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N Deepa Devi
Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

T Arumugam
Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Correspondence
N Deepa Devi
Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Salinity tolerance in vegetable crops: A review

N Deepa Devi and T Arumugam

Abstract

Vegetables are one of the most important crops in human nutrition. Worldwide vegetable cultivated area has increased at about 25% during the last 10 years. Now-a-days salinity is one of the major abiotic stresses that reduce seed germination, plant growth and crop productivity. Ensuring adequate food production is the major issue in the context of an increasing human population, limit to the areas of new land that can be cultivated and loss of existing cultivated lands to abiotic stresses. Of these stresses, salinity consistently has the greatest impact in reducing the area of cultivated land, often due to inappropriate irrigation techniques. To increase food supply, there is a need to produce salt-tolerant crops, which can grow successfully on salt-affected lands. Among crops, vegetables possess a central position in the human diet because of their nutritional value providing vitamins, carbohydrates, proteins, and mineral nutrients. There are many vegetable crops of local importance around the world but others that are very widely cultivated. All of these vegetable crops are affected by salinity more or less severely. Like other crops, considerable crop to crop variation in vegetable crop salinity tolerance has been reported (Maas, 1990). Salinity affects every aspect of vegetable crop development including their morphology, physiological function and yield. Although efforts have been made to understand the mechanisms of salt tolerance in vegetable crops, less attention has been paid to these than to the staple crops. Where attempts have been made to improve salt tolerance of vegetables, the strategies have ranged from exogenous application of fertilizers, compatible solutes or plant growth regulators, plant growth promoting rhizhobacteria, grafting, development of new varieties with tolerance and gene introgression from wild species to use of advanced molecular techniques for genetic modifications. This article focuses on the responses of different vegetables crops to salt stress and the strategies being used to enhance their salt tolerance.

Keywords: Salinity tolerance, vegetable crops

Introduction

Accumulation of excess salt in the root zone resulting in the partial/complete loss of soil productivity is a worldwide phenomenon. The problems of soil salinity are most wide spread in the arid and semi arid region but salt affected soil also occurs extensively in sub-humid & humid climates, particularly in the coastal regions where the ingress of sea water through estuaries and rivers and through ground water causes large scale salinization. Soil salinity is also a serious problem in areas where groundwater of high salt content is used for irrigation. It is a major challenge to crop plants and which limits agriculture all over the world, particularly on irrigated farmlands (Rausch *et al.*, 1996) [30]. Salinization of soils leads to soil degradation and reduced crop productivity on a global scale. (Acosta *et al*., 2011) [2]. Salt stress is one of the most brutal environmental factors limiting the productivity of vegetable crops because most of the vegetable crops are glycophyte in nature. Salt tolerance is important in vegetables because of their cash value. One-third of the land being irrigated worldwide is affected by salinity (Allen *et al.*, 1994) [4]. Microorganisms could play a significant role in this respect, if we exploit their unique properties such as tolerance to saline conditions, genetic diversity, synthesis of compatible solutes, production of plant growth promoting hormones, bio-control potential, and their interaction with crop plants. Ensuring adequate food production is a major issue in the context of an increasing human population. Salinity consistently has the greatest impact in reducing the area of cultivated land, often due to inappropriate irrigation techniques. To increase food supply, there is a need to produce salt-tolerant crops, which can grow successfully on salt affected lands. Among crops, vegetables possess a central position in the human diet because of their nutritional value providing vitamins, carbohydrates, proteins, and mineral nutrients. Salinity affects every aspect of vegetable crop development including their morphology, physiological function and yield. The development of salt-tolerant cultivars normally requires the transfer of several genes due to the multigenic character of plant resistance or tolerance to this abiotic stress (Bonhert and Jensen, 1996) [11]. Pending the release of new genetically-enhanced material, with improved salt tolerance, grafting techniques may represent a quick and it’s reduce the deleterious effects of salt stress on vegetable crops.

This chapter highlights salinity, sodicity, effect of salinity stress on crop plants and mechanism of salt tolerance specific to several vegetables with the latest updates.

Salinity

Salinity is derived from the Latin word Salinium meaning "salt cellar" and ity meaning "condition or quality of being”. Salinity refers to the presence of soluble salts in soil or water. Plant salt tolerance or resistance is generally the inherent ability of the plant to withstand the effects of high salts in the root zone or on the plant's leaves without a significant adverse effect (West, 1978) [36]. Salt is naturally present in soils, surface water and groundwater systems. The most common salt causing salinity is sodium chloride, but there may be a range of other salts such as magnesium, calcium or potassium.

Salt affected areas

Salt affected areas are one of the most important degraded areas where soil productivity is reduced due to either salinization (EC> 4dS/m) or sodicity (ESP>15) or both. The soils with EC more than 2 dS/m in black soils and >4 dS/m in non-black soils was considered as saline in the present situation. Soils with soil pH more than 8.5 results in increase of exchangeable sodium percentage (ESP) in soils (>15) and are termed as sodic. Based on the type of problem, it has been divided into saline, sodic and saline-sodic.

Saline soils

Saline soils contain enough soluble salts to injure plants. They are characterized by white or light brown crusts on the surface. Saline soils usually have an EC of more than 4 mmho cm^{-1}. Salts generally found in saline soils include NaCl (table salt), $CaCl_2$, gypsum ($CaSO_4$), magnesium sulfate, potassium chloride and sodium sulfate. The calcium and magnesium salts are at a high enough concentration to offset the negative soil effects of the sodium salts. The pH of saline soils is generally below 8.5. The normal desired range is 6.0 to 7.0, but many soils are naturally 7.5 to 8.3. Leaching the salts from these soils does not increase the pH of saline soils.

Saline sodic soils

Saline-sodic soils are like saline soils, except that they have significantly higher concentrations of sodium salts relative to calcium and magnesium salts. Saline-sodic soils typically have an EC of less than 4 mmho cm-1, and the pH is generally below 8.5. The exchangeable sodium percentage is more than 15 percent of the cation exchange capacity (CEC). CEC is a measure of the soil’s capacity to hold cations, namely, calcium, magnesium, potassium, sodium, hydrogen and aluminum. The higher the CEC, the more problematic the removal and remediation of the salt problem. Water moves through these soils much as it does in saline soils, although the steps for correcting saline-sodic soil are different. Simply leaching the salts from this soil will convert it from saline-sodic to sodic soils.

Sodic soils

Sodic soils are low in soluble salts but relatively high in exchangeable sodium. Sodic soils are unsuitable for many plants because of their high sodium concentration, which may cause plant rooting problems, and because of their high pH, which generally ranges from 8.5 to 12.0. These high sodium levels disrupt both the chemical and physical composition of soil clays. As a result, the soil surface has low permeability to air, rain and irrigation water. The soil is sticky when wet but forms hard clods and crusts upon drying. This phenomenon may not occur in very sandy soils because they lack clay content.

Table 1: Salt affected area in India

S. No.	State	Saline soils (ha)	Alkali soils (ha)	Coastal saline soil (ha)	Total (ha)
1	Andhra Pradesh	0	196609	77598	274207
2	A & N islands	0	0	77000	77000
3	Bihar	47301	105852	0	153153
4	Gujarat	1218255	541430	462315	2222000
5	Haryana	49157	183399	0	232556
6	J & K*	0	17500	0	17500
7	Karnataka	1307	148136	586	150029
8	Kerala	0	0	20000	20000
9	Maharashtra	177093	422670	6996	606759
10	Madhya Pradesh	0	139720	0	139720
11	Orissa	0	0	147138	147138
12	Punjab	0	151717	0	151717
13	Rajasthan	195571	179371	0	374942
14	Tamil Nadu	0	354784	13231	368015
15	Uttar Pradesh	21989	1346971	0	1368960
16	West Bengal	0	0	441272	441272
Total		1710673	3788159	1246136	6744968

(CSSRI, 2010) [24]

The major source of salinity problems is usually irrigation water. This is a gradual process the salts must accumulate over time before any effects are seen. Fortunately, plants take up many salts in the form of nutrients. But when more salt is added to the soil than is removed, the plants will eventually be affected. In some soils, irrigation and rainwater move through the soil to leach out the salinity. Leaching occurs when water moves materials (such as salts or organic materials) downward through the soil. Several soil factors can inhibit leaching, high clay content, compaction, very high sodium content or a high water table. Salt problems occur when water remains near the surface and evaporates and when salts are not dissolved and carried below the root zone. Soils naturally high in soluble salts are usually found in arid or semi-arid regions, where salts often accumulate because there is not enough rainfall to dissolve them and leach them out of the root zone. Salt spray near coastlines can also cause salts to build up in the soil. In areas with shallow water tables, water containing dissolved salts may move upward into the rooting zone. This occurs by capillary action (similar to the way a wick works), where evaporation serves as the suction of water up through the soil. Water moves the farthest through finer clay and clay loam soils; it moves less in medium-textured soils (loams) and least in coarser, sandy soils.

Table 2: Properties of seawater and of good quality irrigation water

Property	Seawater	Irrigation water
Concentration of ions (mM)		
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)	32000	500

Effects of salinity stress on crop plants

Salinity slows germination rate at low concentration and at higher concentration reduces germination percentage. This effect may be due to anaerobic conditions that cause failures in active transport and exclusion processes in the root membrane. Single salt solutions have differential effects on germination, but mixed salts give more uniform responses and are predominantly related to osmotic potential. Salinity often affects the timing of development. Flowering in onions occurs earlier under salt stress, but salinity delays flowering of tomato. Yield components and growth parameters also show differential responses to salinity stress. At low salinities root growth is often less affected, or sometimes even stimulated by salinity, as compared to shoot growth. Aboveground growth of turnip (Francois, 1984) [20] and carrot (Bernstein and Ayers, 1953) [10] was more sensitive to salinity than root growth. Asparagus spear yield was less affected by salinity than fern production (Francois, 1987) [21], and salinity inhibited artichoke bud growth more than shoot growth (Francois, 1995) [22].

The general effect of salinity is to reduce the growth rate resulting in smaller leaves, shorter stature, and sometimes fewer leaves. The initial and primary effect of salinity, especially at low to moderate concentrations, is due to its osmotic effects (Jacoby, 1994) [25]. Roots are also reduced in length and mass but may become thinner or thicker. Maturity rate may be delayed or advanced depending on species. The degree to which growth is reduced by salinity differs greatly with species and to a lesser extent with varieties within a species. The severity of salinity response is also mediated by environmental interactions such as relative humidity, temperature, radiation and air pollution high concentrations of Na^+ or Cl^- may accumulate in leaves and result in `scorching' or `firing' of leaves; whereas, nutritional deficiency symptoms are generally similar to those that occur in the absence of salinity. Calcium deficiency symptoms are common when Na/Ca ratio is high in soil water.

All salinity effects may not be negative, salinity may have some favorable effects of yield, quality, and disease resistance. In spinach, for example, yields may initially increase at low to moderate salinity (Osawa, 1963) [28]. Sugar content increase in carrot and starch content decreases in potatoes as salinity increases (Bernstein, 1959) [9], cabbage heads are more solid at low salinity levels, but are less compact as salinity increases (Osawa, 1961) [27]. Celery has been reported to be both more resistant and more susceptible to blackheart (Aloni and Pressman, 1987) [5].

As soils become more saline, plants become unable to draw as much water from the soil. This is because the plant roots contain varying concentrations of ions (salts) that create a natural flow of water from the soil into the plant roots. As the level of salinity in the soil nears that of the roots, however, water becomes less and less likely to enter the root. In fact, when the soil salinity levels are high enough, the water in the roots is pulled back into the soil. The plants become unable to take in enough water to grow. Each plant species naturally contains varying levels of root salts. This is why some plants can continue to thrive when others have died. If the salinity concentration in the soil is high enough, the plant will wilt and die, regardless of the amount of water applied.

Effect of salt stress in plants

Excess accumulation of Na^+ and Cl^- in chloroplast inhibit photosynthesis. The carbon metabolism and photophosphorylation get affected, this resulted in reduction in photosynthesis. Therefore the plant growth and productivity get affected.

Mechanism of salt tolerance

The inherent ability of the plant to withstand the effects of high salts in the root zone or on the plant's leaves without a significant adverse effect. Plants avoid toxic salt effects either by restricting ion uptake in to the shoots and then making necessary osmotic adjustments or by allowing osmotic regulation through ion uptake and then adjusting to high salt concentration in the green tissues. A certain proportion of photosynthate normally directed towards growth and must be diverted to salinity responses. The higher respiration rate noted for salt affected plants is a result of increased energy needed to maintain homeostasis.

In root salt may enter root membranes either passively or by active transport against concentrate gradients. Ion passage has been showed to selectively regulated across plasmolemma, tonoplast or in to specialized cells along with xylem parenchyma. Certain ion specific ATP's that regulates this ion movement are affected by concentration of other ions. Thus species and even cultivars may differ in their capacity to regulate ion.

Under saline condition plants synthesize and accumulate the osmotic substances in response to salinity stress. The amino acid proline, organic acids such as malate and oxalate, and other compounds such as choline, betaine have been investigated as possible osmotic agents in higher plants. Soluble carbohydrate may also be selectively accumulated in response to osmotic stress.

Table 3: Vegetable crops classified based on tolerance to soil salinity

Less tolerant	Mod. tolerant	Highly tolerant
✓ Pea	✓ Tomato	✓ Asparagus
✓ Radish	✓ Chilli	✓ Beet
✓ Snake gourd	✓ Watermelon	✓ Kale
✓ Beans	✓ Cumber	✓ Turnip
✓ Brinjal	✓ Summer squash	✓ Bitter gourd
✓ Sweet Pepper	✓ Bottle gourd	✓ Ash gourd
✓ Potato	✓ Cabbage	✓ Palak
✓ Sweet Potato	✓ Cauliflower	✓ Lettuce
	✓ Broccoli	
	✓ Muskmelon	
	✓ Onion	

Approaches to overcome salinity problem

Some of the approaches to overcome the salinity problem are by improving the drainage, leaching, application of chemicals, development of salt-tolerant cultivars by breeding approaches, grafting of high yielding crops onto resistance rootstock.

Table 4: Management of salinity

Management methods	Application in vegetables	Reference
Salt leaching	Bell peppers-higher the salinity of the irrigation water the higher the leaching process	Ben *et al*., 2008 [7]
Primer and companion plants	Pepper- *Salsola soda* used as a companion plant	Colla *et al*., 2006 [13]
Soil mulching	Swiss chard-Mulching with gravel, rice straw improving crop yield	Zhang *et al*., 2008 [37]
Potassium	Potato -increased tuber yield	Elkhatib *et al*., 2004 [17]
Calcium	Tomato and Pepper-reduces blossom end rot and increase fruit quality & yield.	Rubio *et al*., 2009 [31]
Nitrogen	1mM ammonium and 7mM nitrate -minimizing salinity effects on fruit yield	Ben-Oliel *et al*., 2004 [8]
Phosphorus	Radish-reduced the sensitivity to salinity up to a level of 3.5 dS m−1	De Oliveira *et al*., 2010 [14]
Sulfur	Brassica and legume crops- increased salinity stress-defense mechanisms	Rausch and Wachter. 2005 [29]
Zinc	Pepper-Zn reduced excess uptake of Na under saline conditions	Aktas *et al*., 2006 [3]
Biofertilizers	Lettuce-Phosphorine and Nitrobein increases proline and glycine contents	Hasaneen *et al*., 2009 [23]
Manures	Pepper -humic acid was dampen the deleterious effects of salt stress	Cimrin *et al*., 2010 [12]
Application of non-nutritional additives	Spinach under salinity increases the activities of SOD and CAT	Eraslan *et al*., 2008 [19]
Elevated CO2 concentrations	Tomato-increasing aerial CO2 concentration, Alleviate the negative salinity effects	Takagi *et al*., 2009 [34]
Relative humidity	Melons-cultivar grown in salt stress well at 70% than at 30% relative humidity	An *et al*., 2005 [6]
Inoculation with bacteria	Inoculation of artichoke -Bacillus subtilis alleviated the adverse effects of salinity and increased productivity	Saleh *et al*., 2005 [32]
Seed priming	Melon seeds with 18 dS m−1 NaCl solution decreases the negative effects of irrigation with saline water.	Sivritepe *et al*., 2005 [33]
Grafting to tolerant rootstocks	Combinations of melon & pumpkin rootstocks, pumpkin exclude 74% of available Na, while there is nearly no Na exclusion by melon rootstocks	Edelstein *et al*., 2011 [16]
Application of non-enzymatic antioxidants	In bean plants, found that addition of 100 mM ascorbic acid to the nutrient solution alleviates the adverse effects of salinity	Dolatabadian and Jouneghani. 2009 [15]
Application of plant growth regulators	Tomato-Application of 0.5 mM Salicylic acid- facilitates the accumulation of Na in the plant tissues to function as osmolytes	Tari *et al*., 2002 [35]
Compatible solutes	Brinjal- Exogenous application of glycinebetaine (GB) leads to increased growth and yield	Abbas *et al.,* 2010 [1]
Foliar application of nutrients	Brinjal-K_2HPO_4 increased fruit yield	Elwan, 2010 [18]

Conclusion

Among crops, vegetables possess a central position in the human diet because of their nutritional value providing vitamins, carbohydrates, proteins, and mineral nutrients. Now-a-days salinity is one of the major abiotic stresses that reduce plant growth and yield. Salinity affects every aspect of vegetable crop development including their morphology, physiological function and yield. Where attempts have been made to improve salt tolerance of vegetables the strategies have ranged from develop salt tolerance variety generally traditional breeding methods are followed, so along with it biotechnological approaches can also be used, the salt affected area can be brought under cultivation by cultivating salt tolerance varieties, grafting of tolerant root stock to overcome the salt stress.

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