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Perspectives of Salinity Tolerance of Some Crops: A Review

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Abstract

Salinity affects crop productivity in one-fifth part of irrigated agriculture in the world. A brief review has been made on salt tolerance of some field and vegetable crops including major cereals, sunflower and cotton. Sufficient research inputs have been directed on research on salinity in different areas such as ameliorations, its effects on growth and productivity, physiological and biochemical changes, its mechanism of resistance and biotechnology. This review gives a brief account of the adavances on salinity tolerance in several crops *viz.* sorghum, pearl millet, maize, rice, wheat, sunflower, cottons and some vegetable crops. Increasing salinity decreases germination, emergence, seedling establishment, growth and crop productivity. In general, salinity stress causes physiological and biochemical changes depending on crops such as decrease in relative growth rates, K concentrations and leaf osmotic potential values, as well as an increase in Na, soluble sugar contents, proteins, amino acids, proline, glycine betaine, and other osmolytes which help in osmotic adjustment.

There are several antiporters (proteins) present in cell membrane such as Na^+/H^+, Na^+/K^+ operating which does not allow Na^+ and exclude it, but permits K^+ or H^+ to enter thereby maintaining balance. Among the most common effects of salinity is the growth inhibition by Na^+ toxicity. Vacuolar Na^+/H^+ antiporters have been suggested to be involved in sequestering Na^+ into vacuoles, thus preventing toxic effects of Na^+ in the cytoplasm. Compartamentation and sequestring of Na^+ and Cl^- in the vacuole increases osmotic pressure in the cell. A major component of tissue tolerance is the capacity to compartmentalize salt into safe storage places such as vacuoles. This mechanism would avoid toxic effects of salt on photosynthesis and other key metabolic processes. The maintenance of photosynthetic capacity (and the resulting greater salt tolerance) at higher leaf Na^+ levels is associated with the maintenance of higher K^+, lower Na^+ and the resulting higher K^+:Na^+ in the cytoplasm of mesophyll cells. It has been reported that the response of salinity tolerance appears similar to that of water stress. Salt tolerant plants differ from salt-sensitive one for low rate of Na^+ and Cl^- transport to leaves, and the ability to compartmentalize these ions in the vacuoles thereby preventing their accumulation in the cytoplasm and avoiding toxicity and metabolic disorder.

***Key words*: Salt tolerance, salinity, crops, genotypic variability, amelioration, osmotic adjustment, biotechnology.

Introduction

Over 800 millions (m) ha of land throughout the world are affected with salt either by salinity (397 mha) and the rest is associated with sodicity (434 mha) (FAO, 2005). The excess of salt content is one of the major concerns with water used in irrigation. Salinity is one of the major abiotic stress factors affecting the growth and productivity as well as quality of several crops. The quality of the irrigation water plays an essential role especially in arid zones affected by high evaporation rates and the accumulation of salt on the soil surface. A high salt concentration present in the water and soil affect adversely the crop yield, degrade the land and pollute ground water. The suitability of water reuse for irrigation with high salt content depends on various factors such as salt tolerance of the crop species, physical and chemical characteristics of soil under irrigation, and climate conditions. About 20% of irrigated agriculture in the world is adversely affected by salinity (Flowers and Yeo, 1995). It is stated that irrigation has contributed to about 20-27% of the land affected with salt and the rest up to 37% may be saline, sodic or waterlogged (Ghasemi *et al.*, 1995). The problem of soil salinity is increasing futher for the use of poor saline water for irrigation and poor drainage. According to the USDA salinity research laboratory, saline soil is defined as soil having an electrical conductivity (EC) of saturated paste extract of 4 dS m^{-1} (40 µM NaCl) or more. Most of the grain crops and vegetables are highly susceptible to soil salinity even when the soil EC is < 4 dS m^{-1}. The susceptibility of crops is determined by their salinity threshold value varying greatly in mechanism of salt tolerance among crop species (Maas, 1990 cited by Chinnusamy *et al.*, 2005). Adverse effects of salinity on plant growth may be due to ion cytotoxicity (mainly due Na^+, Cl^- and SO_4^{2-}) and osmotic stress (Zhu, 2002). It is recommended water reuse for irrigation purpose mus thave a low to medium salinity level (*i.e.*, EC of 0.6 to 1.7 dS m^{-1}).

For agricultural plants, sensitivity to salinity is commonly (but not exclusively) due to the abundance of Na^+ in the soil as excess Na^+ is toxic to plants (Zhang *et al*., 2010). These authors consider reducing Na^+ uptake to be the key, as well as the most efficient approach, to control Na^+ accumulation in crop plants and hence to improve their salt resistance. Understanding the mechanism of Na^+ uptake by the roots of higher plants is crucial for manipulating salt resistance. In this review, it is highlighted and discussed recent advances in the understanding of the mechanisms of Na^+ uptake by plant roots at both physiological and molecular levels. It is concluded that continued efforts to investigate the mechanisms of root Na^+ uptake in higher plants are necessary, especially that of low-affinity Na^+ uptake, as it is the means by which sodium enters into plants growing in saline soils.

Knowing the gravity of salinity, there is evidence that the farmers replace salt-sensitive crops with salt tolerant ones such as wheat (*Triticum aestivum*) was replaced by salt tolerant barley (*Hordeum vulgare*) in Ethiopia (Marr, 1967 cited by Mann, 1997). Substitution of salt-tolerant crop species is practiced throughout the world. In this respect it may be mentioned that sugar bee, barley, cotton, asparagus, sugarcane and dates are very salt tolerant. Breeders are putting attentions in improving salt tolerance in different crops (Shannon, 1997).

Yeo (1998),stated that the salt tolerance of an organism depends upon the range of external salinity over which it is able to sustain. The unique and overriding consideration for the salinity tolerance of terrestrial plants is the net flux of water due to transpiration. Recent views consider regulatory processes and multiple gene transfers.

Management strategy

Numerous reclamation techniques have been undertaken as an alternative to improve salt tolerance of crop species (Shannon, 1982; Epstein, 1985). Great efforts have been applied in the maintenance of the environment and preservation of natural resources (Ghassemi *et al.*, 1995). Great emphasis has been given to meet the demand on high-quality water resources in the Wester of United States (McClurg, 1993).

Shannon (1997) has recommended to improve the salt tolerance of crops through conventional breeding and selection; to introgress crops with their wild species having salt tolerance; for adaptation to saline environments by breeding and selection for improved agronomic traits.

For management of salinity, the following measures are recommended: 1) adequate internal drainage; 2) appropriate leaching requirement depending on the levels of tolerance for specific crops; 3) high water availability in soil, and 3) addition of soluble calcium such as gypsum $CaSO_4$; calcium sulphate).

In the context of the above review, the gravity of salinity is increasing rapidly in the crop growing world causing a great concern and posing a great threat to food security to the ever increasing human populations. For this, enormous research activities have been directed to understand and find possible solutions of this menace. Although significant progress has been made to understand and to study the mechanism of salinity tolerance in halophytes mainly, but very little progress has been obtained in crop plants. Most of the researches are directly mainly on the following aspects.

1. To estimate the gravity of the problem of salinity and its effect on crop productivity.
2. To develop and adopt suitable management strategy to control.
3. To develop efficient technique for amelioration.
4. To understand and study the effects of salinity on the following plant components:
    a. Morphology and anatomy
    b. Growth
    c. Physiology and biochemistry
5. Development of techniques for screening and to select crop genotypes for tolerance to salinity.
6. To understand the mechanisms of tolerance to salinity.
7. Biotechnology and molecular genetics.
8. Breeding for salinity tolerance.

The present review attempts to discuss a brief account of the research advances on salinity tolerance in only few field and vegetable crops viz. (cereals, legumes, fibre crop, vegetables) in the context of sufficient inputs achieved on different aspects of salinity on halophytes and other glycophytes.

Research progress in salinity tolerance of some crops

Research has been undertaken in different crops to see the effects of salinity of the respective crop on different stages of growth starting from germination to vegetative-reproductive stages, on the physiological and biochemical changes, and finally on the mechanism of tolerance to salinity.

Salinity in sorghum (*Sorghum bicolor* (L.) Moench.)

Effect

Emergence and seedling growth

Increasing salinity reduces seedling emergence, its growth and ultimately productivity. Different researchers have reported that salinity affect emergence and seedling growth in sorghum (Ogra and Baijal, 1978; Francois *et al*., 1984; Peng *et al*., 1994; Daniells *et al*., 2004). *Sorghum* is more tolerant at germination than at later stages of growth (Francois *et al*., 1984).

Biochemical changes

Salinity causes several biochemical changes such as it reduces the level of reducing sugars (Narasagauder *et al*., 1979); causes changes in á-amylase and acid protease during seedling growth (Ogra and Baijal, 1982); fluctuations in concentrations of inorganic phosphate, glucose, fructose, total amino acids and malic acids both in the roots and leaves (Weimberg *et al*., 1984). It affects adversely the activities of various enzymes and the plant development (Läuchli *et al*., 1994; Bernstein *et al*., 1995; Munns, 2002; Lacerda *et al*., 2003a, b); rapid changes in *de novo* protein synthesis in callus cultures of two sorghum cultivars under mannitol (Pérez-Ramos, 1989), accumulation of HCN and proline content, reduction in epicuticular wax content and chlorophyll content (de la Rosa-Ibarra and Maiti, 1995).

Variation and selection

Genetic variation was found to exist for salt tolerance (Grieve and Maas, 1984; Weimberg *et al*., 1984; Boursier *et al*., 1985; Maiti and Huerta, 1990). It is concluded that germination percentage could be used as a reliable selection criteria of salinity tolerance.

Mechanisms

In sorghum, osmotic adjustment under salinity is considered as one of the mechanism of salinity tolerance. According to Lacerda *et al*. (2003a, b), osmotic adjustment occurs due to higher accumulation of Na^+ and Cl^- in salt-tolerant genotype; K^+ contributed the most to the water potential; accumulation of soluble carbohydrates and amino acids contributed the most to the leaf and root water potential in salt tolerant genotypes; the higher decrease in water potential in the salt sensitive genotype was due partly to a higher Na^+ and Cl^- accumulation beyond the amount needed for osmotic adjustment, thereby adversely affecting the plant development (Munns *et al*., 1995; Munns, 2002). The accumulation of soluble carbohydrate might compensate the changes in water potential (Lacerda, 2001; Serraj and Sinclair, 2002). The salt tolerant genotype was capable to maintain an osmotic pool in the cytoplasm, adequate for cellular metabolism under salt stress conditions (Lacerda *et al*., 2003a, b). Similarly, Sunseri *et al*. (2004) reported that salinity tolerance in sweet sorghum under salt stress is mainly due to two main mechanisms involved in plant adaptation to saline condition: 1) exclusion of salt uptake and avoidance of an internal water deficit by enhanced synthesis of organic solutes; 2) inclusion of salts and their utilisation for turgor maintainance or may be for K^+ replacement by Na^+ in various metabolic functions. The concentration of Na^+ and consequently the Na^+/K^+ ratio increased remarkably in salinised treatment.

Salinity in pearl millet (*Pennisetum glaucum* (L.) R. Br.)

Effect

Germination and seedling stage

Salinity decreased seed germination and early seedling growth of pearl millet and *sorghum* cultivars (Ibrahim *et al*., 1991). In pearl millet hybrids, the percentage of germination, length, both the fresh and dry weights of roots and coleoptiles, and osmotic potential decreased with increasing salinity (Chhipa *et al*., 1992). A comparative study on salt tolerance of pearl millet and sorghum treated with different levels of NaCl, indicated that although was no remarkable decrease was observed in the germination percentage of both the species, but there was a delay in the germination of sorghum, decrease in pigment content and plant dimensions which was more noticeably in sorghum. However, an increase in the Ca, Na, N, and P contents were observed in pearl millet. In another study, proline content was increased at the high salinity levels in both the species, but significantly more pronounced in pearl millet (Hajor *et al*., 1996).

An increase in proline was observed, however, there was no significant effect on mid-day stomatal behaviour of the plants (Gupta *et al*., 1978).

While working on different crops, it was assessed that both pearl millet and rice gave higher germination and more root and shoot growth under high salt concentration (Datta *et al*., 1990). The increasing salinity levels subsequently decreased germination, plant height and grain yield significantly, but there was an increase in Na^+/K^+ ratio in plant (Gundalia *et al*., 1991).

Although increasing NaCl concentration significantly reduced seedling root length, but no considerable variation was observed within, and between the accessions of each species. The differences in tolerance are genetically based from broad sense heritability estimates (Kebebew and McNeilly, 1995).

Jain *et al*. (2004) studied the effect of ABA, GA_3, and NaCl on germination and phosphatases in pearl millet seeds and observed that germination decreased markedly under ABA (65%) and salt treatments; however, germination under GA_3 was 90%, respectively. Alkaline phosphatase activity was apparently higher after GA_3 treatment. It was assessed that associated with less germination under ABA and NaCl, a dramatic increase in phosphatase activities was observed than that of control. However, under GA_3, no significant decrease in germination was observed, but higher phosphatase actives were noticed, suggesting that metabolism of phosphatase in germinating pearl millet seeds are regulated differentially by ABA, NaCl and GA_3. It is also suggested that changes in the phosphatase enzymes might play important roles in acclimatization of pearl millet seeds, under the changing environmental conditions.

Variation and selection

Ashraf and McNeilly (1987) studied the effects of increased salinity (NaCl + $CaCl_2$) on seedlings of pearl millet genotypes and observed that sufficient inter-cultivar variation in response to salinity was observed indicating that there is enough scope of the selection of individuals with increased salinity tolerance in pearl millet.

Dua and Bhattacharya (1988) reported that pearl millet populations were better tolerant to salinity than hybrids for grain yield. Hybrids gave higher yield than populations in saline soil which suggests that there a scope of developing salt tolerant hybrids than the populations. Bold seeded with bristle hybrids showed high salinity tolerance.

In another study, Dua (1989) evaluated pearl millet genotypes comprising populations and hybrids in field sowings irrigated with canal water. It is suggested that the tested progenies of selected plants from such populations could be comprised to build up populations through selections. Among different components of grain yield, test weight was considered to be the most important selection criteria in breeding for salinity tolerance in pearl millet. Owing to its maximum expected genetic gain, high heritability and significant correlations with grain yield under saline conditions.

Ashraf *et al*. (1992) observed a large variation in salinity tolerance in twenty four accessions of pearl millet grown for two weeks of growth in saline solution culture at EC 20 dS m^{-1}. No considerable variation was observed between the 24 accessions, suggesting that selection for increased tolerance to salinity for genetic improvement in pearl millet may be possible.

Chopra and Chopra (1993) reported that an increase in salinity level of irrigation water decreased the yield components. They observed a significant reduction of seedling root length due to increased concentration of Na_2CO_3 and also found considerable variation between accessions for growth in salt. In another study, analysis by non-linear least square inversion method using root length data revealed significant differences in pearl millet accessions on the basis of salinity threshold Ct, the Na_2CO_3 solution concentration at which root length begins to decrease. The concentration caused a 50% decrease in root length (C50) and the concentration causing zero root growth (CO). It was suggested that C50 appears to be a useful character by means of assessing and quantifying salinity tolerance (Ghulam *et al*., 2004).

Maiti *et al.* (2006) made a comparative study on the levels of tolerance to NaCl-salinity of some crop cultivars (sorghum, pearl millet, rice, maize, cotton and sunflower) at early emergence and germination stage. They reported that pearl millet is more tolerant to salinity than other crop species studied.

In a recent study (Maiti *et al.*, 2009) genotypic variability was in salinity tolerance of pearl millet and their parents. Some parents have been selected showing tolerance to high level of salinity (0.25 MNaCl) which may be utilized in breeding for salinity tolerance. Increasing salinity increases increases root length in salinity tolerant genotypes, but it decreases in the case of the susceptible ones. The emergence percentage and root length are considered as selection criteria for salinity tolerance in pearl millet.

Ameriolative function

Ashraf *et al*. (2003) carried out another study in an attempt to improve salt tolerance in pearl millet at the germination stage and vegetative stages by soaking the seeds of two cultivars (IC-8206 and 18-BY) for 8 h in distilled water, 150 mol m^{-3} NaCl, or polyethylene glycol (PEG-8000; -0.672 MPa), or by subjecting the seeds to chilling (5ºC) or heating (60ºC) for two days. It was observed that chilling, and to a lesser extent, PEG, increased the final germination percentage but not the germination rate of both the cultivars under both saline and non-saline conditions. Chilling alleviated the adverse effect of salt stress on IC-8206 in terms of fresh and dry weights of shoots and roots following 42 d in sand culture that received 150 mol m^{-3} NaCl. Chilling also reduced Cl^- accumulation and, to a lesser extent, that of Na^+, and increased K^+ and Ca^{2+} accumulation in the shoots and roots of both cultivars under both saline and non-saline substrates. The reverse was true in plants raised from seeds treated with NaCl or PEG.

Maize (*Zea mays* L.)

Effect

Maize is considered as a moderately salt tolerant crop at the germination stage (Jan *et al*., 1995). With progressive increase in NaCl-salinity, germination and seedling growth of maize reduced significantly (Jan *et al*., 1995; Farida *et al*., 1997). Under salt stress condition, a treatment with $CaCl_2$ (soaking seeds in a 20 mM $CaCl_2$ for 12 h at 25ºC) increased germination rate and improved seedling growth (Dolgykjh *et al*., 1996).

Salt stress reduces leaf expansion thereby affecting dry mater accumulation in maize cultivars (Cramer *et al*., 1991). Salinity significantly reduced relative growth rate (RGR) and (LAR) of maize hybrids treated with NaCl. Supplemental Ca^{2+} improved RGR by maintaining LAR. LAR was inhibited in the early stages of salt stress and became limiting to growth relative to controls in later stages. Willadino *et al*. (1999), reported that salinity affects the growth and development of maize plants that may be attributed to restriction on amylase and invertase activities.

Variation and selection

Genotypic variability among maize cultivars was observed for tolerance to salinity and drought at the seedling stage was reported by Maiti *et al.* (1996). It is suggested that in maize, improvement for salt tolerance could be obtained through further cycles of selection and breeding (Ashraf and McNeilly, 1990). The tolerant maize (Deccan 103 and EVB XII) genotypes showed significant variation in mean grain yield during three years and an increase in salinity level decreased the grain yield (Uma *et al*., 1990).

Bioelectric activity of maize leaves caused by a single light pulse (6 s; 70 mmol m^{-2} s^{-1}) can be used to compare the effects of different NaCl treatments on plant growth indicating that a the amplitude of bioelectric activity decreased with increasing NaCl concentration. It is suggested that the leaf bioelectric activity can be considered in screening genotypes for salt tolerance (Shabala *et al*., 1998).

A simulation model was developed by Beltrao and Ben-Asher (1997), to predict maize yields under salinity conditions, where the wilting point is a function of the soil salt content.

Willadino *et al*. (1999) reported that under hydroponic conditions dry matter production, leaf area, and shoot and root growth rates of the genotypes decreased with an increase in salinity.

Mechanism of resistance to salinity

Salinity induces physiological and biochemical changes in maize plants. In general, ion transport to the shoot appeared to be a function of root ion concentration (Cramer *et al.*, 1994a, b). It has been reported that Na^+ and Cl^- concentration increased with salinity treatments, but K^+ and Ca^{2+} concentrations decreased. Willadino *et al*. (1994), did not observe differences in salinity tolerance among maize cultivars. grown in saline and non-saline areas, although the concentrations of Na and K as well as their ratio were greater for plants subjected to salinity indicating the effect of saline stress was well marked for productivity than for vegetative growth.

Cramer (1992) studied the kinetics of maize leaf elongation as a response of a sodium-excluding cultivar and a sodium including cultivar under varying sodium calcium salinities. It was assessed that the Na-includer line (Dekalb hybrid XL75) was more sensitive and responsive to supplemental Ca (10 mol m^{-3}) than the Na-excluder line (Pioneer hybrid 3906).

Khan *et al*. (2003) studied the root growth response of 10-days-old seedlings of 100 maize accessions wunder different concentrations of NaCl ranging from 0-150 µM in solution culture. Using the least square method it was assessed that in broad sense, heritability for relative root length was moderate. This suggests the scope for enhancing salt tolerance in maize through selection and breeding on the basis of root length.

In the context of above review it may be assessed that the mechanism of resistance of maize cultivars to salinity basically involves three principal phenomena: (a) ion accumulation/imbalance, (b) osmotic inhibition or osmotic adjustment, and (c) deranged metabolism.

Ion accumulation

Ion accumulation and exclusion are related to salt tolerance seems to be present in maize. By adding supplemental Ca under NaCl-salinity, the greater total increase in shoot and root dry weights are achieved in the cultivars (Alberico and Cramer, 1993). Salt sensitive maize cultivars had lower shoot and more root Na^+ concentrations and had significantly lower amounts of dry matter than those cultivars with higher concentrations. The shoot Ca^{2+} concentration was reduced in cultivars treated with Na (Fortmeier and Schubert, 1995).

Vergara-Sanchez (1991) reported that plants from saline areas have a high capacity for cation exchange in the roots, resulting in a higher selectivity to divalent cations and, thus, absorbing less Na. Therefore, the determination of absorbed cations is considered to be an indicator of salt resistance in maize.

In a study, the kernels of maize (cultivar Sultan) were kept for seven days in solution culture containing 0, 40, 80 or 120 mol NaCl m^{-3}. It was observed that fresh weight of seeds decreased significantly with increase in NaCl concentration of the growth medium whereas seed dry weight remained almost unaffected. At the same time, Na^+ concentrations in the germinating seeds increased with time in all salt treatments except the control treatment and the marked effect of time was observed at the highest salt regime (120 mol NaCl m^{-3}). The same pattern of Na^+ transport was observed in the shoot axis whereas the reverse was true for radicle in which Na^+ concentrations decreased considerably with time. On the other hand, total lipids decreased significantly in the germinating seeds with time. It is interpreted that the adverse effect of salt on seed germination is partly due to damage caused by breakdown of seed lipids so as to supply soluble sugars to the respiratory metabolism of the growing embryo (Ashraf and Wahid, 2000).

In order to search of K^+ channel genes expressed in the leaf of the *Zea mays*, Philippar *et al*. (2003), isolated the cDNA of KZM1 (for K^+ channel *Zea mays* L.). During leaf development, sink-source transitions, and diurnal changes, KZM1 is constitutively expressed, pointing to a housekeeping function of this channel in K^+ homeostasis of the maize leaf. Therefore, the voltage-dependent K^+-uptake channel KZM1 appears to mediate K^+ retrieval and K^+ loading into the phloem as well as K^+-dependent stomatal opening.

ABA increased the growth rate and reversed the negative effect of NaCl in maize. The elastic modulus was increased under NaCl stress indicating a possible implication of a change in the elastic conditions of the cell walls in stress responses (Erdei and Taleisnik, 1993). High concentrations of Na in the leaves may help to maintain turgor, but cannot substitute for K to give adequate growth of maize under water stress. Increasing the K supply in the rooting media also did not improve growth reduction (Cerda *et al*., 1995).

Changes in Na and Ca concentrations occurred in the apoplast and symplast of etiolated maize seedlings under NaCl stress. Na concentration in apoplast was more increased in roots than shoots. Ca concentration in apoplast and symplast of shoots was decreased at all salinity levels, while in the root apoplast was increased only in some salinity treatments (Wang and Zhao, 1997).

Salinity affected photosynthesis per unit area indirectly through stomatal closure and to some extent through direct interference with the photosynthetic apparatus. Salinity reduced leaf area, chlorophyll contents, assimilation rate, stomatal conductance, and transpiration significantly (Netondo *et al*., 2004).

Differences in growth and water relations were compared in salt acclimatization and salt shock treated maize. A salt-acclimatization treatment increased a root extension similar to an unsalinized control for at least 6 days at concentrations up to 100 mM NaCl while salt shock treatment rapidly inhibited extension followed by a gradual recovery. Salt shock caused a rapid decrease in root water and solute potentials for the apical zones, and the estimated turgor potential showed only a small decline; similar but more gradual changes occurred with salt acclimatization (Rodriguez *et al*., 1997).

An *in vitro* characterization of salt-selected maize genotypes showed that the adaptation of the embryogenic cultures to NaCl caused qualitative and quantitative changes in the polypeptide patterns. Cultures like Arizona 8601 have shown an over expression of the polypeptides of approximately 26-28 kDa. This over expression was not induced by salt (Lusardi *et al*., 1992).

An *in vitro* nuclear magnetic resonance investigation of ion transport in maize and *Spartina anglica* roots during exposure to high salt concentrations Spickett *et al*. (1993), revealed that the root tips exposed to different NaCl concentrations showed changes in the chemical shift of the pH from the cytoplasmic to vacuolar orthophosphate pools with the uptake of sodium. The vacuolar alkalinization gives evidence for the operation of a tonoplast Na^+/H^+-antiport with an activity that exceeded the activity of the tonoplast H^+ pumps.

The salt tolerance of 20 inbred lines of maize was tested using salt stress (0, 3000, 5000 and 7000 ppm NaCl) in sand culture for 45 days where salt stress significantly increased sodium and calcium contents but decreased potassium content. SDS-PAGE patterns of water-soluble leaf proteins revealed four distinctive bands (MW 58.0, 34.5, 27.5, and 14.0 kDa) that were associated with salt stress. These protein bands were induced under salt stress in salt tolerant as well as salt sensitive inbreds (Shadi *et al*., 1999).

Osmotic adjustment

The accumulation of osmolites in the cytoplasm is a mechanism of salt tolerance. Rodriguez *et al*. (1997), working on the growth, water relations, and accumulation of organic and inorganic solutes in roots of maize seedlings during salt shock and salt acclimatization assessed that both salt shock and acclimatization caused a rapid decrease in root water and solute potentials for the apical zones and the estimated turgor potential shows a small decline. In salt shock, an osmotic adjustment occurred rapidly, while there were changes in concentration of inorganic solutes (Na, K and Cl) and organic solutes (proline, sucrose, fructose and glucose).

Maize lines containing glycinebetaine showed less shoot growth inhibition under salinized conditions than that which was associated with maintenance of significantly higher leaf relative water content, a higher rate of carbon assimilation and a greater turgor. A single gene conferring glycinebetaine accumulation seems to play a key role in osmotic adjustment (Saneoka *et al*., 1995).

In a study, tolerance to salt stress was tested in maize callus lines with different polyamine (PA) content with high and low PA levels, exposed and not exposed to 0.171 M NaCl. It was assessed that low-PA lines were salt stress tolerant, while high-PA lines were sensitive. The sensitive lines contained increased putrescine contents in comparison with control, while putrescine content remained constant in tolerant lines (Zacchini *et al*., 1997).

Callus cultures from different mature embryos at medium with different concentrations of NaCl + $CaCl_2$ (ratio 1:1) showed that callus growth decreased with an increase in salt concentration in the culture medium. There was an increase for Na, Ca and proline content accumulated in the different maize calli which is associated with a slight decrease in K content with increasing salt levels in the culture media (Haggag *et al*., 2000).

Ameliorative functions

Zhao *et al*. (1995) reported that exogenous ABA treatment increased salt resistance and dry weight of maize seedlings in saline conditions owing to enhanced osmotic adjustment activity and the exclusion of sodium ions from the shoot through the action of exogenous abscisic acid, which accumulates sodium in the roots. Foliar and root absorption of Na and Cl in maize and barley have great implications for salt tolerance screening and the use of saline sprinkler irrigation. When foliar and root absorption processes operated together, leaves accumulated less Na and Cl than the sum of individual absorption processes which indicates that there is a slight interaction between these absorption processes. Saline sprinkling significantly reduced vegetative biomass at maturity and cumulative plant water use (Benes *et al*., 1996a, b).

NaCl and growth regulators induced changes in growth and N assimilation in maize plants. Treatments with 100 µM NaCl inhibited the biomass accumulation, chlorophyll and carotenoid contents in leaves, and also nitrate content and uptake and nitrate reductase activity. The application of kinetin, ascorbic acid and 10 to 50 µM abscisic acid, 50 to 100 µM ABA, induced a substantial increase in the those parameters. However, the effect of ABA was high both in salinized and non-salinized plants (Khan and Srivastava, 1998).

Biotechnology

In a study, the frequency of regenerated plantlets from cultured embryos is inversely proportional to NaCl concentration. In most of the tolerant traditional lines studied, 80% of the seeds germinated at the maximum NaCl concentration (Ivanova and Petrova, 1995).

Mycorrhiza

Fungus *Glomus mosseae* and phosphorus supply have significant interactive effects on the growth and phosphorus status of maize plants under saline and non-saline conditions. The improvement of phosphorus status is the main mechanism by which this fungus enhances plant salinity tolerance in phosphorus deficient soil. However, even under optimum phosphorus supply, this fungus is still able to enhance the salinity tolerance by other mechanisms (Feng *et al*., 2000).

Molecular basis

Rao-Sajjad and McNeilly (1999), suggested that salinity tolerance is under the control of genes with additive and non-additive effects while working on 10 day-old seedlings grown in salinized solution culture at control (0 µM), 60 µM and 80 µM NaCl concentrations. The estimated broad and narrow sense heritability were 0.7 and 0.4 respectively over all treatments.

Abdel *et al*. (1997) studied the molecular basis of tolerance of salinity where SDS-PAGE showed that most of the very tolerant F_2 genotypes were characterized by higher band intensities under salt treatment than the control. Band 7, in particular, could be considered as a biochemical marker associated with salt tolerance. The tolerant parent markedly surpassed the sensitive one in both density and intensity of bands 2 and 3. Band 3 was absent in the sensitive line under stress. Therefore, the allele *Acp1* could be considered as a putative molecular marker linked to salt tolerance in maize. Random amplified polymorphic DNA (RAPD) markers for salt tolerance were detected by bulked segregant analysis with 10-mer primers. Primer D10 found no complementary sequences in either the genome of inbred or their subsequent generations. Primers C18, C20, D3 and D7 showed no consistent bands related to salt tolerance. On the other hand, primer C19 generated a marker for salt tolerance, where a 2 kb band was exclusively present in the tolerant parent and tolerant F_2 population.

Transfer of *Escherichia coli* GutD gene into maize and regeneration of salt-tolerant transgenic plants was studied. The GutD gene, encoding a key enzyme of the sugar alcohol metabolic pathway of glucitol-6-phosphate dehydrogenase in *E. coli*, was transferred into maize and has been integrated and expressed in transgenic maize plants and their progenies. The synthesis and accumulation of sorbitol were detected in transgenic maize plants and these have increased salt stress tolerance (Liu *et al*., 1999).

Management strategy

Numerous reclamation techniques have been undertaken as an alternative to improve salt tolerance of crop species (Shannon, 1982; Epstein, 1985). Great interests have been generated in the maintenance of the environment and preservation of natural resource (Ghassemi *et al*., 1995). Great emphasis has been given to meet the demand on high-quality water resource in the Wester United States (Mc Clurg, 1993). The use of recycled water, drainage water or other poor quality water in crops with improved salt tolerance has been suggested as an alternative strategy in increase crop productivity under saline saline (van Schilfgarde and Rhoades, 1979).

Shannon (1997), has recommended to improve the salt tolerance of crops through conventional breeding and selection; to introgress crops with their wild species having salt tolerance; for adaptation to saline environments by breeding and selection for improved agronomic traits. For management of salinity the following measures are recommended:

adequate internternal drainage, appropriate leaching requirement depending on the levels of tolerance for specific crops, high water availability in soil, and addition of soluble calcium such as gypsum.

Rice (*Oryza sativa* L.)

Salinity affects crop production in rice growing areas worldwide (Funakawa *et al*., 2000; Kotb *et al*., 2000; Wilson *et al*., 2000). Salt concentration causes osmotic effect, thereby delaying water penetration into cells and dehydration of protoplasm thereby inhibiting enzyme activities and suppressing respiration and phosphorylation process and ultimately seed germination and seedling growth (Turr, 1978, cited by Zelensky, 2003). Breeding for abiotic stress resistance offers a serious challenge to the breeders. Most of these characters are inherited quantitatively with a large number of quatitative trait loci (QTLs) involved in the genetic control of several factors leading to stress resistance. Breeding for salinity tolerance is tedious owing to the heterogeneity of salinity in the field conditions and the absence of efficient technique for screening a large number of genotypes for salinity tolerance (Bhatt *et al*., 2008).

Rice is a salt-sensitive crop (Shannon *et al*., 1998), but is more tolerant at germination than at other stages (Narale *et al*., 1969; Khan *et al*., 1997). Salinity affects germination and seedling growth in rice which might be due to osmotic stress (Narale *et al*., 1969; Heenan *et al*, 1988). It is highly highly sensitive to salinity (Pearson and Birnstein, 1959; Kaddah, 1963; Yeo and Flowers, 1986; Lutts *et al*., 1995). Salinity causes significant reduction in seedling establishment, leading to loss in yield components and yield (Heenen *et al*., 1988; Khatum *et al*., 1995; Kato and Takeda, 1996; Scardaci *et al*., 1996; Shannon *et al*., 1998; Linghe Zeng and Shannon, 2000). Azaizeh *et al*. (1992), reported that NaCl has adverse effects on water transport in root cells and supplemental Ca^{2+} could compensate for these effects. This is also supported by Alam *et al*. (2005). Patel *et al. (*2004) reported large variability for salinity tolerance in rice genotypes at the germination stage. In another study, Bhatt *et al*. (2008) studied the effect of two levels of salinity (EC 20 and 24) showing significant differences in seedling traits recorded (root and shoot dry weight and root/shoot ratio).

In a recent study genotypic variability was observed for salinity tolerance and salt tolerant parents and hybrids are selected in rice (Maiti *et al*., 2009**).**

Wheat (*Triticum aestivum* L.)

Introduction

Salt problem sites are becoming more common. Salinity is among the most widespread and prevalent problems in irrigated agriculture. Wheat productivity is severely affected by soil salinity mainly due to Na^+ toxicity to plant cells. Increased salt tolerance is needed for crops grown in areas at risk of salinisation. The way in which salt affects wheat plant metabolism is reviewed briefly herewith.

Germination and seedling growth

Increasing salinity affects affect seed vigor. Wheat (*Triticum aestivum* L.) plants grown under soil salinity levels (1.7, 4.7, 8.7 and 14.5 dS m^{-1} showed a decrease in seed weight (7-35%) and seed yield (4-96%). Results of multivariate analysis of variance (multiple *F*-test) showed that in total seed germination and vigor of spring wheat cultivars are not sensitive to salinity stress imposed on mother plant (Soltani *et al*., 2004). Increasing level of NaCl level reduced the germination percentage, the growth (Mer *et al*., 2000; Al-Ansari, 2003) parameters (fresh and dry weight), potassium, calcium, phosphorus and insoluble sugars content decreased in both shoots and roots of 15-day old seedlings and resulted in development of burning symptoms (Mer *et al*., 2000). KNO_3 and KCl were found to be inhibitory to initial growth of wheat cultivars (Ashraf and Iram, 2002).

Leaf relative water content (RWC) and the photosynthetic pigments (Chl a, b and carotenoids) contents also decreased with increasing NaCl concentration. On the other hand, Na, soluble sugars, soluble proteins, free amino acids including proline content and lipid peroxidation level and peroxidase activity were increased in the two plant organs with increasing of NaCl level (Gadallah, 1999). Electrolyte leakage from plant leaves was found to increase with salinity level (El-Tayeb, 2005).

Salt stress at the seedling stage induces a decrease in relative growth rates, K concentrations and leaf osmotic potential values, as well as an increase in Na, proline and soluble sugar contents (Almansouri *et al*., 1999).

Salinity effect on growth

Plants grown under saline conditions can experience elevated matric and osmotic stress between irrigation events.

Vegetative stage

Salinity stress has adverse effect on seed yield than biomass production at the vegetative stage. The root and shoot dry weights were reduced (Del Zoppo *et al*., 1999; Keles and Oncel, 2002 and 2004; Houshmand *et al*., 2005).

The reduced plant growth under highly saline soils may be attributed to the negative effect of the high osmotic potential of the soil solution of the highly saline soils. They tend to reduce the nutrient and water uptake as well as result in reduced plant root growth (Wilson *et al*., 2002; Ashraf and Orooj, 2005).

RGR, leaf area, and K^+ content decrease with increasing salinity and pH. Electrolyte leakage rate, proline content, citric acid content, and Na^+ content increased with increasing salinity and pH in sunflower (ShiandSheng, 2005). The a-tocopherol content increased under salinity stress (Keles and Oncel, 2002).

Ionic content in plant shoots vary with the increase in salinity. K content in plant shoot is strongly regulated by Na^+ ions followed by a gradual decrease in K with the increase in Na accumulation in shoot (Shirazi *et al*., 2002). Plant growth was found to be stimulated by low concentrations of NaCl and depressed by high concentrations of NaCl. Shoot: root ratio was also depressed by salinity. Concentrations of K decreased with salinity, while the concentrations of Cu in the roots decreased with high salinity. The concentration of Mn in both shoots and roots was generally higher with high salinity (Drihem and Pilbeam, 2002).

Salinity stress decreased relative water content (RWC), chlorophyll (Chl), carotenoids (Car), membrane stability index (MSI), biomass and grain yield, and increased hydrogen peroxide (H_2O_2), thiobarbituric acid reactive substances (TBARS), proline, glycine-betaine (GB), soluble sugars, superoxide dismutase (SOD), catalase (CAT) and glutathione reductase (GR) activity in both the genotypes and at all the stages. Salinity induced decrease in RWC, Chl, Car, MSI, biomass and grain yield were significantly higher in KRL 19 than more tolerant Kharchia 65. Kharchia 65 recorded higher activity of SOD, CAT, GR, as well as contents of proline, soluble sugar, GB and K, and comparatively lower H_2O_2 and TBARS contents compared with KRL 19. KRL 19 also showed higher Na and Na/K ratio. Results show that salinity tolerance of Kharchia 65 as manifested by lower decrease in biomass and grain yield is associated with higher antioxidant activity, osmolyte concentration and potassium contents, and lower H_2O_2, TBARS and sodium contents than KRL 19 (Sairam *et al*., 2002).

After 120 d of seed sowing, plant biomass production was decreased by 49% and 65%, in response to 5 and 10 dS m^{-1} salinity levels. The adverse effect of salinity was observed on plant height. Wheat shoot and root lengths were reduced by salinity (Noori and McNeilly, 2000).

Salinity reduced nitrate reductase activity (NRA) of the leaf (Aldesuquy, 1998; Sarwar *et al*., 2003). The inhibitory effect of salinity on nitrate reduction rate was more pronounced at the reproductive stage than at the vegetative stage of plant growth. Increasing salinity reduced potassium (K^+) and calcium (Ca^{2+}) accumulation in shoots, while the concentration of sodium (Na^+) was increased (Iqbal *et al*., 2006).

Salt or osmotic stress effects shoot growth and water status in *Triticum aestivum. Azospirillum brasilense* inoculation reverts the negative effects of salinity (Creus *et al*., 1997).

The low Na^+ genotypes show much longer chlorophyll retention than the high Na^+ genotypes, the start of leaf senescence being prolonged by a week or more in the low Na^+ genotypes. The low Na^+ genotype show a greater yield due to enhanced grain number and grain weight in the tiller ears (Husain *et al*., 2003). Increased soil salinity caused appreciable inhibition of shoot growth (Gadallah, 1999). At higher salt concentrations, the shoots were moribund (Barrett-Lennardet *et al*., 1999).

In wheat, plants grown in aerated solutions, the rates of leaf production exceeded rates of leaf senescence at all salt concentrations. At various stages of leaf development, irrigation of wheat plants by seawater at 10 or 25% generally decreased cumulative leaf area, relative water content and water-use efficiency (WUE) in grain (WUEG) and biomass (WUEB), and at the same time induced accumulation of free and bound-ABA and amino acid content in harvested grains (Aldesuquy, 1998).

Seawater irrigation decreased the carbohydrate content and increased the protein content of the developing grains.The application of growth bioregulator gibberellic acid appeared to mitigate the effect of seawater salinity stress on wheat productivity. The economic yield (grain yield) has a strong positive correlation with RWC, water use efficiency for grain yield, water use efficiency for biomass, plant height, shoot fresh and dry weights, grain number/main spike, kernel weight and harvest index (Aldesuquy and Ibrahim, 2001).

Ion accumulations on root and shoot growth

Wheat shoot elongation is sensitive to any diminution of water potential. Though the alleviation of toxicity by Ca^{2+} is weak solute concentrations <250 mos, it alleviated Na^+ and K^+ toxicity to roots by at least three separate mechanisms. K^+ was found to be more toxic to roots than Na^+, but Na^+ was more toxic to shoots (Kinraide, 1999).

Higher shoot Na^+ concentrations indicate higher shoot damage. The higher shoot K^+/Na^+ and Ca^{2+}/Na^+ ratios indicate lower shoot damage (Dasgan *et al*., 2002). Aerenchyma development is higher near the root-shoot interface compared to near the root tip. Salinity under hypoxic conditions significantly reduces the aerenchyma development near the root tip and root-shoot interface compared to hypoxia alone (Akhtar *et al*., 1998).

Reproductive development

Salinity affected reproductive development leading to reduced spikelet primordial, and final spikelet numbers at ear emergence, but greatly enhanced the time of floral initiation in the wheat cultivars. The modification of apical development by salinity is mediated by signals or substrates derived from elsewhere in the plant (Munns and Rawson, 1999). Wheat callus weights decreased due to increasing residue effects of NaCl concentrations (Dokuyucu *et al*., 2005).

Water availability

High salinity and sodicity, rather than B, exert the major effects on water extraction of wheat from the deep subsoil (Nuttall *et al*., 2005). Wheat cultivars could all tolerate an EC up to about 9 dS m^{-1}. The presence of high levels of soil B does not appear to be the cause of salt tolerance in wheat. Because high levels of B and salt usually co-exist in the field, plant tolerance to these limitations need to exist in combination (Nuttal *et al*., 2006). Water retention capacity and relative water content decrease while water uptake capacity and water saturation deficit increase with the increasing levels of salinity. Salinity increases the diffusive resistance but decreases the transpiration rate. Chlorophyll content also decreases due to salinity. Accumulation of Mg^{2+}, Ca^{2+} and Na^+ increase, while that of K^+ decrease in the salt treated plants (Hossain *et al*., 2006). There is a great need to breed cultivars with increased sodium tolerance, pyramided with current B-tolerance, for those crops targeted to many alkaline soils. A decrease in ash content is associated with an increase in water use efficiency (Katerji *et al*., 2005a).

Yield

The increasing salinity of irrigation water caused significant adverse affects on yield attributes and yield of wheat (Chopra and Chopra, 1997; Phogat *et al*., 2001; Dehdari *et al*., 2005); reduced straw and grain weight (Ansari *et al*., 1998), but had a slight positive effect on the grain quality (Noaman, 2000).

Shoot-magnesium (Mg), and potassium (-K) decrease with an increases in salinity and substrate B. Salinity and B and their combined effects reduce wheat biomass production, yield components, and final grain yield (Grieve and Poss, 2000).

Besides the adverse effects of the higher leaf Na concentration on grain drymatter, the processes involved in the rate and/or duration of grain filling may be more efficient in terms of salt tolerance where grain yield is concerned. Higher rates of salt tolerance are through the more suitable dry matter partitioning pattern. In some cultivars salinity did not reduce the grain K/Na ratio and ion selectivity, but its grain filling period and harvest index decreased (Poustini and Siosemardeh, 2004).

Effect on mitochondria

Seawater stress affected the mitochondrial ATP synthesis and membrane potential in germinating durum wheat seedlings. The germination percentage was reduced. Na^+ and Cl^- accumulation showed a sharp increase under moderate stress. Proline-dependent oxidative phosphorylation, however, was inhibited under moderate stress. An adaptation mechanism is accumulation of proline that acts as an osmoprotectant. The effects of seawater stress on mitochondrial ATP synthesis vary in relation to the substrate oxidised and stress increase under severe stress, which was more pronounced for Cl^- (Flagella *et al*., 2006).

In all salinity treatments tested, a salt-induced increase in contents of proline and the activity of the alternative pathway was found. ATP production changed in parallel with CP operation. Salt-tolerant plants could produce more ATP than salt-sensitive plants (Konget *et al*., 2001).

Salinity causes a decrease in total phospholipids, increase in saturated fatty acids and alters distribution of sterols and phospholipids. NaCl also induces an increase in sterol/phospholipid ratio (Mansour *et al*., 2002). Salt sensitive wheat cultivars suffer greater damage to cellular membranes due to lipid peroxidation as indicated by higher accumulation of H_2O_2, MDA and greater leakage of electrolytes. The activities of catalase, peroxidase and ascorbate peroxidase and glutathione reductase increase with increase in salt stress (Mandhania *et al*., 2006).

Photosynthesis

With increasing salinity, the photosynthetic rate is saturated at low irradiances and stomatal frequencies increase. Salinity induces only a small decrease in the actual PSII efficiency at midday steady-state photosynthesis, indicating that the photosynthetic electron transport is little affected by salinity (Katerji *et al*., 2000). The concentrated Na^+ within a leaf under salinity treatments may decrease the stability of photosystem II functions and lead to photochemical inactivation (Ozalp *et al*., 2000; Muranaka *et al*., 2002a).

The net photosynthetic rate (P_N), stomatal conductance g_s (Riveli *et al*., 2002; Ashraf and Shahbaz, 2003) and transpiration rate (E) decreased with the addition of NaCl (Ashraf and Parveen, 2002). NaCl increased the activities of superoxide dismutase (SOD) and peroxidase (POX) (Sharma *et al*., 2005; Huang *et al*., 2006). The sodium and potassium contents were higher in the roots and leaves. At cellular level the wheat varieties impart salt tolerance by manipulating P_N, E, g_s and K accumulation in leaves along with overproduction of antioxidative enzyme activities (SOD and POX) (Sharma *et al*., 2005).

Salt-induced reduction in photosynthetic capacity can be ameliorated by exogenous application of glycine betaine (GB). High accumulation of GB mainly contributes to osmotic adjustment. Better osmotic adjustment or plant water status due to GB application increases the stomatal conductance and thus favor higher CO_2, fixation rate. The protective effect of GB on photosynthetic pigments and GB induced reduction in transpiration rate which might contribute to better growth of wheat cultivars under salt stress (Raza *et al*., 2006).

Effect on protein

Salinity has a two-phase effect on plant growth, an osmotic effect due to salts in the outside solution and ion toxicity in a second phase due to salt build-up in transpiring leaves. Salt-resistant and salt-sensitive genotypes showed a similar biochemical reaction at the level of proteins after 10 d exposure to 125 μM NaCl. The total soluble protein increased. The protein polypeptides 29 and 49 kDa increased with NaCl (Ashraf and O'Leary, 1999). Wheat seedlings grown in the presence of 200 μM NaCl showed a change in protein polypeptide of molecular weight 26 kDa (Majoul *et al*., 2000). The initial biochemical reaction to salinity at protein level in wheat is an unspecific response and not a specific adaptation to salinity protein change (up-regulated, down-regulated, disappeared (Saquib *et al*., 2006).

The amounts of total soluble protein and ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) per fresh weight increased, while the relative amount of Rubisco per protein remained unchanged , but its activity per fresh weight did not change. The total respiratory electron flow and flow through the cytochrome pathway were increased in CS under the salinity condition; whereas there were no changes in these traits in both amphiploid and 5E disomic addition lines (Kasai *et al*., 1998). A gradual depression of photosynthesis occurs due to stomatal closure under salinity stress (Muranaka *et al*., 2002b).

Exogenous ABA acid induces two characteristic proteins of high molecular weights (109.4 and 84.0 kDa) in wheat seedlings under high salinity. Guaiacol peroxidase that is *de novo* synthesized may reduce the active oxygen produced by salinity. The changes in gene expression and peroxidase isoforms may be selected to adaptation of wheat seedlings to NaCl-salinity (El-Enany, 2000).

A single locus, Knal, plays a key role in the control of K^+/Na^+ discrimination in wheat (*Triticum aestivum* L.) adapted to salinity, has been mapped within a 1.1-cM region on the 4D/4B map. Protein changes found in the salt-stressed parental Knal and knal lines were mapped using a population of 4D/4B recombinant lines with variable distal regions of the 4D chromosomes. On the basis of sequence analysis, the membrane protein was identical to the extrinsic 23-kDa protein of the oxygen-evolving complex (OEC) of photosystem II. The steady-state mRNA accumulation remains unchanged among different lines under conditions of salt stress. It is concluded that the response of protein expression to NaCl stress treatment might attribute to the mechanism of K^+/Na^+ discrimination in wheat (Gao *et al*., 2001).

CO_2 assimilation

Salinity causes a large decrease in stomatal conductance g_s in wheat. Reductions in assimilation rate are initially due to g_s and, with time, are due to a combination of stomatal and non-stomatal limitations. The non-stomatal limitations are associated with a build up of Na^+ above 250 μM. The potential and actual quantum yield of PSII photochemistry begins to decline as the leaf ages and the thermal energy dissipation of excess light energy (NPQ) increase. This coincides with high Na^+ and Cl^- concentrations in the leaf and with chlorophyll degradation, indicating that these later reductions in CO_2 assimilation are a consequence of a direct toxic ion effect. The most sensitive indicator of salinity stress is g_s, followed by CO_2 assimilation (James *et al*., 2002).

Mineral uptake

The presence of high Cl ions in the soil most likely inhibits the subsoil water extraction by the crops restricting the water availability. An increase in the levels of subsoil constraints led to an increase in Na and Cl concentration with a corresponding decrease in Ca and K in young mature leaf of bread wheat and durum wheat. Of the two ions, Na and Cl, the latter appears to be more damaging than the former resulting to plant dieback and reduced grain yields (Dang *et al*., 2006).

The uptake and translocation of mineral nutrients changes drastically. The high presence of Mg^{2+} in seawater affects the plant nutritional requirement considerably. The uptake of Ca^{2+}, is more influenced and its uptake is restricted due to the competition for the enhanced uptake of ions like P and Mn (D'Amico *et al*., 2004). The sea water can possibly be used as an alternative source of irrigation when adequate dilutions for tolerant plants are adopted. This prospect could therefore have a fundamental role in the economy of natural basins in numerous where the dry weather problem has a particular importance.

Higher salinity decreased Zn concentrations in the wheat shoots (Khoshgoftar *et al*., 2004). NaCl proved very harmful for the plants. Increases in concentrations of toxic ions were greater at high pH than at low pH. High pH depressed the uptake of potassium and enhanced sodium, magnesium and chloride uptake particularly at 100 mol m^{-3} NaCl salinity (Ahmad, 2002).

The toxic effect of ammonium nutrition on wheat can be related to retarded uptake of K^+ and Ca^{2+} and to enhanced uptake of Na^+. The nitrate, rather than ammonium, is favored as a nitrogen source for wheat cultivars, particularly under salt stress (Al-Mutawa *et al*., 2001).

Sodium uptake

Durum wheat genotypes exhibit variation in the uptake of ^{22}Na at low and moderate salt concentrations. A correlation was found between high ^{22}Na uptake at low NaCl concentration (presumably a detrimental attribute) and high K accumulation at higher salinity. ^{22}Na uptake into low-salt-grown seedlings was not necessarily closely correlated with Na leaf concentration at higher salinity (Pecetti and Gorham, 1997).

Genetic studies of two varieties of durum wheat (*Triticum turgidum* L.) subsp. durum known to differ in salt tolerance and Na^+ accumulation, indicated that these genotypes differ at two major loci controlling leaf blade Na^+ accumulation (Munns *et al*., 2003).

The major differences in Na^+ transport between the genotypes are: (1) the rate of transfer from the root to the shoot (xylem loading), which is much lower in the salt tolerant genotype, and (2) the capacity of the leaf sheath to extract and sequester Na^+ as it entered the leaf. It is likely that xylem loading and leaf sheath sequestration are separate genetic traits that interact to control leaf blade Na^+ (Davenport *et al*., 2005).

Spacial distribution of nutrients

Wheat leaf growth is known to be spatially affected by salinity. The patterns of spatial distribution of Na^+, Cl^-, K^+, and Ca^{2+} in the growing leaves are affected by salinity, while those of Mg^{2+}, total P, and total N are not. Na^+, K^+, Cl^-, Ca^{2+}, Mg^{2+} and total N concentrations (mmol kg^{-1} FW) are consistently higher at 120 mM NaCl than at 0 mM NaCl along the leaf axis from the leaf base, whereas concentration was lower at 120 mM NaCl. Deposition rates of all nutrients are greatest in the elongation zone. The elongation zone is the strongest sink for mineral elements in the leaf tissues (Hu and Schmidhalter, 1998; Hossain *et al*., 2006). Wheat showed increasing Na^+ accumulation with increasing salinity levels. The shoot K^+ levels had decreased by almost 40% at 19 dS m^{-1} (Wilson *et al*., 2002).

Both drought and salinity cause nutrient disturbance leading to a decrease in the diffusion rate of nutrients in the soil and the restricted transpiration rates in plants for drought and extreme soil Na/Ca, Na/K, and Cl^-/ratios for salinity. Ion deficiency might occur in expanding wheat leaves under drought but not under saline condition (Hu *et al*., 2006).

Physiological and biochemical basis of tolerance to salinity

Membrane fluidity remains stable in response to salinity. The membrane responses to salinity will facilitate a better understanding of halophyte tactics for salt tolerance (Wu *et al*., 2005). Growth of salt-tolerant genotypes of wheat is affected by salinity primarily due to a decline in photosynthetic capacity rather than a reduction in leaf area. NAR is the most important factor in determining RGR of moderately tolerant and salt-sensitive genotypes. Salinity reduces RGR, NAR, photosynthetic rate, stomatal conductance, water and osmotic potentials. A marked decrease of stomatal conductance and root hydraulic conductance is also seen under saline conditions (Bastias *et al*., 2004). K^+ and Ca^{2+} increased leaf respiration, and Na^+ and Cl^- content in stems and leaves. K^+ in the leaves and Ca^{2+} in the leaves and stems are closely associated with genotypic differences in salt tolerance (El-Hendawy *et al*., 2005). Wheat cultivars that differed in salinity tolerance maintained high leaf turgor potential under varying soil N levels (Saneoka *et al*., 1999; Ashraf and NO_3^- Khanum, 2000; Ashraf *et al*., 2002).

Root channel

A variety of ion channels have been identified in plant cell membranes that play a key role in both toxicity to high salt (NaCl) and tolerance mechanisms. In cereal roots there are voltage-independent non-selective cation channels in the plasma membrane that may be primarily responsible for Na^+ influx. A good correlation exists between the Ca^{2+} sensitivity of Na^+ influx into roots and the Ca^{2+}sensitivity of the Na^+ currents through the non-selective cation channel in wheat and maize (Laurie *et al*., 2002).

Non-selective cation channels that are sensitive to external Ca^{2+} will also be present in root membranes of horticultural plants (Tyerman and Skerrett, 1999). NaCl substantially reduce the plasma membrane ATPase specific activity, while it exhits a little effect on the apparent Km for Mg^{2+}. The root plasmamembrane ATPase (PM ATPase) of salt sensitive and resistant genotypes responded similarly to salinity stress (Mansour *et al*., 2000).

Silicon reduces Na uptake

Silicon can reduce sodium uptake in crop grasses in saline conditions. In rice, the silicate supplementation partly overcame the reduction in growth and net photosynthesis caused by salt. Further, the amelioration was correlated with a reduction in sodium uptake. Silicate supplementation increased the stomatal conductance of salt-treated plants, showing that silicate was not acting to reduce sodium uptake *via* a reduction in the transpiration rate. Moreover, it reduced both sodium transports. Silicate may act by the partial blockage of the transpirational bypass flow, the pathway by which a large proportion of the uptake of sodium occurs (Yeo *et al*., 1999).

Exclusion of ions

It is widely held that a major component of tissue tolerance is the capacity to compartmentalize salt into safe storage places such as vacuoles. This mechanism would avoid toxic effects of salt on photosynthesis and other key metabolic processes. The maintenance of photosynthetic capacity (and the resulting greater salt tolerance) at higher leaf Na^+ levels is associated with the maintenance of higher K^+, lower Na^+ and the resulting higher K^+:Na^+ in the cytoplasm of mesophyll cells (James *et al*., 2006).

In most glycophytes, Na^+ and Cl^- ions increase in both shoots and roots, whereas K^+ and Ca^{2+} decreases consistently with the progressive increase in salt level of the growth medium. The response to salinity is associated with maintenance of high K^+/Na^+ and Ca^{2+}/Na^+ ratios in both shoots and roots (Ashraf and Orooj, 2005).

In saline media, the building of high concentration of Na^+ and Cl^- in plant leaves may be delayed by rapid growth. Glycophyte plants growing slowly are more sensitive to salt than those growing rapidly (Lachaal *et al*., 2002). Sodium is excluded from the xylem in the root of Chinese Spring (Watson *et al*., 2001).

Wheat plants subjected to salt stress exclude Na^+ and Cl^- ions from the shoot to varying extents. Exclusion preferentially maintains lower Na^+ and Cl^- levels in the apical tissue. The leaf-to-leaf gradient in Na^+ and Cl^- become steeper as the external salinity increase. Plants exclude Na^+ at low salinity, and Na^+ and Cl^- at high salinity and growth performance is found to be correlated with the exclusion of these ions. Large variations occur in Na^+, and to a lesser extent, Cl^- transport in homozygous cultivars. Seedling traits could be used in breeding programs for salt-tolerance (Rashid *et al*., 1999).

Lower external K^+ concentrations (0.1 µM $CaCl_2$ and Basal salt medium) and Fusicoccin pre-treatment causes shifts in Na^+ fluxes towards net influx at 120 µM NaCl stress (Babourina *et al*., 2000).

The reduction of salt tolerance was associated with carbohydrate depletion that reduced the plant's genetic abilities to generate osmo-protectants (such as reducing sugars), to reduce Na accumulation in shoots, and to selectively uptake and transport K^+ (Qian *et al*., 2005).

The salinity tolerant varieties show shorter mean germination time at low osmotic potential. During the seedling stage, tolerant varieties show higher K^+ concentrations, lower Na^+ concentrations, lower Na^+/K^+ ratio and higher photosynthetic rate than susceptible varieties under salinity stress (Ashraf *et al*., 2004; Tajbakhsh *et al*., 2006).

The differential shrinkage of protoplast volume plays a role in the genotypic difference in K^+ retention. Differences in Na^+ net uptake are attributed to differences in the transport of Na to the shoot. The presence in the amphiploid of fast acting mechanisms able to enhance Na^+/K^+ selectivity at different plant levels minimizes the early build-up of Na^+ concentration, and K^+ substitution by Na^+, in the growing tissue of the leaf (Santa-Maria and Epstein, 2001).

The capacity of plants to tolerate high levels of salinity depends on the ability to exclude salt from the shoot, or to tolerate high concentrations of salt in the leaf (tissue tolerance). Protoplasts from salt tolerant cultivars temporarily take up sodium in the cytosol and have a mechanism for fast extrusion of sodium from that compartment. Calcium blocks the sodium uptake into the cytosol of wheat protoplasts (D'Onofrio *et al*., 2005).

Toxicity from sodium accumulation is an important aspect of salinity stress that has been well studied at the organ and tissue level. However, the effects of salinity on sodium accumulation in the cytosol, where much of the sodium toxicity is thought to occur, are poorly understood due to the difficulty of direct non-invasive measurements of ion activities in living cells. The Na^+-sensing fluorescent probe sodium-binding benzofuran isophthalate (SBFI) and the K^+-sensing fluorescent probe potassium-binding benzofuran isophthalate (PBFI) were used to quantify Na^+ and K^+ activity in living root hairs under salinity stress. SBFI and, to a lesser extent, PBFI are useful tools for quantifying the dynamics of ion activities in the cytosols of living plant cells (Halperin and Lynch, 2003).

Among the most common effects of salinity is the growth inhibition by Na^+ toxicity. Vacuolar Na^+/H^+ antiporters have been suggested to be involved in sequestering Na^+ into vacuoles, thus preventing toxic effects of Na^+ in the cytoplasm. The expression of endogenous vacuolar Na^+/H^+ antiporters relates to the salt resistance of wheat (*Triticum aestivum* L.) genotypes that differ in Na^+ translocation from root to the shoot and Na^+ accumulation in the young and old leaves. The expression of endogenous vacuolar Na^+/H^+ antiporters in roots and shoots is higher in the salt-resistant genotype. However, within a genotype there might be a little difference in the expression of vacuolar Na^+/H^+ antiporters between shoots and roots, and between cortical and stelar root parts. It is suggested that the higher expression of endogenous vacuolar Na^+/H^+ antiporters in roots and shoots of the salt-resistant wheat genotypes facilitate Na^+ exclusion from the cytoplasm of its shoot cells and improves its salt resistance (Saqib *et al*., 2005).

Biochemical mechanism of salinity tolerance

Some of the major sugar components are involved in the adaptive processes of salt stresses in wheat. Tolerant genotypes accumulate more soluble carbohydrate. The reducing sugars, sucrose, and fructans also increase their concentration. Further the drought tolerant varieties accumulate sucrose to a greater level. Total water-soluble carbohydrate (WSC), might be a useful marker for selecting genotypes that are more drought or salt tolerant. An increase in monosaccharides and the delayed response is an increase in fructan (Kerepesi and Galiba, 2000).

The amount of lipoic acid in wheat increased with growth in shoots and decreased in roots under salinity. The ascorbate pool exerted its positive influence especially in the shoots, while ascorbate peroxidase and glutathione reductase activities are differently modulated by the salinity level (D'Amico *et al*., 2004).

Proline and sugar concentrations increase (Karimi *et al*., 2005) in cultivars of wheat under salinity with a maximum increase at crown root initiation (CRI). Electrolyte leakage increased and chlorophyll content decreased with the plant age. In wheat, plant resistance to salinity increases with the age of plant (Khatkar and Kuhad, 2000). Leaf proline content increased markedly in wheat (Keles and Oncel, 2004). In mutated populations of cauliflower, frost and hydroxyproline resistance are stable traits over repeated *in vitro* sub-cultures and prolonged low temperature storage (Fuller *et al*., 2006). Salinity test indicated that proline acts as an osmoprotectant and its overproduction in transgenic wheat plants results in the increased tolerance to salt (Sawahel and Hassan, 2002).

With decreasing water potential caused by increasing concentrations of NaCl, germination percentage, fresh weight of seedlings and protein amount markedly decrease, whereas proline amount slightly increases (Morant-Avice *et al*., 1998). The activities of pyrroline-5-carboxylate synthetase (P5CS), ornithine aminotransferase (OAT), and proline dehydrogenase (PDH) peak at -0.2 MPa water potential. Germination percentage and amounts of proline and protein increases as germination temperature elevated to 25ºC from 15ºC, and decrease above 25ºC (Song *et al*., 2005).

Higher soluble carbohydrates and fructan in leaves, roots and maturing seeds of saline stressed plants indicate that their accumulation may help plant to tolerate salinity. Salt-sensitive cultivars accumulate less soluble sugars in the maturing seeds and higher soluble sugars in the apices, which might be used as an indicator in screening wheat genotypes for salinity tolerance (Kafi *et al*., 2003).

In saline conditions paclobutrazol (PBZ) also promotes a process of osmotic adjustment, probably through the accumulation of organic osmotic compounds (Banon *et al*., 2005).

Plant dehydration is commonly caused by some adverse environmental conditions such as salinity, drought and freezing. Differences in the level of cell tolerance to osmotic, saline and freezing stress are related to their different capacity of ABA synthesis under stress conditions (Perales *et al*., 2005). ABA wheat seed pre-treatment increased the plant growth of salinity sensitive wheat variety. ABA pre-treatment caused new proteins to be synthesized-induced proteins, were of molecular weights 15, 18 and 23 kDa (Din and Flowers, 2002).

Wheat germ agglutinin (WGA) was induced in 4-day-old wheat (*Triticum aestivum*) seedlings by 0.3 M NaCl and 3.7 mM ABA accumulation under conditions of suppressed transcription and translation owing to some rapid mechanisms controlling the level of this protein. Exogenous WGA could protect wheat seedlings against salinity by preventing the salt-induced inhibition of mitotic activity in the apical root meristem (Shakirova *et al*., 2003).

Betaine on freeze tolerance

Wheat cultivars accumulate the osmolyte betaine during the cold acclimation period. A subset of low temperature responsive genes, such as the wcor410, and wcor413, are induced by salinity or drought stresses on exogenous betaine accumulation. Betaine treatment improves the tolerance to photoinhibition of PSII and the steady-state yield of electron transport over PSII in a manner that mimicked cold-acclimated plants. Betaine improves freezing tolerance by eliciting some of the genetic and physiological responses associated with cold acclimation (Allard *et al*., 1998).

Compounds in alleviating tolerance

Under osmotic and salt stresses a production of cadaverine is observed in plants. A study demonstrates that under salt-stress putrescine catabolism (*via* diamine oxidase) can contribute to proline (a compatible osmolyte) accumulation (Bouchereau *et al*., 1999).

Exogenously application of putrescine caused a considerable decline in Na^+ level and increased K^+ level in leaf of the mustard seedlings under low salinity and metal (Pb/Cd) stress. Putrescine reversed the Na^+ accumulation in leaf under high saline and metal stress conditions up to 35%. IAA application to the plant exposed to metal and salinity stress also checked the increase in Na^+ level. The putrescine alleviated the growth in metal and salinity stressed plant through maintaining high K^+ level and lowering Na^+ in leaf (Lakra *et al*., 2006).

Pre-treatment with spermidine was effective in reducing shoot Cl^- under saline conditions in spring wheat. In the tolerant cultivars root Na^+ decreased. Under saline conditions spermine, spermidine and putrescine are effective in alleviating the adverse effect of salt stress on wheat plants (Iqbal and Ashraf, 2005).

Kinetin application ameliorates the deleterious effects of salinity and oxygen deficiency. It reduces Na^+, Ca^{2+} and Cl^- accumulation and improve K^+ uptake under salinity and waterlogging stresses. Increased K^+/Na^+ ratio helps the plants to avoid Na^+ toxicity and enhances shoot growth and grain yiel (Gadallah, 1999). Seed treatment with 2,4-D led to improvement in the number of productive tillers, yield of straw and grain, and grain protein content of all wheats grown in saline soil (Gulnaz *et al*., 1999).

Seed enhancement (seed priming) with cytokinins is reported to increase plant salt tolerance. Cytokinins could increase salt tolerance in wheat plants by interacting with other plant hormones, especially auxins and ABA. Kinetin increased the early seedling growth in salt tolerant cultivars. Kinetin-priming improved growth and grain yield under salt stress (Iqbal *et al*., 2006, Iqbal and Ashraf, 2006).

Pre-soaking wheat grain in GA_3 alleviated the inhibition of the cumulative leaf area, improved water status of leaves by increasing their relative water content and, at the same time, reduced the accumulated free-ABA in developing leaves as well as the amino acids in harvested grains of seawater-treated plants. Furthermore, grain pretreatment with GA_3 induced a dramatic increase in proline relative to total amino acids (Aldesuquy, 1998). Gibberellic acid mitigated the effect of seawater salinity stress on wheat productivity (Aldesuquy and Ibrahim, 2002).

Root pretreatment with salicylate, promotes the formation of hydrogen peroxide H_2O_2, and prevents the initial increase in hydraulic conductivity (Lp) (Ktitorova *et al*., 2002).

Inoculation with exopolysaccharide- (EPS-) producing bacterial strains restrict Na^+ uptake by roots of wheat seedlings grown in a moderately saline soil. The decreased Na^+ uptake by roots was probably caused by a reduced passive (apoplasmic) flow of Na^+ into the stele due to the higher proportion of the root zones covered with soil sheaths (Ashraf *et al*., 2004).

Application of Zn had a positive effect on salt tolerance of plants (Khoshgoftar *et al*., 2006). Calcium can ameliorate Na^+ toxicity in plants by decreasing Na^+ influx through nonselective cation channels.

Increasing external Ca^{2+} concentration reduce the accumulation of Na^+ in the shoot, the effects are greater in the low Na^+ genotypes, and greater as the salinity increases, indicating that the plateau in shoot Na^+ concentration is relied on the maintenance of a minimal Ca^{2+} activity of 1 µM. Increasing external Ca^{2+} concentration did not reduce the root Na^+ concentration, however, suggested that Ca^{2+} influences the loading of Na^+ in the xylem (Husain *et al*., 2004).

Elevated external Ca^{2+} concentration also inhibits Na^+-induced K^+ efflux through outwardly directed, K^+-permeable channels. K^+ efflux channels in roots and leaves showed different Ca^{2+} and Na^+ sensitivities, suggesting that these organs may employ different strategies to withstand salinity (Shabala *et al*., 2006).

Spermidine, spermine polyamine seed pretreatment reduced leaf free abscisic acid (ABA) but putrescine (Put) priming caused a maximum increase in leaf ABA concentration in wheat (*Triticum aestivum* L.) cultivars MH-97 under saline conditions. Spermidine and Spermine are very effective in enhancing salicylic acid (SA) concentration (Iqbal *et al*., 2006).

Antioxidative responses

A higher constitutional content of ascorbate in wheat cultivars enables to induce ascorbate synthesis when subjected to salt stress. Higher levels of NaCl results in increasing glutathione contents in the roots likely for an increased requirement of antioxidants in the organs that firstly suffer stress (Meneguzzo *et al*., 1999).

Genetics of tolerance

A genomic map of major loci and QTLs affecting stress tolerance in Triticeae identified the crucial role of the group 5 chromosomes, where the highest concentration of QTLs and major loci controlling plant's adaptation to the environment (heading date, frost and salt tolerance) has been found. In addition, a conserved region with a major role in drought tolerance has been localized to the group 7 chromosomes. Extensive molecular biological studies have led to the cloning of many stress-related genes and responsive elements. The expression of some stress-related genes was shown to be linked to stress-tolerant QTLs, suggesting that these genes may represent the molecular basis of stress tolerance. The development of suitable genetic tools will allow the role of stress-related sequences and their relationship with stress-tolerant loci to be established in the near future (Cattivelli *et al*., 2002).

Salinity tolerance and yield potential appears to be controlled by different gene complexes (Singh and Singh, 2000).

Intervarietal variation for salt tolerance in wheat is controlled by genes which could be transferred to sensitive genotypes to improve their tolerance, and that the K^+/Na^+ ratio of the youngest leaf could be used to screen for salt tolerance (Salam *et al*., 1999).

Salinity affects large areas of agricultural land and all major crop species are intolerant to high levels of sodium ions. The principal route for Na^+ uptake into plant cells remains to be identified. Non-selective ion channels and high-affinity potassium transporters have emerged as potential pathways for Na^+ entry. A third candidate for Na^+ transport into plant cells is a low-affinity cation transporter represented by the wheat protein LCT1, which is known to be permeable for a wide range of cations when expressed in yeast (*Saccharomyces cerevisiae*). LCT1 expression results in a strong decrease of intracellular K^+/Na^+ ratio in G19 cells due to the combined effect of enhanced Na^+ accumulation and loss of intracellular K^+. Na^+ uptake through LCT1 was inhibited by K^+ and Ca^{2+} at high concentrations and the addition of these ions rescued growth of LCT1-transformed G19 on saline medium. LCT1 was also shown to mediate the uptake of Li^+ and Cs^+. Expression of two mutants LCT1 cDNAs with N-terminal truncations resulted in decreased Ca^{2+} uptake and increased Na^+ tolerance compared with expression of the full-length LCT1. LCT1 represents a molecular link between Ca^{2+} and Na^+ uptake into plant cells (Amtmann *et al*., 2001).

As the products of abiotic stress and ABA inducible genes are predicted to play an important role in the mechanism of salt tolerance, the expression of transcription factor that recognizes abscisic acid-responsive element (ABRE) is likely to be regulated when plants are exposed to abiotic stress. GTP mediated activation is probably one of the way to regulate the expression of ABRE-binding factor (Gupta *et al*., 1998).

A full-length cDNA for S-adenosylmethionine decarboxylase (SAMDC), a key enzyme involved in the biosynthesis of spermidine and spermine. The deduced polypeptide sequence of TaSAMDC is homologous to SAMDC genes in dicots and monocots. Two or three homologous sequences of TaSAMDC gene are present in the wheat genome. This gene is located on the long arm of the homologous group 2 of the wheat genome and was isolated from wheal (*Triticum aestivum* L.) by using reverse transcription PCR technique. The conserved regions include a proenzyme cleavage site and a putative PEST domain which is characteristic of the rapid protein turnover. Salinity, drought and exogenous ABA can all induce the expression of TaSAMDC, suggesting that this gene is implicated in response of wheat plants to the adverse circumstances (Li and Chen, 2000).

Cellular accumulation of mannitol can alleviate abiotic stress. Ectopic expression of the mtlD gene for the biosynthesis of mannitol in wheat improves tolerance to water stress and salinity (Abebe *et al*., 2003).

Wheat productivity is severely affected by soil salinity mainly due to Na^+ toxicity to plant cells. To improve the yield performance of wheat in saline soils, transgenic wheat expressing a vacuolar Na^+/H^+ antiporter gene AtNHX1 from *Arabidopsis thaliana*, to enhance the plant capacity of reducing cytosolic Na^+ by sequestering Na^+ in the vacuole was generated. The salt tolerance of wheat and grain yield in saline soils can be improved by enhancing the level of the vacuolar Na^+/H^+ antiporter (Xue *et al*., 2004). The amphidiploid material showed greater salinity tolerance than either parent, suggesting the presence of different genes for tolerance in the parents (Noori, 2005).

A number of cold responsive (Cor)/late embryogenesis abundant (Lea) genes are induced by both low temperature (LT) and dehydration. A DREB2 homolog Wdreb2, is the candidate gene for a transcription factor of the Cor/Lea genes. The Wdreb2 expression is activated by cold, drought, salt and exogenous ABA treatment. Two distinct pathways involved in its activation are, a drought and salt stress-responsive pathway and a cold-responsive pathway. The transient expression analysis showed that the Wrab19 expression was directly activated by the WDREB2 transcription factor in wheat cells. Three transcript forms of Wdreb2 (Wdreb2 a, Wdreb2 b and Wdreb2 g) are produced through alternative splicing. Under drought and salt stress conditions, the amount of the Wdreb2 b form remains fairly constant, while those of the Wdreb2 a and Wdreb2 ? forms show transient increase. Thus, under the LT and drought/salt stress conditions the amount of the WDREB2 transcription factors in wheat is differentially controlled by the level of transcription and alternative splicing (Egawa *et al*., 2006).

Gene expression profiles of group 2 (dehydrins) and group 4 Late embryogenesis abundant (Lea) genes in developing seeds of *Triticum* *durum* and *T. aestivum* and in coleoptiles and coleorhizae of *T. durum* seedlings, the five genes exhibited clear differences in their accumulation pattern in wheat seed and in response to dehydration, low temperature, salinity and ABA. Td29b, Td16 and Td27e gene transcripts accumulate late in embryogenesis as expected for Lea genes, Td11 gene transcripts were present throughout seed development whereas no Td25a gene transcripts were detected in seeds. Drastic changes in the relative levels of Td29b, Td16, Td27e and Td11 transcripts occurred at the shift between the cell expansion and desiccation phases. All genes except the Td11 gene are more highly induced by dehydration in coleorhizae than in coleoptiles. In contrast, response to low temperature, salinity or ABA is higher in coleoptiles than in coleorhizae. Depending on both the gene and on the type of stress, a wide range of induction levels (8- to 100,000-fold) was observed (Ali-Benali *et al*., 2005).

Breeding for adaptation to abiotic stress is extremely challenging due to the complexity of the target environments as well as that of the stress-adaptive mechanisms adopted by plants. Currently the following groups of candidate traits are being considered for drought adaptation in wheat: traits relating to: (i) pre-anthesis growth, (ii) water extraction, (iii) water use efficiency, (iv) photo-protection (Reynolds *et al*., 2005). A number of mechanisms relating to root function have potential to ameliorate drought stress. From an agronomic point of view, crop water use efficiency can be increased by exploiting the stress-adaptive mechanism whereby leaves reduce transpiration rate in response to a chemical root signal in response to drying soil. While there is limited genetic diversity for adaptation to salinity in wheat, tolerance has been found in the ancestral genomes of polyploid wheat and their relatives associated with sodium exclusion into the xylem.

Spatial variability

The electromagnetic surveys and geostatistical techniques indicated that salinity ECe is spatially distributed. It varies between 4.9 and 15.4 dS m^{-1}, with within-field coefficients of variation between 37 and 79% (Isla *et al*., 2003).

Strategy

The original population and the sub-populations produced during the selection process (two cycle 1 and two cycle 2 populations) are to be evaluated for their germination-emergence ability under saline conditions in the laboratory (in trays with moist folded filter paper) and in a saline field. Through the selection pressure is higher on emergence than on germination, consistent responses to selection in the laboratory are evident only for germination. Field emergence in an artificially salinized soil confirms the effectiveness of the selection procedures to shift populations in the desired direction (Igartua and Gracia, 1998).

The best strategy for increasing the productivity in moderately salt-affected soils (average field ECe between 5 and 7 dS m^{-1} is to breed and grow high potential yielding durum wheat cultivars. On the other hand, breeding for increased productivity in highly salinized soils (average field ECe around 15 dS m^{-1} should be based, at least at the parental line's selection stage, on the combination index B (ECe50 Ym 10^{-3}) which takes into account both the potential yield and the salinity tolerance of crops (Isla *et al*., 2003).

Management

Consequent to population growth and high living standards in several and and semi-arid regions, competition for freshwater among different water-use sectors is expected to increase vis-a-vis its decreased allocation to irrigation. Non-conventional water resources, such as saline and/or sodic drainage and groundwater represent complementary supply to narrow the gap between freshwater availability and demand (Murtaza *et al*., 2006). Low-cost drip irrigation has already been successfully implemented in sub-Saharan Africa and has the potential to contribute to improved and sustainable crop production for smallholder farmers (Karlberg and de Vries, 2004).

Increasing the productivity of water and making use of poor quality waters in agriculture will play a vital role in easing competition for scarce water resources, prevention of environmental degradation and provision of food security. There are two major approaches to improving and sustaining productivity in a saline environment: modifying the environment to suit the plant and modifying the plant to suit the environment. Some important interventions include appropriate crop/variety selection, blending saline/alkali and fresh water to keep the resultant salinity below threshold, or their cyclic application by scheduling irrigation with salty water at less salt sensitive stages. The other viable options include salinity tolerant agro-forestry systems and bio-saline agriculture (Sharma and Minhas, 2005).

Prospects for improving salt tolerance in wheat and barley include the use of: (i) intra-specific variation, (ii) variation for salt tolerance in the progenitors of these cereals, (iii) wide-hybridisation with halophytic 'wild' relatives (an option for wheat, but not barley), and (iv) transgenic techniques (Colmer *et al*., 2005).

Screening for salinity

Screening techniques for selecting salt-tolerant progeny in breeding programs in which genes for salinity tolerance have been introduced by either conventional breeding or genetic engineering showed that the biomass or leaf elongation rates revealed large decreases in growth rate due to the osmotic effect. Specific traits Na^+ exclusion correlated well with salinity tolerance in the durum subspecies, and K^+/Na^+ discrimination correlated to a lesser degree. Both traits were environmentally robust, being independent of root temperature and factors that might influence transpiration rates such as light level. In four *T. turgidum* subspecies there was no correlation between salinity tolerance and Na^+ accumulation or K^+/Na^+ discrimination. The trait of tolerance of high internal Na^+ can be assessed indirectly, by measuring chlorophyll retention. Factors affecting field performance of genotypes are to be selected by trait-based techniques (Munns and James, 2003).

Salt tolerance in the genus *Triticum* is associated with low accumulation of Na^+ in leaves. Durum and other tetraploid wheats generally have high accumulation of Na^+ relative to bread wheat, and are salt sensitive. Realised heritabilities across populations indicate good response to selection for low Na^+ accumulation in the F_2 generation. The simple genetic control of Na^+ accumulation suggests relative ease of selection of lines with low Na^+ accumulation. However, presence of dominance will require selection to be delayed until after 1 or 2 generations of inbreeding, or after progeny-testing of selected low Na^+ accumulation families (Munns *et al*., 2003).

An increase in tiller number per plant and spikelet number per spike will improve the salt tolerance of wheat genotypes in breeding programs (El-Hendawy *et al*., 2005).

Physiological mechanisms that underlie traits for salt tolerance could be used to identify new genetic sources of salt tolerance. Important mechanisms of tolerance involve Na^+ exclusion from the transpiration stream, sequestration of Na^+ and Cl^- in the vacuoles of root and leaf cells, and other processes that promote fast growth despite the osmotic stress of the salt outside the roots. Precise phenotyping is the key to finding and introducing new genes for salt tolerance into crop plants (Munns *et al*., 2002, 2006).

The characteristics of the salt tolerant variety are: a shorter growing season and earlier senescence; a higher pre-dawn leaf water potential; a stronger osmotic adjustment; a better maintenance of the number of productive stems per plant. Salt tolerance of durum wheat corresponds with drought tolerance because the tolerance is caused by earlier senescence and stronger osmotic adjustment, both reducing the transpiration of the plant (Katerji *et al*., 2005).

There is considerable variability in salt tolerance amongst members of the Triticeae, with the tribe even containing a number of halophytes. Most investigators have concentrated on differences in ion accumulation in leaves, describing a desirable phenotype with low leaf Na^+ concentration and a high K^+/Na^+ ratio. The sources of Na^+ 'exclusion' amongst the various genomes that make up tetraploid (AABB) durum wheat (*Triticum turgidum* L. ssp. *durum*), hexaploid (AABBDD) bread wheat (*Triticum aestivum* L. ssp. *aestivum*), and wild relatives (e.g. *Aegilops* spp., *Thinopyrum spp., Elytrigia elongata syn., Lophopyrum elongatum, Hordeum* spp.). K^+/Na^+ ratios were lower in the durum parents than in the elite synthetics, confirming that the trait was present in the synthetics, and demonstrating its successful transfer from wheat ancestor *Aegilops tauschii* to the synthetic hexaploid wheat (2n=6x=42, AABBDD) (Pritchard *et al*., 2002).

Although there has been a great deal of work on the development of salt-tolerant wheat over the years, there has been little success in carrying the advances in understanding the mechanisms of salt tolerance through to improved yields for poor farmers in saline lands. This may be due to neglect of the interactions between salinity and waterlogging where such stresses occur. Use of the relationship between leaf production and senescence is evaluated as a technique for the simultaneous screening of wheat for salinity and waterlogging tolerance, and found unsuitable. However, the inverse relationship between the numbers of live and dead leaves allowed the identification of genotypes with higher than expected leaf production, which would be likely to have better aerenchyma production, as well as good root growth. A possible linkage exists between early maturity and high sodium and chloride uptake and low yields under saline conditions in a mapping population of Chinese Spring × SQ1, a low ABA line. This is a potentially serious constraint on the development of new salt-tolerant wheat for India, Pakistan and other regions where temperatures rise sharply before harvest, although further work will be needed to see if the linkage exists in other genotypes (Hollington *et al*., 2002).

The halophytes display a capacity for Na^+ 'exclusion', and in some cases Cl^- 'exclusion', even at relatively high salinity. Significantly, it is possible to hybridize several wild species in the Triticeae with durum and bread wheat. Progenitors have been used to make synthetic hexaploids. Examples of improved Na^+ 'exclusion' and enhanced salt tolerance in various derivatives from these various hybridization programmes are given. As several sources of improved Na^+ 'exclusion' are now known to reside on different chromosomes in various genomes of species in the Triticeae, further work to identify the underlying mechanisms and then to pyramid the controlling genes for the various traits, that could act additively or even synergistically, might enable substantial gains in salt tolerance to be achieved (Colmer *et al*., 2006).

Salinity levels soils can range from very slight to very severe within a few metres. Such variability makes it impossible to evaluate the salt tolerance of crops in the field. Canadian engineers have overcome this difficulty by fabricating an environmentally-controlled testing facility near Swift Current, Saskatchewan. Plants growing in sand tanks and irrigated with hydroponics can be evaluated from emergence through maturity. Salt tolerance response functions have been determined for wheat, barley, alfalfa, kochia, quinoa, and perennial forage grasses. The facility can serve private companies and producer organizations through the Western Region Business Development Office of Agriculture and Agri-Food Canada (Steppuhn, 1999).

Salinity and waterlogging are having substantial adverse social and economic effects in many arid and semiarid regions that are irrigated. In addition to this, waterlogging is a serious problem affecting irrigated agriculture. In rice tract or soils having dense structure due to relatively high clay contents and other salt-affected areas having associated problem of waterlogging, the wheat crop typically suffers a dual stress of oxygen shortage and moderate salinity (Akhtar *et al*., 2002).

Exposure to high ambient levels of NaCl affects plant water relations and creates ionic stress in the form of the cellular accumulation of Cl^- and, in particular, Na^+ ions. A genomics approach can greatly help with the identification of genes, and therefore potentially gene products, that are involved in plant salinity. The efficacy of genomics approaches in isolation is low due to large inherent variability and the exclusion of gene products that are predominantly regulated post-transcriptionally. In conjunction with complementary approaches, however, transcriptomics can help identify important transcripts and relevant associations between physiological processes. This analysis identified (i) vascular K^+ circulation, (ii) root shoot translocation of Ca^{2+}, and (iii) transition metal homeostasis as potentially important aspects of the plant response to salt stress (Maathuis, 2006).

Salinity tolerant crops

Variation both among and within a number of crop species in response to soil salinity is present and in most of cases is under genetic control. Spring wheat possesses a great magnitude of intra-specific variation for salt tolerance. Mechanism of salt tolerance in these genotypes may be associated with particular reference to ion accumulation in different plant parts, water relations and gas exchange characteristics The high salt tolerance is associated with its low accumulation of Na-divided by in the leaves (Ashraf, 2002).

Primitive bread wheat varieties 236/1 and 245/1 have the highest salt tolerance potential as they showed dry matter reduction less than 50% at the highest salinity level (Sarwar *et al*., 2003).

The salinity tolerance of a crop relates to its inherent ability to yield economic product as root-zone salinity increases. Barley (*Hordeum vulgare* L.) ranks as one of the more salt-tolerant of the annual cereal grain crops. The salinity tolerance of a crop relates to its inherent ability to yield economic product while subjected to root-zone salinity. Tall wheatgrass [*Thinopyrum ponticum* (Podp.) Liu & Wang, previously *Agropyron elongatum* (Horst.) Beauv.] ranks as one of the most salt-tolerant forage crops (Steppuhn and Asay, 2005). The salinity tolerance of the canola cultivars equalled that of Harrington barley (Steppuhn and Raney, 2005).

Salt tolerance in bread wheat is linked with a locus on the D genome that results in low Na^+ uptake and enhanced K^+/Na^+ discrimination. Selections for salt tolerance include screening for low Na^+ uptake and enhanced K^+/Na^+ discrimination. These selections have the potential for improving salt tolerance in durum wheat breeding programs (Munns *et al*., 1999). Salt tolerance in *B.carinata* varies with the change in stage of its life cycle. Selection based at one particular stage may not produce individuals tolerant at all growth stages (Ashraf and Sharif, 1998).

Abiotic stresses are static mechanisms that tend to be more durable due to the absence of pathogen influence. Three abiotic stresses of significance deal with heat, drought and salinity tolerance. Unique genetic diversity in the wheat family resides in three gene pools; primary, secondary, and tertiary. Harnessing this resource has a simple to complex range based upon the species genetic distance as compared to the three bread wheat genomes; 2n=6x=42, AABBDD. The primary gene pool species are relatively simple to exploit, and of these *Aegilops tauschii* (2n=2x=14, DD) has a priority. The synthetic hexaploid germplasm developed from combinations of this grasses several accessions with *Triticum turgidum* L., provides a resource that possesses superb potential for transferring salt tolerance genes into wheat cultivars. The homologous association of the D genome provides a rapid output for breeding, and whean combined with doubled haploidy protocols end-products emerge even more swiftly. Data are presented to substantitate the salt tolerance potential of some of these D genome synthetic hexaploid wheats. A cytogenetic manipulation strategy promising multiple wheat/alien chromosomal exchanges,mediated by the ph gene action and facilitated by PCR molecular diagnostics has been under study. A tester set of reportedly tolerant cultivars and land races is in our resource (Mujeeb-Kazi and De Leon, 2002).

It is suggested that breeding for drought/salinity tolerance requires the identification of traits for phenology and those contributing to yield so that these can be pyramided using conventional means (Khanna-Chopra and Sinha, 1998).

Water use efficiency-salinity

Recent studies have shown that carbon isotope composition of a plant may be a useful criterion to assess water use efficiency in C_3 plants and, therefore, an effective method to screen genotypes for improved drought resistance. ^{13}C isotope discrimination can be an effective method to screen genotypes of wheat with a high drought resistance in soils affected by salinity and gypsum addition (Arslan *et al*., 1999).

Vegetable crops

Vegetables have great demand owing to important sources of vitamins and minerals for human beings. The productivity of vegetable is highly affected by salinity. Several researches have been undertaken to investigate the effect of salinity on germination and seedling growth, and its effect on the physiological and biochemical reactions of various vegetable crops. An increase in salinity reduces the germination percentage and seedling growth and impairs the enzymatic activities, thereby affecting the growth and the productivity of the vegetables. Variations exist among crop species in response to salinity levels. Chinese cabbage, leaf lettuce and carrot were highly sensitive at high salinity, while radish, celery, tomato, chicory and cowpea were tolerant to salinity. Under EC various phytotoxicity symptoms appeared such as stunted leaves, chlorosis and necrosis of leaf margins, and root tip dieback. With irrigation with sea water, several interactions occur among ions such as sodium reduces the uptake of potassium due to ion antagonism and chloride antagonizes the uptake of nitrate. Decreased iron concentrations induced chlorosis. The uptake of phosphate increased significantly in response to ion balance. Na^+ and K^+ may play a significant role in maintaining cellular turgor under salinity. Osmotic adjustment, ion balance and Na/K ratio are some of the mechanisms of tolerance to salinity

Effect

Germination and seedling growth

Several studies have revealed that salinity affects germination and seedling growth of vegetable crop species.

It is assessed that percentage of germination decreased and germination was delayed at matric potentials lower than -0.2 MPa. Moderate water stress caused a gradual decrease in shoot fresh weight and a significant increase in root growth (Schmidhalter and Oertli, 1989a, b).

Cucci *et al.* (1994) reported that that the salinity ranged from 6 to 16 dS m^{-1}, with bean and egg-plant as the most sensitive, and chicory and spinach as the most resistant.

A study has been made by Lombardo and Saladino (1997) to test the influence of saline water on seed germination of four vegetable crops: endive (*Cichorium endivia* L.), chicory (*Cichorium intybus* L.), carrot (*Daucus carota* L.), curly parsley (*Petroselinum crispum* L.); of four forage crops: berseem (*Trifolium alexandrinum* L.), vetch (*Vicia sativa* L.), alfalfa (*Medicago sativa* L.) and sulla (*Hedysarum coronarium* L.) and one of grain legume: lentil (*Lens culinaris* L.) and are reported by the AA. The results revealed that, with an increase in water electric conducibility (EC_w), germination of the different vegetable seeds tested significantly decreased, showing large variability to salinity tolerance among species.

Choi *et al*. (2003) investigated the responses to varying electrical conductivity (EC) levels in soils on growth of leafy and root vegetables of 18 cultivars of nine vegetable crops. Seedling emergence of Chinese cabbage and leaf lettuce reduced markedly in soils with EC values of 2.5 dS m^{-1} or higher. Radish exhibited good tolerance, whereas carrot showed poor tolerance to high EC. Best growth of Chinese cabbage and cabbage was obtained with EC 1.5 dS m^{-1}, whereas leafy lettuce and spinach showed best growth at EC 1.0 dS m^{-1}.

Maiti *et al.* (2004) working on salinity tolerance of 11 vegetable crop species of Mexican highlands under different concentrations at the germination and seedling stage reported significant variation in their tolerance to salinity conditions. Celery exhibited higher level of tolerance at germination stage, followed by cabbage, beet leaves, green tomato and the lettuce. Small gourd, spinach, pea and carrot were susceptible to salinity.

Growth and productivity

Several studies had documented that salinity affected the quality and productivity of vegetables. A study on the sodium tolerance of 10 vegetable crops (aubergines, tomatoes, Indian beans (*Lablab purpureus*), okras, cowpeas and various gourds) on experimental plots irrigated with water containing 2.8 or 12 meq of residual sodium carbonate (RSC) L^{-1}. With irrigation at 12 meq RSC L^{-1}, tomatoes and cowpeas were the most tolerant crops (Sube Singh and Margal, 1991).

Yo and Shaw (1990) reported salinity tolerance of various crops. If supplemental irrigation is used (as is typical of most of Queensland), then significant leaching of salts occurs and leaching would exceed 15%. Jaradat (1999), reported genetic variation of salt tolerance in indigenous halophytes and glycophytes including vegetable crops.

Pascale and Barbieri (1995) reported that salinity reduced gas exchange rates and stomatal conductance in lettuces. Soil salinity reduced the product quality of lettuces and endives and induced more tip burn and necrotic symptoms under saline-sodic conditions; fennel heart length, width, and thickness were also significantly reduced grown under salt-affected plots.

Kowalski and Palada (1995) under a series of greenhouse experiments determined the effects of different sea water concentrations on the growth of tomatoes [*Lycopersicon esculentum* (L.) var. Heatwave], bell pepper [*Capsicum annuum* (L.) var. California Wonder], and sweet basil (*Ocimum basilicum* L.) at two different stages of growth (seedling and reproductive). Results revealed that species showed variation in tolerance to the percentage of sea water.

An evaluation of thirty potato varieties under saline, sodic and normal soil conditions revealed that in general, plants grown in saline or sodic soils emerged 1-2 weeks later and were around 30 cm shorter than those in normal soils. Some varieties were tolerant to salinity (Yulin *et al.*, 1995).

Sharma *et al.* (2000) evaluated the performance of seven onion (*Allium cepa* L.) genotypes. During post-rainy season, both under alkali (pH 9.20, 9.45 and 9.70) and salinity (ECe 3.5 and 5.2 dS m^{-1}) stresses besides a non-stress control. The results revealed that with increasing alkali stress, mean seedling fresh weight decreased at pH 9.7 compared to control. Genotypic variability was observed in seedling weight and bulb weight. Final bulb yield was positively correlated with seedling fresh weight both under alkali (r=0.86) and salinity (r=0.56) stresses. Similarly, bulb yield was negatively correlated with Na/K ratio under alkali (r=-0.83) and salinity (r=-0.79) stresses.

Sharma *et al.* (2001) evaluated the salinity tolerance of three leafy vegetable crops *viz.*, spinach (HS 23 and All green), fenugreek (Kasoori, Pusa Early Bunching and HM 57) and coriander (Pusa Harit) under two levels of alkalinity (pH 9.2 and 9.45) and salinity (ECe 3.5 and 5.0 dS m^{-1}). Among the three vegetables, spinach produced three times more biomass compared to fenugreek and coriander both under salinity and alkalinity stresses. These findings support the ionic uptake behaviour of these crops and their cultivars.

Calcium deficiency is usually related to the inability of the plant to translocate adequate calcium to the affected plant part. Sufficient root growth is essential for uptake of calcium. An abundant supply of N increases the growing rate, and owing to high growing rates. Ca deficiency injury on plants increased. Increased light period and/or light intensity increases the incidence of Ca deficiency symptoms on plants. Higher temperature results in increased level of tipburn injury on plants. Foliar Ca sprays are used to correct deficiencies (Kleemann, 2000).

Mechanism

Physiological and biochemical basis of tolerance to salinity

Water requirement of carrots is affected by salinity, nutrient supply and soil aeration in a silty soil under field and growth chamber conditions. Soil nutrient level (mainly nitrate) had a greater effect on the evapotranspiration (ET) coefficient than soil salinity or aeration. ET coefficient did not change upto a salt concentration of 16 mS cm^{-1} in the soil solution but increased to 600-700 L kg^{-1} RDW at higher salt concentrations. Low soil nutrient levels increased ET coefficients to >1000 L kg^{-1} RDW and greatly decreased ET efficiency when salinity was high and soil aeration was insufficient. Root DW production was more negatively affected than ET efficiency by low soil nutrient levels, salinity or poor soil aeration (Schmidhalter and Oertli, 1989a, b).

A transpiration activated quantity called the salinity stress index (SSI) is introduced and defined in terms of the xylem solute flux (J_s) and the shoot volume production rate (V_s). DW increased between 15 and 25°C and decreased between 25 and 30°C. This suggested that salt tolerance in tomatoes was not a fixed quantity under genetic control but in fact could increase with increasing root temperature. In contrast, when shoot dry weight was plotted as a function of SSI, there appeared to be a common threshold value at each temperature studied, even though Js and V_s were significantly different. It was suggested that for tomatoes, salt loading of the shoot relative to shoot growth was the critical factor affecting dry matter production and the plant salt tolerance did not vary with root temperature (Dalton and Poss, 1990).

In a study, tomato, cucumber and sweet pepper were grown in hydroponic systems in which the nutrient solutions were recirculated. Most fruit quality characteristics, decreased by increasing blossom-end rot at higher EC values with special reference for sweet pepper, with NaCl addition. The absorption of Na and Cl varied among crop species and with the Na and Cl concentration (Sonneveld and Van Der Burg, 1991).

Ullah *et al.* (1993) reported that salt stresses increased the concentrations of sodium, magnesium and chloride ions in faba bean. Sodium reduced the uptake of potassium due to ion antagonism. Decreased iron concentrations induced chlorosis. Chloride antagonized the uptake of nitrate. Phosphate increased significantly in response to ion balance. Significant increases in glucose, fructose, in some cases sucrose, proline and calcium contents in faba beans showed tendency of osmotic adjustment against salt stress. Grain as well as straw yields of faba beans decreased significantly by artificial salinity.

Oxalate and nitrate are considered as antinutritional factors in many vegetable crops including *Amaranthus*. A study has been made on the influence of salinity on the level of these two metabolites in leaves of three *Amaranthus* species (*A. caudatus* L., *A. hypochondriacus* L. and *A. paniculatus* L.). It was assessed that the level of total oxalic acid and soluble oxalic acid faction decreased by salt treatment, but this decrease was more pronounced in *A. hypochondriacs*. Salinity also decreased markedly in the amount of nitrates in the leaf tissue in all the three *Amaranthus* species (Gaikwad and Chavan, 1995).

Salinity affects the productivity, fruit quality and physiological processes of vegetable crops. Fruit yield was decreased at any salt concentration. Fruit quality, based on chemical constituents (mainly glucose content), taste and shelf life, and production and dry weight accumulation increased when the crop was irrigated with water containing salts. The quality increase is owing to a rise in glucose and ions (mainly chlorides). Salinity also decreased fruit size, but had a smaller effect on fruit number. The decrease in fruit size was partly due to their increase in solute content. It is recommended that an allocation of solutes especially to fruits should have taken into account for their osmotic adjustments (Plant, 1997).

Seedling emergence of Chinese cabbage and leaf lettuce was markedly reduced in soils with EC values of 2.5 dS cm^{-1} or higher. Radish exhibited good tolerance, whereas carrot showed poor tolerance to high EC. The best growth of Chinese cabbage and cabbage was obtained with EC 1.5 dS cm^{-1}, whereas leafy lettuce and spinach showed the best growth at EC 1.0 dS cm^{-1} (Choi *et al.*, 2002).

Jumberi Achmadi *et al.* (2002) studied the responses of vegetable crops to salinity and sodicity in relation to ionic balance and ability to absorb microelements, grown in Tottori sand dune soil with four soil treatments consisting of original soil (exchangeable sodium percentage (ESP=-5.8: Control), saline soil (ESP= 8.8: Saline), saline-sodic soil (ESP=16.2: Sodic 1) and sodic soil (ESP=40.8: Sodic 2). Shoot dry weight (DW) of the three species was smaller with increasing ESP. Growth of asparagus and tomato was reduced in the saline soil and strongly suppressed in both sodic soils. Bean could not survive under saline and sodic conditions. The Na concentration in the shoots of the three species was higher with higher ESP. The suppressed growth of asparagus in the sodic soils was partly due to high concentration ratios of Na to essential cations in the shoots. Higher ability of bean to absorb microelements compared with asparagus and tomato, except for Mn, could not improve growth, due to the inadequate ionic balance in the shoots. It is concluded that ionic balance in the shoots and the ability to absorb low-available microelements control the tolerance to salinity and sodicity of vegetable crops.

Kaya *et al.* (2002) studied the effect of supplementary potassium sulphate applied to the root zone at high NaCl (60 µM) and high pH (8.5). On tomato (*Lycopersicon esculentum*) cultivar Marilyn F_1, cucumber (*Cucumis sativus*) cultivar, Seraset F_1 and pepper (*Capsicum annuum*) cultivar Charliston 52 grown in sand culture for five weeks. Reductions in both dry matter and chlorophyll concentrations were greater for pepper than tomato and cucumber. The deleterious effect of high salinity on plant growth was more striking than that of high pH. Membrane permeability increased with addition of 60 µM NaCl and as the pH increased from 5.5 to 8.5. These increases were greatest for pepper. Supplementary K_2SO_4 decreased membrane permeability in all three species, but significantly different from the control values. Water use was decreased by salinity in cucumber and tomato but increased in pepper compared to control values (Kaya *et al.*, 2002).

The response of two speciality vegetable crops, New Zealand spinach (*Tetragonia tetragonioides* Pall.) and red orach (*Atriplex hortensis* L.), to salt application at three growth stages was investigated by growing the plants with a base nutrient solution in outdoor sand cultures and salinized at 13 (early), 26 (mid) and 42 (late) days after planting (DAP). Both species were salt sensitive at the early seedling stage and became more salt tolerant as time to salinization increased. Both species showed high Na^+ accumulation even at low salinity levels. Examination of K-Na selectivity data indicated that K^+ selectivity increased in both the species with increasing salinity (Wilson *et al.*, 2000).

Production of vegetable crops can be limited by saline irrigation water.Pascale *et al.* (2002), the investigated the long-term effect of irrigation with saline water on soil properties and on responses of field-grown pepper (*Capsicum annuum* L.) plants in these soils. Increasing the electrical conductivity of the irrigation water to 8.5 dS m^{-1} caused a 34% reduction in plant dry weight and a 58% reduction in marketable yield. Leaf and root cellular turgor and net CO_2 assimilation rates of leaves in salt-stressed plants decreased along with a reduction in leaf area and dry matter accumulation. Although high concentrations of Na^+ and Cl^- in the irrigation water did not show significant change in the level of K^+ in leaves and fruit, drought stressed plants contained higher concentrations of leaf K^+ compared to well watered control plants. These results indicate that Na^+ and K^+ may play similar roles in maintaining cellular turgor under salinity and drought stress, respectively.

Calcium deficiency is usually related to the inability of the plant to translocate adequate calcium to the affected plant part. Increasing the level of salinity reduced Ca uptake due to restricted water uptake by high salinity. In the situations of high humidity Ca deficiency injury on plants increased. Increased light period and/or light intensity increases the incidence of Ca deficiency symptoms on plants. Higher temperature results in increased level of tipburn injury on plants. Foliar Ca sprays are used to correct deficiencies (Kleemann, 2000).

Bie *et al.* (2004) studied the responses of two butterhead lettuce (*Lactuca sativa* L.) cultivars ‘P’ and ‘L-2’ under Na_2SO_4 and $NaHCO_3$ salinity stress. With increasing concentration of Na_2SO_4 or $NaHCO_3$, leaf area, shoot dry weight, leaf length and leaf width decreased, photosynthetic rate and stomatal conductance also decreased. $NaHCO_3$ was more toxic to lettuce shoot growth than Na_2SO_4. Leaf necrosis appeared in both cultivars at Na_2SO_4 concentrations above 40 µM, and leaves were chlorotic at $NaHCO_3$ concentrations above 5 µM. The K concentration in the shoot decreased and Na concentration increased with increasing Na_2HCO_3 concentration.

Tedeschi and Menenti (2002a, b) undertook simulation studies of long term saline water use: model validation and evaluation of schedules to determine the impact of saline water on crop yield and soil properties in the Mediterranean environment characterized by hot, dry summers. The increasing concentrations were obtained by adding NaCl to fresh water.

Concerted research activities are directed to demonstrate that with an increase in salinity, there is substantial decrease in germination, seedling growth (Crucci *et al.*, 1994; Lombardo and Saladino, 1997; Choi *et al.*, 2003) and productivity of vegetables (Sharma *et al.*, 2000, 2001). Soil salinity affected product quality of lettuces and endives showing tipburn and necrotic symptoms under saline-sodic conditions; and fennel heart length, width and thickness were also significantly reduced in plants grown under salt-affected plots (Pascale and Barbieri, 1995). Studies have indicated that some vegetable crop species are more tolerant than other species. Chinese cabbage, leaf lettuce and carrot were highly sensitive to high salinity, while radish was tolerant to high EC (Choi *et al.*, 2002). Similarly, tomatoes and cowpeas were the most tolerant crops (Sube Singh and Margal, 1991). Variability in salinity tolerance of different vegetable crops was reported (Maiti *et al*., 2007).

Tolerance of a crop species to salinity is attributed to several factors such as ionic interaction, antagonisn, osmotic balance, some of which may be mentioned below.

The greater accumulation of Na and Cl affected crop growth, but the absorption of Na and Cl varied among crop species and with the Na and Cl concentration, thereby giving opportunity for the selection of desirable species tolerant to this high accumulation of ions (Sonneveld and Van Der Burg, 1991).

Salt stresses increased the concentrations of sodium, magnesium and chloride ions in the plants. In faba bean, sodium reduced the uptake of potassium due to ion antagonism. Decreased iron concentrations induced chlorosis. Chloride antagonized the uptake of nitrate. Phosphate increased significantly in response to ion balance (Ullah *et al.*, 1993).

In a study it was observed that the level of total oxalic acid and soluble oxalic acid faction decreased by salt treatment, but this decrease was more pronounced in *A. hypochondriacs*. Salinity decreased markedly in the amount of nitrates in the leaf tissue in all the three *Amaranthus* species (Gaikwad and Chavan, 1995).

Salinity decreased fruit size, but had a smaller effect on fruit number of several vegetables. The decrease in fruit size was partly due to their increase in solute content. It was suggested that an allocation of solutes specifically to fruits should have taken into account for their osmotic adjustments (Plant, 1997).

The K concentration in the shoot decreased and Na concentration increased with increasing $NaHCO_3$ concentration in lettuce. The reduction in crop growth under $NaHCO_3$ stress may be due to the combined effects of osmotic stress and excess accumulation of Na, while in the $NaHCO_3$ experiment, the growth reduction may be related to the toxicity and high pH rather than water stress or excessive Na (Bie *et al.*, 2004).

Management

Soil salinity research was carried out on a clay loam soil (Haplustoll) in a Mediterranean environment by applying irrigation with commercial NaCl in solution at 0, 1.25, 2.5, 5 and 10 g NaCl L^{-1} (0-1% w/v) on spring-summer vegetable crops at irrigation intervals of 2, 5 and 10 days. Soil samples were analysed for water retention, è (theta) and unsaturated conductivity (K_h) characteristics by calculating the parameters of the Van Genuchten functions. Significant differences on the è and K_h curves were observed. The è curve of the 1% NaCl treatment at both irrigation frequencies had lower values of theta than the 0% NaCl treatment at the same pressure head. Significant differences were observed between the mean values of most of the Van Genuchten's parameters, particularly between the (0%; 2 days) and (1%; 2 days) (Tedeschi *et al.*, 1995).

Ameliorative effects

The rhizobacterium *Bacillius subtilis* FZB24 selected as biocontrol agent was field tested as a promoter for salt-tolerance to two cultivars of eggplant and pepper in saline soil in the Sinai region (Egypt) under the condition of irrigation with ground saline water. It was observed that by using *B. subtilis* FZB24 in the plots irrigated with saline groundwater, the yield increased upto 550% in eggplants, and upto 430% in the pepper cultivars, as compared with unbacterized ones. A study was conducted to investigate the mode of actions of the salt stress tolerance-inducing effect of *B. subtilis* FZB24, with auxin precursors and IAA in tomato seedlings under controlled, axenic conditions and under salt-stress conditions similar to the field experiment. In the model experiments, the pre-treatment of seedlings with millimolare amounts of auxin precursors, tryptophan, indole-3-pyruvic acid or indole-3-acetic aldehyde, 75% growth reduction in untreated seedlings under salt stress could be achieved completely after one week. This was not observed in the same degree in the case of pre-application of auxin (IAA). This supports the hypothesis the salt-stress tolerance is induced in *B. subtilis* FZB24-treated plants by causing the anti-stress effect of *B. subtilis* FZB24 (Bochow *et al.*, 2001).

Caines and Shennan (1999) studied interactive effects of Ca^{2+} and NaCl salinity on the growth of two tomato genotypes differing in Ca^{2+} use efficiency. It was observed that root growth and length appeared to be more sensitive to the effect of $CaCl_2$ treatment alone and to the effects of $CaCl_2 \times NaCl$ treatments. This suggests that both root growth and root length may be used as more sensitive indicators of salinity effects than shoots. Supplemental $CaCl_2$ had shown no ameliorative effect on NaCl stress in shoot growth. It is assumed that the inability of Ca^{2+} to counter Cl^- entry or toxicity may account for the lack of amelioration.

It was found that with sub-irrigation with brackish water in and conditions it is possible to grow salt-sensitive crops, such as green peppers and potatoes. Under this condition, some form of salt leaching occurs. When nitrate enriched water is supplied with sub-irrigation, the nitrate in this water can move upward into the root zone and crop yield can be increased (Patel, 1997).

In California, recycled water blended with well water, is used to irrigate artichokes, broccoli, Brussels sprouts, celery, cauliflower, lettuce and strawberries. In this system, salts, particularly Na and Cl, in the recycled water would reduce yield and quality of their crops. On a long term monitoring of soil samples, it is assessed that using recycled water mixed with well water (2:1 blend of recycled and well water) for vegetable production increased EC_e (saturated paste extract) of the soil profile from 2.0 to 2.9 dS m^{-1} but decreased the sodium adsorption ratio (SAR) from 2.9 to 2.6. The SAR and EC of soil samples from all sites were in a range acceptable for vegetable production (Pratt *et al.*, 2004).

Salinity tolerance in sunflower (*Helianthus annuus* L.)

A good progress has been directed in different aspects related to the effect of salinity on growth, yield and biochemical changes, and its mechanism of tolerance and ameliorative methods of sunflower.

With increasing salinity there was a delay and decrease in seedling emergence and seedling growth showing significant variability among genotypes thereby offering a great scope for selection (Maiti *et al*., 2005a, b; Maiti *et al*., 2007).

Wahid *et al*. (1999) studied phenotypic flexibility in three high yielding sunflower genotypes under NaCl salinity condition. A positive relationship of RGR and NAR with leaf relative growth rate (RLGR) indicated that increased leaf growth rate plays a great role in sustaining plant growth. Therefore, increased RLGR is considered as a reliable indicator of salinity tolerance. It is suggested that the problems of reduced germination can be overcome by enhancing seed rate to optimum plant population.

Kogan *et al*. (2000) studied the effect of pre-treatment with ethanolamine on sunflower. Pre-treatment of seeds with this regulator increased seedling tolerance to saline condition. Betaine levels in seedling treated ethanolamine starting at early seedling stage. Ethanolamine acted as precursor for betain biosynthesis which is responsible for the enhanced growth.

Muralidharudu *et al*. (1999) reported genetic variability among sunflower hybrids and selected several hybrids tolerant to salinity.

The physiological basis of salinity tolerance in sunflower has not studied by some authors. This has been reported by Delgado and Sanchez-Rayu (1998) that the effects of salinity and germination and growth were more prominent at higher salinity levels. Salinity reduced N, P, K, Ca and Mg contents in sunflower seedlings and their distribution. In general salinity reduces the levels of Fe, Cu, Mn and B and their distribution between stem and root. Fe supply in saline environment increases the levels with increasing salinity. In another study, the same authors reported that salinity reduces both both vegetative and reproductive growth and yield. Under high salinity Fe and P supply alleviated salt damage in leaf area and shoot dry mass. Shoot length was adversely affected under high salinity condition. Fe, K and Mn enhanced leaf dry matter, leaf area, stem length, while Fe supply ameliorated shoot biomass. It has been reported that Fe application, particularly in ferrous form cotneracted the effect of salinity on germination and growth, especially at higher salinity level. Salinity reduced N, P, K, Ca and Mg contents in sunflower seedlings and their distribution pattern. N, P, Ca and Mg decreased in roots and N, P, K, Ca and Mg in stem. Fe application increased the contents of some of these elements.

Salinity has been shown to alter a number of physiological processes, including the plant–water relations of some crop species. Sohan *et al*. (1999) examined the initial effects of NaCl salinity on the plant–water relations of sunflower (*Helianthus annuus* L.) and the potential of calcium supplements to ameliorate those effects. Sunflower plants were grown in a controlled-environment and treated solely with 0, 50, 100, or 150 µM of NaCl or the same rates of NaCl plus 10 µM Ca^{2+}. Increasing salinity levels significantly decreased stomatal conductance in the 100 and 150 µM treatments compared to the control and 50 µM treatments, produced significantly more negative water potentials in the 100 and 150 µM treatments compared to the control, and significantly decreased root hydraulic conductance in all treatments compared to the control.

It has been reported by Hebbara *et al*. (2003) that salinity stress affects several physiological parameters leading to poor yield indicating that leaf temperature increased with increasing salinity, while osmotic potential, stomatal conductance and transpiration rate decreased with an increase in soil salinity in all sunflower lines tested.

Rivelli *et al*. (2002) reported that salinity reduced the activity of Rubisco with an increase in salinity. Under severe salt-stress conditions, chlorophyll fluorescence reduced electron transport in the PSII levels. Leaf ionic concentration was correlated with the values of leaf osmotic potential.

Kurdali and Al-Ain (2002) reported that high levels of water salinity caused more inhibition in shoot than in root growth in sunflower. It is suggested that *H. annuus* grown in saline soils can be irrigated with saline water up to 12.3 dS m^{-1} or with gradually increased levels of salinity.

Quintero *et al*. (1998) reported that K^+ status and ABA affect both exudation and hydraulic conductivity in sunflower roots. K starvation and ABA promoted both the flux of exuded Na^+ and the accumulation of Na^+ in the root. It is suggested that ABA acts as a regulating signal for the radial transport of water across the root and that potassium may be an effector of this mechanism.

Santos *et al*. (2002) reported that the growth of *H. annuus* calli was reduced in the presence of Na_2SO_4 and Na concentration increased in stressed calli and plants while , Cl, P, K, and Mg decreased in stressed plants and Ca in shoots. It is concluded that the increase of pyrroline-5-carboxylase reductase (PSCR) ornithine aminotransferase (OAT) activities increased. The increase of PSCR andn GS1 activities are responsible for the decrease of glutamate concentration an increase of proline levels in Na_2SO_4 stressed sunflower cells. The results suggest that salt stress increases the release of endogenous ammonium and that the increase of cytosolic glutamine synthetase (GS1) plays an important role in its elimination.

Davenport *et al*. (2003) investigated the response of antioxidant defense in the adaptive response in salt stress in *H.annuus*. Their results suggest the involment of an enzymatic antioxidant defense system in the adaptive response in salt stressed sunflower plants. In another study, Alvarez *et al*. (2003) stated that in salt adapted calluses, ethylene was related to stress tolerance and ethyle formation was related to senescence. There was a close relationship between proline, polyamines, ethylene and salt tolerance in sunflower tissues.

Santos *et al*. (2004a) reported the regulation of glutamine synthetase expression in sunflower cells exposed to salt and osmotic stress. It is observed that glutamine synthetate activities showed an increase of GS1 activity in NaCl-stressed cells and PEG stress. Plastidial glutamine synthetase decreased (GS2) activity decreased in NaCl-stressed leaves. NaCl and osmotic stresses induced GS1 expression by increasing GSI mRNA and polypeptide leading to increased enzymatic GS1 activity.

Mutlu and Bozcuk (2005) investigated the effects of salt stress (150 µM NaCl) on the levels of free, bound and total polyamine in the leaf tissues of salt-stressed tolerant and susceptible sunflower plants. It is assessed that the amounts of spermine increased in the leaf tissues of sunflower plants subjected to salt stress, while the levels polyamines decreased. The increase of some polyamines suggests their potential role in overcoming the adverse effects of salinity stress.

Several studies have been undertaken to determine biotechnological basis of salinity tolerance in sunflower.

Differential expression of genes regulated in response to drought or salinity stress in sunflower. Five drought regulated cDNA and 12 salinity-regulated cDNA were cloned and sequenced. Thirteen of these cDNAs were confirmed to be expressed differentially in response to drought or salinity stress by quantitative reverse transcriptase polymerase chain reaction (RT-PCR). Results revealed that certain genes respond to both stresses (Liu and Baurd, 2003).

Salt tolerance candidate genes were identified in expressed sequence tag (EST) of sunflower.

Lexer *et al.* (2003) reported selection for salt tolerance quantitative trait loci (QTLs) in wild sunflower hybrids. It is concluded that salt tolerance in *Helianthus* is achieved through increased Ca uptake, coupled with greater exclusion of Na^+ and related mineral ions.

Liu and Baird (2004) identified a novel gene, HaABRCS from *Helianthus annuus* that is upregulated in response to drought, salinity and abicisic acid. A longer cDNA of 812 nucleotides, designated HaABRCS was cloned by rapid amplification of cDNA ends. Three ABA-responsive elements were detected within the HaABCRCS promoter region. This gene is probably an ABA-responsive nuclear protein playing a role in plant stress response.

Dezar *et al.* (2005) identified a Hahb-4, a sunflower-leucine zipper gene is a developmental regulator and confers drought tolerance to *Arabidopsis thaliana* plants. Plants transformed with a construct that bears the Hahb-4 promoter fused to gusA show reporter gene expression in defined cell types and developmental stages that are induced by drought and absicic acid. It is proposed that as Hahb-4 is transcription factor, it may participate in the regulation of the expression of genes involved in developmental responses of plants to dessication. The results of the present studies coincides with the findings of the previous authors that with an increase in salinity there was a decrease in emergence, seedling growth in terms of shoot length and dry weight. It is interesting to note that the sunflower hybrids/tolerant to salinity showed an increase in salinity, although at a higher salinity level there was a decrease, while in the susceptible genotypes root length showed a decrease. Some salinity tolerant hybrids/ parents showed not only an increase in root length, but also produced sufficient fine lateral roots. This is supposed to function as osmotic adjustment for adaptation under saline environment.

Liu and Baird (2003) reported that the ribosomal subunit protein S28 gene from *Helianthus annuus* is down-regulated in response to drought, high salinity and abscisic acid.

Salinity tolerance in cotton (*Gossypium hirsutum* L.)

Introduction

Cotton is the most important natural textile fibre for its highest commercial importance. The productivity of cotton is highly affected owing to poor seedling emergence and seedling vigour. Besides several abiotic factors salinity causes a serious problem affecting seedling emergence and seedling growth of cotton (Sun *et al*., 2000; Javid *et al.*, 2002; Zheng *et al.*, 2002; Ghajari and Zeinali (2003) and Kornejadi *et al*. 2004). Ashraf *et al.* (2002) reported that the increase in NaCl concentration caused the decrease in a-amylase activity and break down of starch into reducing and non-reducing sugars in cotton cultivars.

Sun *et al.* (2000) suggested that salt tolerance of cotton plants at seedling emergence stage may be ameliorated / regulated by soaking seeds in Pix (DPC) and CaCl SUB 2 solutions.

A study has been made on the genotypic variability of salinity tolerance of 15 cotton genotypes at the seedling stage (using distilled water as control, 0.15 M NaCl and 0.20 M NaCl as saline treatments. It is observed that increasing NaCl concentration significantly reduced germination, emergence, seedling shoot and root length, showing considerable variation between the cotton genotypes. High heritability for almost all the salinity tolerant traits offers good scope for selection and genetic improvement of cotton (Maiti *et al.*, 2005). In another study it has been reported that cotton hybrids showed a large variability in salinity tolerance at the seedling stage. Some cotton hybrids have been selected for tolerance to salinity. In this study, root canopy length showed high positive correlation with emergence percentage in all treatments (salinity treatments indicating that root mass/elongation play a role in contributing tolerance to salinity (Maiti and Vidyasagar, 2005). But no studies are available on genetic variability of Bt cotton hybrids for salinity tolerance. Several insect/pests affect cotton yields, but the introduction of Bt cotton hybrids has made significant increase of cotton production in the world. The identification of Bt cotton hybrids with tolerance to salinity and other abiotic stress factors could be of great advantage in enhancing cotton production under saline and insect prone areas. In a recent study significant variability was fond in salt tolerance of several Bt cotton hybrids exposed to different levels of saline concentrations. Increasing salinity concentration increased tapt root length in salinity tolerant hybrids. Several Bt cotton hybrids were selected for high salinity tolerance. The emergence and root length is considered as selection criteria for salinity tolerance in cotton (Maiti *et al*., 2009).

In the context of the above research findings, very few studies are available on the salinity tolerance of cotton genotypes and hybrids. The results of the present study corroborate the findings of Sun Xiao-Fang *et al*. (2000) indicating that salinity affected germination and growth of cotton (*Gossypium hirsutum* L.) at emergence and seedling stages. Similar observations were found by some other authors (Sun *et al., 2000;* Zheng *et al., 2002;* Kornejadi *et al*., 2004). In addition, Ghajari and Zeinali (2003) reported that the percentage and rate of seed germination and percentage of normal seedlings were increased by increasing both salinity and drought levels. On the other hand, salinity induced changes and reduces a-amylase activity and the tolerant line had a capacity of mobilization and had higher levels of total free amino acids and less reserve protein during germination and early seedling growth stages (Ashraf *et al*., 2002).

In conclusion, the investigation reveals that increasing salinity reduces germination and seedling growth and affects crop growth in Bt cotton hybrids at the seedling stages.

Considering that all the Bt cotton hybrids showed normal expression under control condition (T1), we have considered the deviation due to saline conditions (T1 and T2) from the control (T1) to determine the salinity tolerance of that genotype. All the genotypes were given score for each character based on the deviation value in ascending order, where 1 has been given to the genotype having smallest deviation from T1 to T2. Lastly total scores of a hybrid was considered to measure its salinity tolerance potential. Depending upon the total scores of the genotypes, they were grouped in 3 categories; tolerant moderately tolerant and susceptible. In view of the facts that with increasing salinity root length increased which was found in tolerant hybrid, not in susceptible lines (Maiti *et al*., 2009).

Discussion and Conclusions

In the context of world literatures on salinity tolerance in halophytes and crop plants, it is observed that significant progress has bbe directed on varios field and vegetable crops owing to increasing gravity of salinity in crop fields. One third of the irrigated crop field in the world are affected with salinity which is increasing gradually thereby reducing crop productivity. Though different management strategies are dopted, but there is little success. Selection of crops/varieties is considered as a feasible approach. Use of biotechnology including transfer of genes, genetic transformation, gene cloning has become a great tool in increasing stress tolerances (biotic and abiotic).

High variability in soil salinity and inter-environmental interactions makes it questionable. The genetic variability among plants in responses to salt has also been reviewed (Norlyn, 1980, Shannon, 1982, 1984). According to Epstein (1985) the breeding for resistance to salinity cannot be separated from breeding from various other desirable traits of mineral nutrition and metabolism. In breeding crops are developed by pedigree selection. In this process, one parent is selected for genetic properties that are useful viz. salt tolerance, while the others are chosen for desirable agronomic characteristics. Self pollination leads rapidly to homozygous lines which can be tested for overall improvements. Selection may be delayed until the F_6-F_8 generation. Bulk generation can be maintained to assume the maximum number combinations.

Although soil salinity is widely reported, but a few instances of the development of cultivars resistant to saline soil were available. Salinity is a complex character controlled by a number of genes or a group of genes and involves a number of quantitative traits. It is suggested that enhancing the salt resistance of some crops is necessary which will provide yield stability in subsistence agriculture (Flowers and Yeo, 1995).

Very little progress has been made on breeding for salinity resistance in crops. According to Ashraf (1994) stated that although variability in salinity tolerance is very important for crop species to exploit saline habitats, other prevailing environmental factors may prevent the effective selection pressure for the evolution of resistant lines. It appears that variability in salinity tolerance is more widely available; it can be exploited to enhance salinity tolerance of a considerable number of species. However, for successful selection may be suggested the following steps, 1) the high selection pressure to select tolerant individuals; 2) the imposition of high selection pressure to select a few individuals with considerable tolerance; and 3) a large number of plants should be screened for the selection of tolerant. Apart from the conventional selection and breeding, the utilisation of biotechnological techniques such as tissue culture, protoplast fusion and recombinant DNA techniques may help in the the improvement of crop salinity tolerance.

In rice, studies by Indian Council of Agricultural Research revealed that there was no correlation between vegetative stage salinity tolerance and reproductive stage tolerance; and grain yield too. Reproductive stage salinity score is more reliable for grain productivity. K^+ content exhibited a strong positive correlation with grain yield while Na^+ content showed a poor negative correlation. Both additive and non-additive types of gene action, with a preponderance of additive types, were observed. The involvement of one group of genes having dominance for salinity tolerance and Na^+/K^+ ratio; and two groups of genes for K^+ was observed. Isozyme studies demonstrated the presence of Est. 21 in tolerant and Est. 22 in susceptible genotypes (Mishra *et al*., 1997).

The above system may be adapted to salt tolerance in the three cereals discussed. Modifications that may improve selection efficiency include the use of saline irrigation to reduce natural variations in soil salinity. Ultimately, the objective should be to increase tolerance by increasing both mean yield and yield stability. An understanding of the basic principles of both salt tolerance and plant breeding will be required (Shannon, 1985).

There exist two types of salt tolerance: a) minimizing the entry of salt in plant and b) minimizing the concentration of salt in the cytoplasm.

Halophytes have both types. They exclude salt, but effectively compartamentalize in the vacuoles. Some glycophytes also exclude the salt well, but are unable to compartamentalize the residual salt taken up. Ion salt transport to leaves in the mechanism is known as salt exclusion. Reduce the rate of at which salt accumulates in the transpiring organs (leaves and stem). It is done by three ways:

1. Selectivity of uptake by root cells
2. Initial uptake of Na^+ and K^+ could occur at the epidermis, at the exodermis and endodermis.
3. Loading of the xylem. There is evidence for preference of salt leading of K^+ rather than that by the stellar cells that is under genetic control (Gorgham *et al*., 1990). Removal of salt from the xylem in the upper part of the roots, the stem, petiole or leaf sheath.
4. Excretion through salt gland or bladders.
5. Extracellular ion compartamentation: Excess of Na^+ and Cl^- are pumped into cytoplasm.
6. Maintaining high osmotic pressure by proline, glycine betaine in the cytoplasm.

Quantitative evidence suggests that perception of salt stress leads to cytosalic calcium signal that activates the calcium sensor, protein kinase. The activated SOS2 kinase regulates activities of SOS1, a plasma membrane Na^+/H^+ antiporter, and NHX1, a tonoplast Na^+/H^+ antporter. This results in Na^+ efflux and vacuolar compartamentation. A putative osmosensory histine kinase (AtHK 1), MAPX cascade probably regulates osmotic homeostasis and ROS scavenging. Osmotic stress and ABA-medited regulation of LEA (Late embryogenesis-abundant) type proteins also play important roles in plants salt tolerance.

There exist several biochemical mechanisms for salt tolerance operating in plants cited below:

Plants grown under saline environments lowers the levels of protein in salt-stressed plant as a result of the decreased synthesis of protein and also increased activities of protein hydrolyzing enzymes (Delauney and Verma, 1993). Compatible solutes may also function as enzyme oxygen radical (Tenhaken *et al*., 1993).

Under saline condition plants can survive by adaptive process which is ion transport, compartamentation and by accumulation of osmotic soloutes (Marschner, 1995). Compatible solutes integrate into whole plant stress responses that include maintenance of ion homeostasis water relation/carbon/nitrogen paths (Bohnert *et al*., 1995; Niu *et al*., 1995). Different compounds can function as compatible solutes such as potassium, amino acids and amino acid derivatives, sugars, acyclic and cyclic compounds, fluctans, amino and sulfonium compounds (Niu *et al*., 1995).

The main function of a compatible solute may stabilization of proteins, protein compounds or maintenance under environmental stress.

Gomaa and Gaballah (2004) undertook a study on the effects of different levels of salinity (1000 to 6000 ppm NaCl) on the changes of compatible solutes and addition of biofertilizers with soil yeast of *Rhodotorula glutinas* in maize. The results reveal that protein in leaves decreased. Maize seedlings grown under high salinity accumulated more polyamines in their leaves grown under low salinity level. Similarly potassium decrease with increasing salinity but reverse was found regarding sodium in sodium leaves content. The addition of biofertilizer alleviated the adverse effect of high levels of salinity and biofertilizer increased K-content in the leaves.

Recently, Behdane *et al*. (2008) studied the effect of different levels of salinity stress on growth and morphological characters of two legumes, *Medicago polymorpha* L. and *Trifolium michelianum* L. The results indicated that sodium (Na) and potassium (K) content in both stem and leaves increased with increased level.*Medicago polymorpha* is moderately tolerant to salinity.

Salinity is an environmental component that usually reduces yield. Recent advances in the understanding of salt effects on plants have not revealed a reliable physiological or biochemical marker that can be used to rapidly screen for salt tolerance. The necessity of measuring salt tolerance based upon growth in saline relative to non-saline environments makes salt tolerance measurements and selection for tolerance difficult. Additionally, high variability in soil salinity and environmental interactions makes it questionable whether breeding should be conducted for tolerance or for high yield. Genetic techniques can be used to identify the components of variation attributable to genotype and environment, and the extent of genetic variation in saline and nonsaline environments can be used to estimate the potential for improving salt tolerance. Absolute salt tolerance can be improved best by increasing both absolute yield and relative salt tolerance (Shannon, 1985). An understanding of the basic principles of both salt tolerance and plant breeding will be required.

According to Shannon (1997) salinity exert complex effects on plants owing to ionic, osmostic and nutritional interactions. The exact physiological mechanisms of salt stress are unknown. Salt tolerance also is influenced by the anatomical complexity of the plant. In his review, he has categorized different mechanisms of salt tolerance e.g.: 1) ion selectivity; 2) ion accumulation; 3) osmotic adjustment; 4) accumulation of organic solutes; 4) water use efficiency (for details vide, Shannon, 1997). In this respect he made a review on the progress undertaken in field and vegetable crops, ornamentals, fruit crops and others. Breeding methods include 1) identifyingfor tolerance: heritability: field screening techniques; selection methods; novel concepts including tissue culture; molecular biology and modeling. Genes have been identified for salt tolerance in different crops and some progress has been made in genetic transformation (Munns, 2005). In this review, it is mentioned that salinity tolerance is controlled by genes that limit the rate of salt tolerance from the soil and transport of salt throughout the plant, and adjust the ionic and osmotic balance of cells in roots, shoots and regulate lead leaf development and the initiation of sequence. Several candidate genes for salt tolerance have been hypotheis working together for salt tolerance. Very little progress has been made gene expression studies owing to the fact that the studies are not tissue specific. Emphasis has been made in identifying genes for salt tolerance in some crops, but very little progress has been made in their getic transformation.

Molecular basis of salinity tolerance

Wang *et al*. (2003) made an extensive review on plant responses to drought, salinity and extreme temperatures related to genetic engineering for salt tolerance for stress tolerance. Research emphasis should be given on breeding for drought and salinity in crop plants and high research priority should be addressed on biotechnology. Molecular basis for mechanism for abiotic stress tolerance are based on the activation of and regulation of specific stress-related genes. These genes are responsible for the control of the whole plant sequence of stress responses such as signaling, transcriptional control, protection of membranes and proteins and free radical and basic compound scavenging. Good advances have been made recently on stress response mechanisms including transgenic plants.

Molecular control relationships for abiotic stress tolerance are based on the activation and regulation of specific stress related genes. These genes are involved in the whole sequence of stress responses such as signaling transcriptional control, protection of membranes and proteins and free radical and toxic compound scavenging.

Chinnusamy *et al.* (2005) stated that the progress in breeding for salt tolerance is hampered by the lack of understanding of the molecular basis of salt tolerance and lack of the availability of genes conferring resistance. An analysis of genetic basis of salt tolerance suggests that the pereception of salt stress induces a cytosolic calcium-signal which in turn activates the calcium sensor protein SOS3. SOS3 in turn binds to and activates a ser/thr protein kinase SO_2. Hence the activated SOS2 kinase regulates activities of SOS1, a plasma membrane Na/H^+ antiporter, and NHXX1, antiporter. This leads to N^+ efflux and vacuolar compartamentation. In addition a putative histidine kinase (NHHK1-MAPK cascade seems to regulate osmotic homeostasis and ROS scavenging. Osmotic stress and ABA-mediated regulation of LEA (late embryogenesis-abundant) type proteins also play an important role in plant salt resistance.

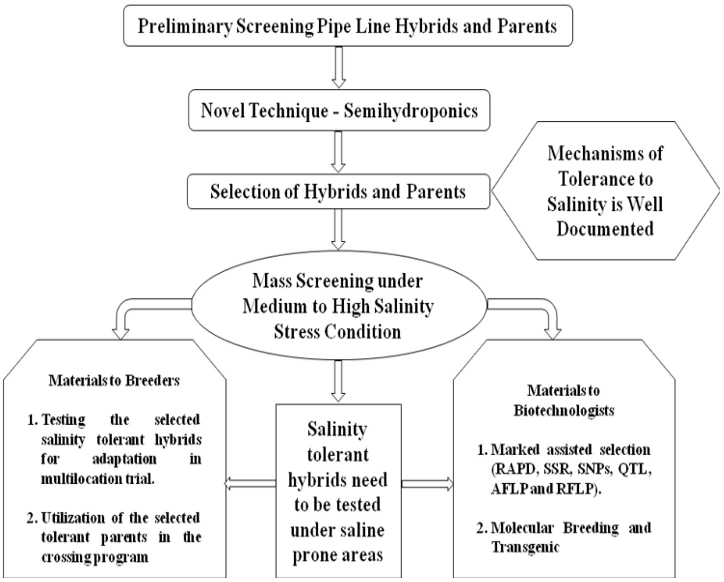
Salinity tolerance *vs* drought tolerance

Munns (2002) made a comparative study on the physiology of salt and water stress. He came to the conclusion that plant response to salt and water stress is common. Salinity reduces the capacity of plants to take up water causing reductions in growth rate along with metabolic changes similar to those caused by water stress. The initial reduction appears be due to hormal signals generated by the roots. Salinity stress will rise to toxic levels causing leafsenescence and reduce the photosynthesis, leaf area leading to reduction of productivity. Salt tolerant plants differ from salt-sensitive ones in having low rate of Na^+ and Cl^- transport to leaves and the ability to compartatize these ions in the vacuole to prevent their build-up in the cytoplasm and thus avoid toxicity. It is important to avoid treatments that induce plasmolysis.

Conclusions

Suficient research activities have been directed to understand the gravity of salinity, its management strategies, its effects on plant growth, metabolism, and selection of tolerant cultivars and mechanism of resistance. Various techniques have been formulated to evaluate and select cultivars tolerant to salinity, but not satisfactory. A novel semi-hydroponic has been developed for screening crop cultivarts for salinity tolerance with good success (Maiti *et al.*, 2008, Maiti, 2009a, b). A new strategy has been proposed to evaluate pipe line hybrids/parents of crop cultivars (with high yielding background) *viz.* cotton, maize, sunflower, pearl millet, rice and vegetable crop species for salinity tolerance using this novel technique (Cultivars of different field crops showed significant differences in seedling traits offering great opportunity in selecting genotypes of these crop species for salinity tolerance (Maiti, 2009). In general it has been observed that in case dicots such as cotton, sunflower there was an increase in tap root length with an increase in salinity in the salinity tolerant lines, but a decrease in the susceptible ones, while in the case of monocots such as maize, pearl millet and rice there was also increase in root canopy and the number of lateral roots and mesocotyle length. Therefore, in the case of docots the emergence percentage and root length and in the case of monocots both emergence percentage and root mass may be considered as selection criteria for salinity tolerance, Deeper root system and profuse root mass are essential for adaptation under saline prone areas acting as osmotic adjustment,

In the following flow diagram is shown tentative lines of research on salt tolerance of crop species:



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