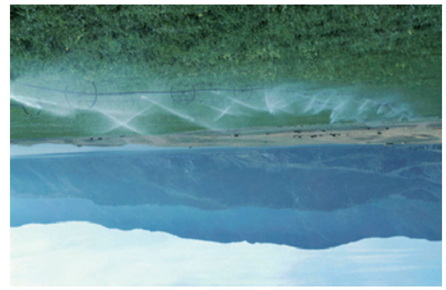
Pocket K

Biotechnology with Salinity for Coping in Problem Soils

GLOBAL KNOWLEDGE CENTER ON CROP BIOTECHNOLOGY

Salinity and Agriculture



High salinity in agricultural fields has been a problem since the beginning of cultivation practices, since the evaporation of irrigated water of poor quality leaves behind salt solutes which accumulate in the soil over time. While irrigation has made it possible to extend agriculture to semi-arid and arid areas of land, and has been partly responsible for the large increases in food production of the last 40 years, it has also resulted in large-scale water lodging and salinity. Land degradation due to increased salinity presently affects about 20 percent of world's area under irrigation, without taking into account arid areas or deserts, which comprise a quarter of the total land of the planet (*1*). Most crops are very sensitive to salt, which severely affects yield; increases the severity of other stresses, diseases and pollutants; and can be lethal to the plant. The excessive presence of salt also has a very negative effect on the soil structure, affecting porosity and water retention properties, and can eventually render fields unsuitable for agriculture.

A more rational and sustainable use of natural resources- land and water- is therefore essential to reverse the degradation of the environment and to ensure sustained productivity. Changes in farming practices, such as the selection of suitable species and varieties for cultivation, and the use of mixed cropping systems to mitigate the accumulation of salt in soils are all needed.

Meeting current and future food demands necessitates nevertheless a short term increase of food production in both irrigated and rain-fed lands, including those areas where water scarcity and high salt concentrations represent important constraints to yield. The development of crop varieties with increased tolerance to abiotic stresses such as drought and salinity is therefore an important strategy to this end (*2*).

Salt Stress

Salt stress effectively decreases the availability of water in the soil to plants, and hence there is a substantial overlap between plant responses to drought and to salinity (see pocket K 30 for more information on drought tolerance, *3*). Generally, varieties developed to be more tolerant to drought and that use water more efficiently, will also be more resilient to salt stress (*4; 5*). However, in addition to affecting the water balance of the plant, salt poses another problem to plants: excess accumulation of salt ions in cells is toxic, and potentially fatal. Salt ions impair enzyme function, inhibit protein synthesis, affect the structure and permeability of cell membranes, inhibit photosynthesis, and lead to the production of toxic reactive oxygen species.

References

Salt flat in Utah, United States

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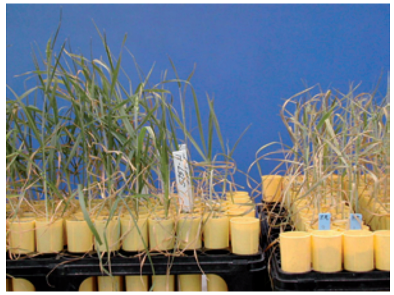
Development of Salt-Tolerant Crops by Conventional Breeding

The existence of plants that thrive in soils with high level of salts (termed halophytes), and the occurrence of variation between crop cultivars in salt sensitivity, indicate that salt tolerance is to a large extent under genetic control. Halophytes represent only about 2 percent of plant species, however, they can be found among half of the terrestrial plant families and are very variable and diverse. Although the development of tolerance to salt is believed to have occurred independently several times during the evolution of land plants, halophytes seem to have evolved the same basic method for dealing with salinity: storing harmful salt ions in the cell vacuole and accumulating organic solutes (which act as osmoprotectants) in the cell cytoplasm (*6*).

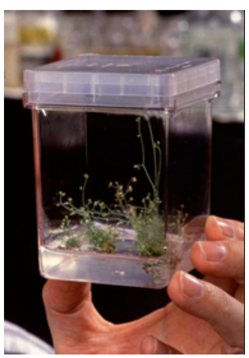


Exposure to high salinity is killing Yecoro Rojo (right), a wheat cultivar that has moderate salt tolerance. Plants resulting from hybrid crosses with W4910 (left) show much greater tolerance of high salinity. Photo by Richard Wang, USDA.

Plants growing in a salt marsh, Canada

Conventional breeding requires the identification of genetic variability to salinity among different varieties or cultivars of a crop, or in sexually compatible species, and breeding this tolerance into lines with suitable agronomic characteristics. Conventional breeding programs for salinity tolerance include the development of rice, wheat and Indian mustard varieties tolerant to salt and to alkali soils by the Central Soil Salinity Research Institute in Karnal, India (*7*) and efforts to incorporate salt tolerance to wheat from wild related species (*8)*. A number of genomic tools, such as molecular markers and gene profiling methods, can greatly improve the efficiency of breeding programs, and should be fully exploited for conventional breeding initiatives.

Engineering Salt-Tolerant Crops by Genetic Modification



Tissue-cultured *Arabidopsis thaliana*. Photo by Keith Weller, USDA.

Although not a crop plant, *Arabidopsis* has played a vital role in the elucidation of the basic processes underlying stress tolerance, and the knowledge obtained has been transferred to a certain degree to important food plants (*4*). Several features make *Arabidopsis* an ideal model organism: a small fully-sequenced genome, a small size, and a short life cycle. In addition, a wealth of genomic resources is available for Arabidopsis, and insights gained can be used to improve our understanding of the same processes in crop plants, which are less amenable to genetic studies. Many of the genes known to be involved in stress tolerance have been isolated initially in *Arabidopsis*.

Mutant analysis- the screening for mutations that affect the plant's response to stress- has been a crucial tool in the discovery of genes acting in the network. Screens designed include those aimed to identify mutations with increased or decreased sensitivity to drought, salinity and cold stresses. Also important has been the use of DNA microarray technology, which allows monitoring changes in gene expression in response to stress, and to identify genes that are either induced or repressed by the treatment (*5*).

The development of salt-tolerant crops by genetic engineering have focused on the following strategies: increasing the plant's ability to limit the uptake of salt ions from the soil; increasing the active extrusion rate of salt ions; and improving the compartmentalization of salt ions in the cell vacuole where they do not affect cellular functions. Genes encoding osmoprotectants have also been the targets of genetic modification experiments, but although their over-expression in some cases improves salt tolerance, in general they also affect plant growth in the absence of stress with negative effects in yield, a highly undesirable trait for farmers (*2, 9*).

Wheat

Tomato plants

Salt intake is controlled by low and high affinity ion transporters: trans-membrane proteins that move ions across the cell membrane, which are also required for the intake of potassium ions (K+). The efflux of ions from the plant depends on the activity of the *SOS1* gene (for *Salt Overly Sensitive1*), initially characterized in Arabidopsis but recently identified in rice, and shown to be functionally conserved between dicots and monocots (*10*). Vacuolar membrane transporters, including the one encoded by *AtNHX1* gene of *Arabidopsis*, play a role in the sequestration of ions into the vacuole. NHX1 proteins are also conserved across species, and have been isolated from several crops. Over-expression of *NHX1* genes in *Arabidopsis*, rice, canola and tomato have been reported to increase the tolerance to salt stress (*3*).

Conclusion

Salt tolerance is a very complex trait, both at the physiological and at the genetic levels, and is also very influenced by other environmental factors acting on the plant at the same time. In addition, the genetic control to salt stress differs in different stages of the plant's life cycle: tolerance at the adult stage does not necessarily correlate with tolerance at the seedling and juvenile stages, or to the ability to germinate in the presence of salts (*2, 9)*. Rice, for example, is much more affected in grain filling than in vegetative growth by the presence of salt in the soil. To complicate matters further, it is very difficult to design field trials to test the agronomic performance of improved salt-tolerant varieties, as the salt concentration in soils is very variable, and is complicated by the presence of additional pollutants and inland water intrusion .

Plant genomes need to be very plastic, a feature required to cope with a variable environment that requires a constant adjustment of the plant's metabolism. It is therefore essential to test newly developed stress-tolerant varieties to multiple stresses in laboratory conditions, and the importance of carrying out extensive field studies in a large range of conditions that assess tolerance as absolute yield increases cannot be over-emphasized (*11*).