and avoidance of irrigating trees with high saline water at sensitive stages of growth are good and safer strategies to reduce the negative impact of salt stress.

- In the last twenty years, dates plantations extended in Jordan.
- More expansion is expected in the coming years.
- Most date palm plantations depend on the underground water which is characterized by its high content of Na, Ca, Mg, Cl, SO_4, CO_3^{2-} and HCO_3, that are concentrated, as H2O evaporates, and build up in the soil. In these areas, salinity stress is increased dramatically.

- **Classification of date palm salt tolerance** listed by Maas and Hoffman
- only a **qualitative evaluation** for trees and it was unable to determine the precise salinity threshold and slope.
- Much majority of the investigation quantifying the salinity resistance of date palm has been based on ***in vitro*** or greenhouse studies and conducted by treating the plants with a saline solution using a single salt, usually NaCl, as the salinizing agent, which does not reflect the composition of ordinary irrigation water

Osmotic effect versus specific ion effect

- The soil solution and irrigation water contain Ca, Mg, Na; Cl, SO4, CO_3^{2-} & HCO3-.
- The varied **ionic composition** strongly affected date palm growth & development

- **Influence of salinity on dates**
- Osmotic potential of soil & irrigation water
- Specific toxicity: more suppressive than osmotic stress
- Cl, and Na are more toxic than SO4 and Ca.
- V. little information has been published about specific ion toxicity on palm date
- The extent of salinity stress on date palm varied according to nature of salt used. **$CaCl_2$** caused the lowest reduction followed by **KCl** then **NaCl**.
- Tolerant cvs can restrict the uptake and accumulation of Na and Cl in leaf tissue.
- Nutritional imbalance

Mechanism of salt tolerance

Till date, no sufficient information available mechanism of salinity tolerance in date palm.

- Osmoregulation
- Ion transport and uptake

Shoot Na exclusion

- -Maintaining a high K/Na ratio in the activity growing tissues.
- The mechanism, preventing ions absorption and transport to higher part of the crop.
- - Increase in K/Na ratio is used as good criteria for salt tolerance in *Phoenix dactylifera*
- Ion homeostasis
- Activation of antioxidant molecules and enzymes.
- Morphological, physiological and biochemical influences: increases in root/canopy ratio & chlorophyll content in addition to changes in leaf anatomy.

Xeromorphic leaf properties & minimized stomatal apertures contributed to tolerance

Maas–Hoffman model

معادلة ماس وهوفمان

$$100 - b\,(EC_e - a)$$

- **Where**
- a = the salinity threshold expressed in dS/m;
- b = the slope expressed in percent per dS/m;
- EC_e = EC of a saturated paste taken from the rootzone.

- **Date palm** is classified as a **relatively tolerant** tree crop

- **Salinity threshold**
- The tolerance is described by plotting relative growth or productivity as a function of soil salinity (Maas and Hoffman).
- This response curve could be represented on the basis of two parameters:

a. Salinity threshold (ECt): max. soil salinity without yield reduction

b. Slope (s): fractional yield decline per unit increase in salinity beyond the threshold.

- According to Maas and Grattan (1999) and FAO: date palm tree is considered as salt-tolerant tree with a threshold of 4 dS/m and slope of 3.6 based on fruit yield.
- Maas and Hoffman response doesn't take into account stage of growth, soil type, duration of osmotic duration, ionic composition of salts, moisture level and environmental conditions prevailing during the salt stress.

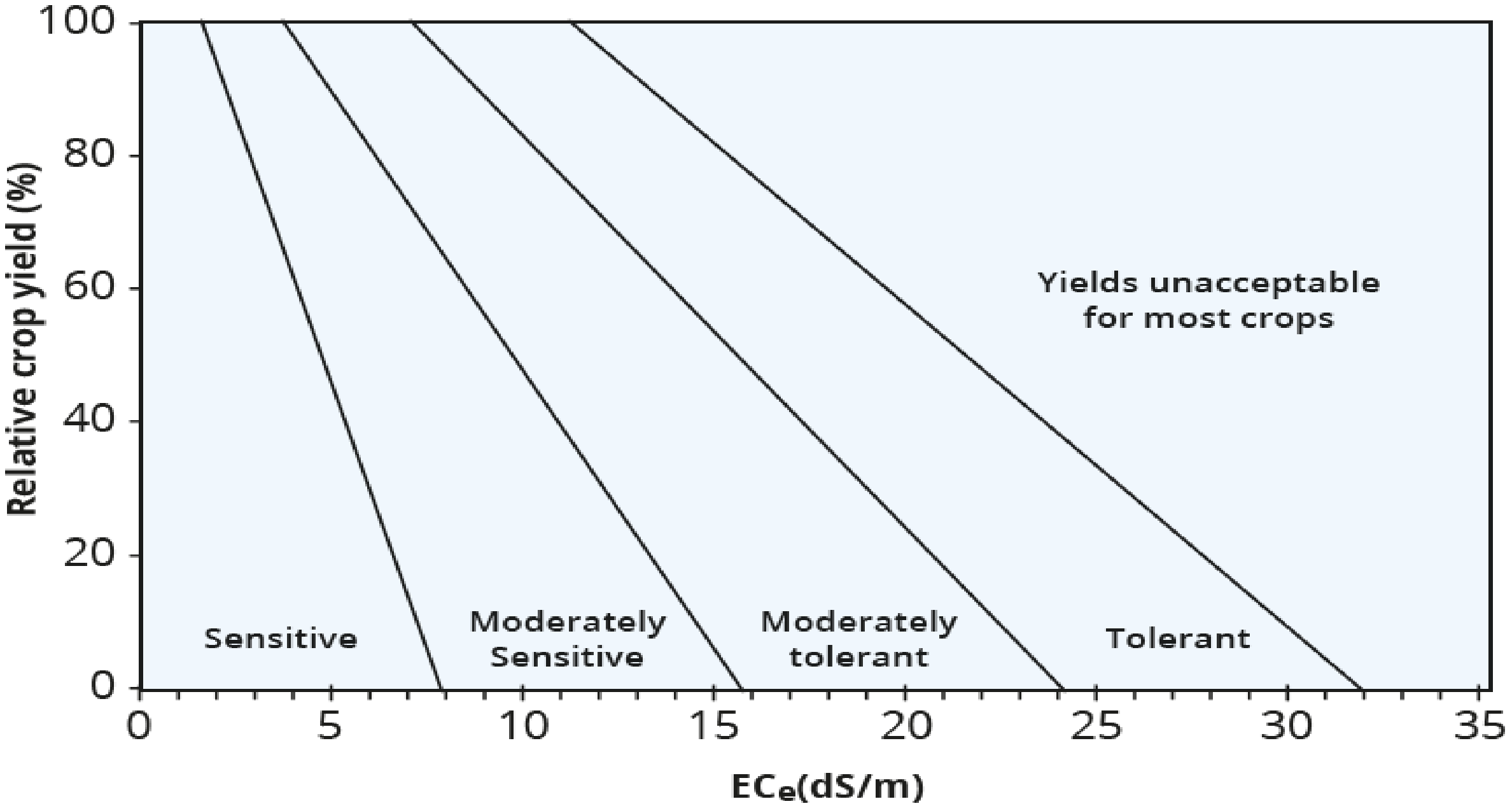
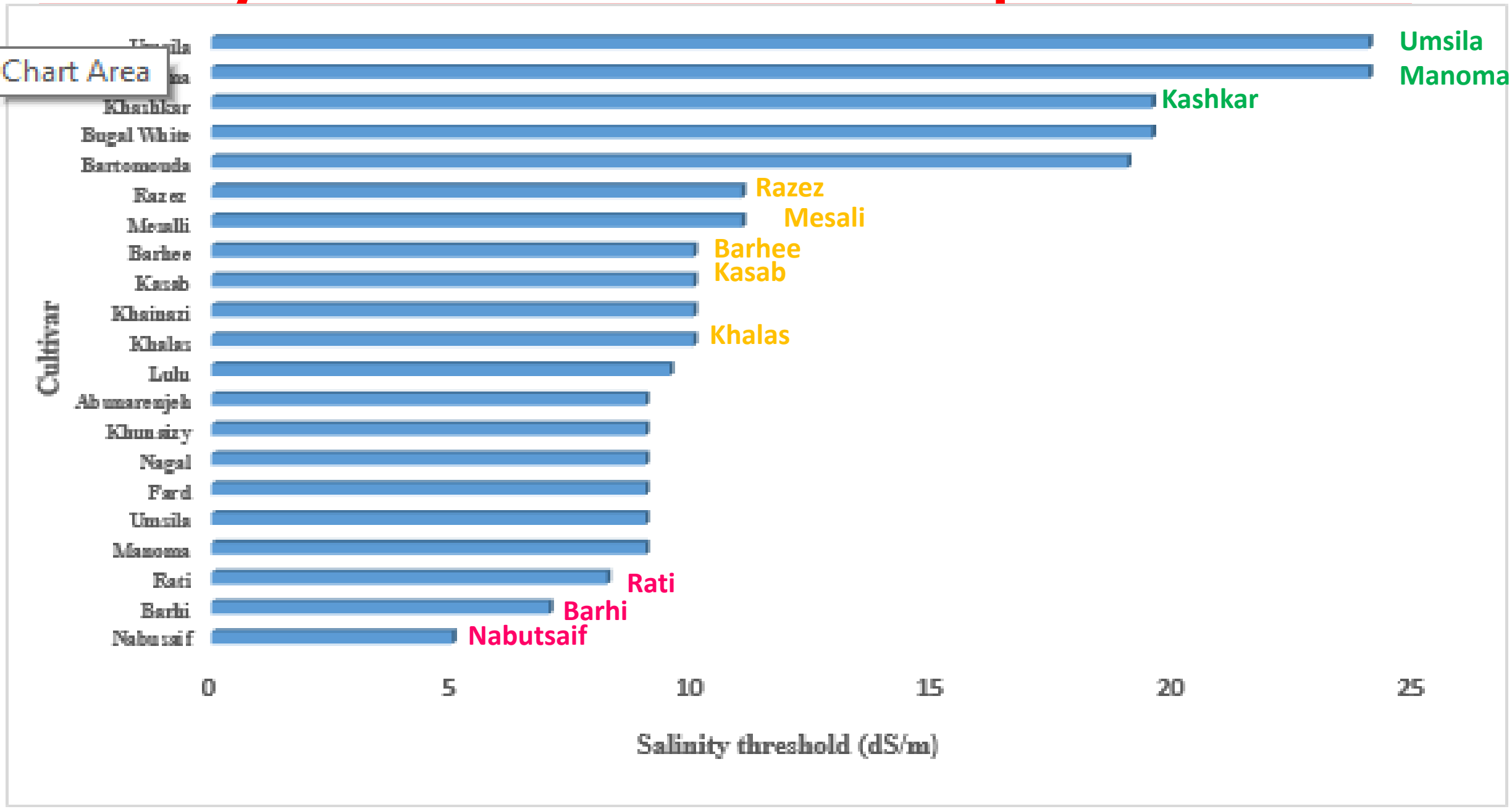


Figure 1. *Division for classifying crop tolerance to salinity (Maas and Hoffman, 1977).*

Salinity threshold of some date palm cultivars



Varietal response to salinity

Table 1: Classification of various date palm cultivars according to their salt-tolerance.

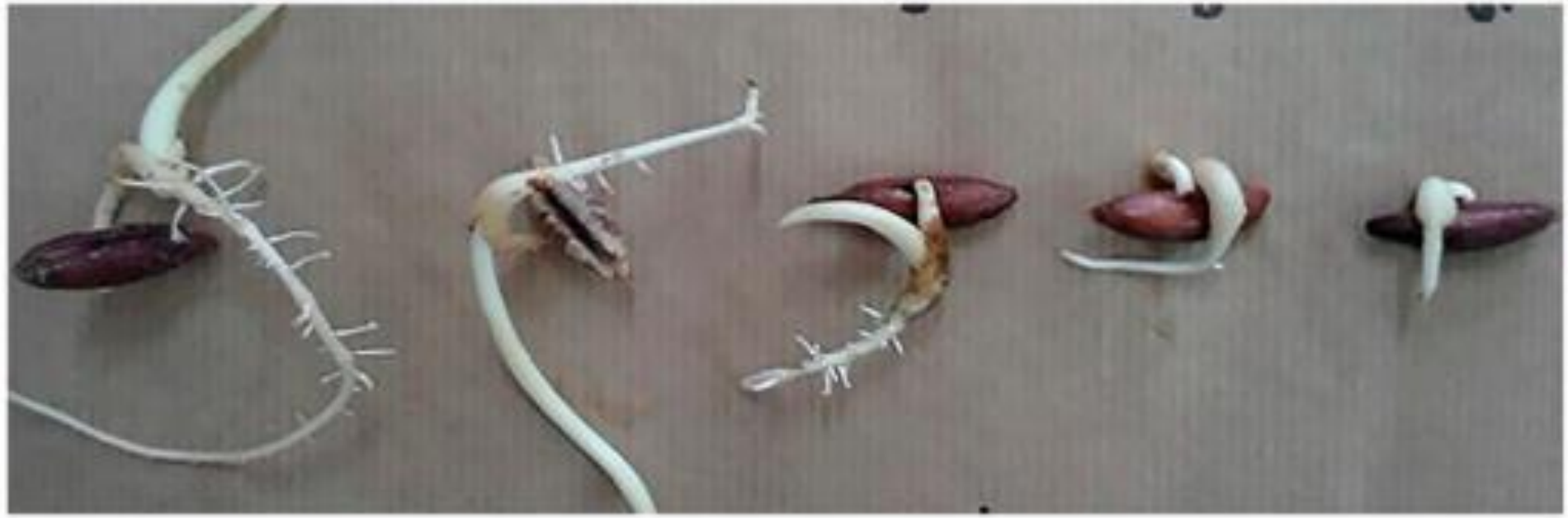
Resistance classification	Cultivar	Country	Parameter used to determine threshold	Source
Sensitive	Nabusaif	Kuwait	Survival % & growth rate	Al-Mulla et al., 2013
	Abunarenja, Nashukhanna, Barni, HilaliOmani, Zahad	Oman	Dry wt. shoots & roots	Al Kharusi et al., 2017
	Mesalli, Razez	UAE	Plant height, girth & Leaves no. le	Kurup et al., 2009
	Rati	India	Seed germination	Ramoliya and Pandey, 2003
	Barhi	Saudi Arabia	Callus diameter	Aldhebiani et al., 2018
		Saudi Arabia	Leaf growth	Abdulhadi, 2001
	Lulu	UAE	Seedling leaf number	Aljuburi, 1992
	Mabroom	Saudi Arabia	Germination% & shoot length	Al-Qurainy et al., 2020
	Madjol	Saudi Arabia	Leaf growth	Abdulhadi, 2001
	Hayany	Egypt	Leaf area, no. branches & yield	Khawaja, 2013
Moderately tolerant	Fard, Nagal	Oman	Dry weight of shoots & roots	Al Kharusi et al., 2017
	Khunaizy, Abunarenjeh	Oman	Seedling height & girth	Alrashi et al., 2010
	Khalas	Saudi Arabia	Callus diameter	Aldhebiani et al., 2018
	Khainazi	Saudi Arabia	Stem & root length	Alturki, 2018
	Kasab, Barhee	Kuwait	Survival % & growth rate	Al-Mulla et al., 2013
	Ajwa	Saudi Arabia	Germination% & shoot length	Al-Qurainy et al., 2020
	Zaghloul	Egypt	Leaf area, no. branches & yield	Khawaja, 2013
Tolerant	Bugal White, Khashkar	UAE	Plant height, collar girth & leaves no.	Kurup et al., 2009
	Manoma, Umsila	Saudi Arabia	Shoot & root dry wt.	Al Kharusi et al., 2017
	Bartomouda	Egypt	Plant height and dry weight of leaves	El-Sharabasy, 2008
	Sewy	Egypt	Leaf area, no. branches & yield	Khawaja, 2013

Analysis of salt stress response in date palm

- **Growth**
- Salinity influences all aspects of development including:

germination, vegetative growth and reproductive development.

- The growth response of date palm to salt stress depends on variety, growth stage, environmental factors, and nature of the salts.
- Seed germination is the most critical stages in the life cycle of date palm.
- Salt-tolerant cvs of date palm displayed a **higher root/shoot** growth and a **higher** growth compared to salt-sensitive cvs
- Limited growth is associated with:
- decrease in gas exchange, including stomatal closure and the inhibition of mesophyll conductance to CO_2 diffusion



Water relations

- **Under salt stress:** Rapid changes in RWC, water retention & leaf Ψ_w .

➢ Salt stress disturbs the tree's water relations due to decreased availability of water from soil solution as a result of lowered Ψs.

➢ RWC was considered a contributing factor in stress sensitivity of date palm cvs.

➢ Reduced RWC retards tree growth under salt stress: dependent on salt type, genotype and exposure duration.

➢ RWC is **higher in tolerant** date palm cvs in comparison with **susceptible ones**

Leaf gas exchange of date palm

- **Osmotic** and/or **specific toxicity** of Na & Cl

1. reduced Photosynthesis.
2. affected stomatal aperture: **ABA enhances** stomatal closure to conserve water
3. Morphological changes
4. CO_2 assimilation rate
5. transpiration
6. stomatal conductance

- ABA accumulation mitigate the inhibitory effect of salinity on photosynthesis & translocation of assimilates.

Fig: % reduction in CO_2 assimilation rate of date palm genotypes

Cultivar	Salinity level (dS m^{-1})	Assimilation reduction (%)	Reference
Abunarenja	24	56.3	Al Kharusi et al., 2017
Barni	24	60.7	Al Kharusi et al., 2017
Farad	24	55.1	Al Kharusi et al., 2017
HilaliOmani	24	60.0	Al Kharusi et al., 2017
Khalas	24	59.3	Al Kharusi et al., 2017
Manoma	24	38.7	Al Kharusi et al., 2017
Nagal	24	55.6	Al Kharusi et al., 2017
Nashukharma	24	60.7	Al Kharusi et al., 2017
Umsila	24	45.5	Al Kharusi et al., 2017
	20	33.3	Al Kharusi et al., 2019
Zabad	24	69.6	Al Kharusi et al., 2017
	20	51.8	Al Kharusi et al., 2019
Lulu	30	12.2	Youssef & Awad, 2008
Madjool	20	31.3	Al-Abdoulhadi et al., 2012
Barhi	20	39.6	Al-Abdoulhadi et al., 2012
Khalas	20	26.5	Al-Abdoulhadi et al., 2012

Biochemical constituents

- Osmoregulation is a common adaptive response to salinity and ion toxicity.
- Stressed date palms accumulate osmotically active compounds: sugars, mannitol, glycine betaine and proline.
- A dramatic accumulation of leaf proline content in date palm upon exposure to osmotic stress .
- The **main role** of these compounds in stress is mitigation involves scavenging of ROS, osmoprotection, and carbon storage.
- **Proline** is the most prevalent a.a and org. solute accumulated at osmotic stress.
- Proline is used as a **biochemical marker** in selection date palm tolerant to salt stress.
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Oxidative stress

- Under normal conditions, plant cells produce ROS in peroxisomes, mitochondria, and the cytoplasm either in a radical or non-radical form.
- **Salinity stimulate oxidative stress** which induces production of ROS, such as hydrogen peroxide (H_2O_2), hydroxyl-radical (OH^-), superoxide-radical (O^-_2), and singlet-oxygen ($^1O_2$) to regulate ROS homeostasis.
- ROS have an injurious effect on cell organelles and tissues.
- ROS leads to oxidative damage to the proteins, nucleic acids, degradation of membrane lipids through peroxidation; leading to electrolyte leakage.
- Date palm develop complex defense mechanism involving enzymatic antioxidants (catalase (CAT), glutathione (GSH), superoxide dismutase (SOD), ascorbate peroxidase (APX) and guaiacol peroxidase (GPX)) & non-enzymatic antioxidants (ascorbate, carotenoids, flavonoids and other phenolics) to mitigate the deleterious effects of oxidative damage.
- Non-enzymatic and enzymatic components **scavenge or detoxify** excessive ROS

Hormone regulation

- **ABA** alleviates the adverse influence of salinity stress.
- **SA** is an important signal molecule for mitigating dates trees response to salinity .
- Growing date palm in saline environments reduces promoter's (IAA, GA_3 and Zeatin) & increases inhibitors (mainly ABA), and in turn led to inhibition of growth and development .

Mitigation of salt stress in dates

- Agronomic practices : mulching, balanced nutrition, deep plowing and application of green manure.
- Exogenous application of yeast and amino acids
- arbuscular mycorrhizal fungi & compost separately or in combination
- Supplemental Ca^{2+} by competing with Na for membrane-binding sites and maintaining high ratio of K/Na and regulating levels of IAA to ABA
- Application of humic acid
- Elemental Sulphur
- Actinomycetes
- Citric acid

Conclusion

- Date palm evolved regulatory mechanisms to adapt salt stress.
- Understanding mechanisms of salt stress tolerance in date palm is necessary to optimize WUE.
- Cultivation of salt-tolerant cvs is the most effective way to overcome salinity.
- Develop. salt-tolerant genotypes is a promising solution.
- Molecular mechanism of salt adaptation remains to be elucidated.
- Further investigation is required to identify integration of morphological, physiological & molecular approaches for salinity tolerance among date palm genotypes.