# Salinity Tolerance in *Triticeae*

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**Abstract**: Salinity is a major problem found on all continents except Antarctica. The extent of salt affected soils around the globe is about 955 million hectares. In some countries, more than 50% of the arable land is affected by salinity. The problem is increasing which may result in 30% of land loss within next 25 years and 50% by the year 2050. This is happening concomitant with a burgeoning population especially in the developing countries where approximately 6.8 billion of anticipated 8 billion people would be living in 2025. Wheat and wheat based products are their major staple food. In order to fulfill the demand of increasing food, wheat production has to be increased possibly through using saline lands that are about 98 millions hectares. This would require salt tolerant wheat varieties, which have to be selected or evolved. This paper provides information on the status of salinity tolerance in *Triticeae* in general and wheat in particular with special reference to cultivation of saline lands around the globe.

**Keywords**: *Aegilops*; saline soils; salt tolerance; *Thinopyrum*; *Triticeae*; wheat grasses

**What is salinity and extent of salt affected soils?**

The salinization and desertification are among the two most common processes leading to deterioration of land and impoverishment of many nations. Salinity and alkalinity commonly occur where evaporation exceeds precipitation. Exceptions to this generalization are found in the areas of the world where precipitation is in excess of evaporation and many hectares of salinized land can be found. In these areas, rainfall leaches through soil deposits, and due to physiography of the region the leaching solution seep out onto flat areas and concentrated by evaporation. Examples are Canada, Russia, and South America (Rains 1991) where temperature is cool and climate is temperate. In arid regions of the world, the cause of soil and/or water salinization is the accumulation of water soluble salts in ground, soils and water. The chemistry of salt can be different and hence there are different types of salt affected soils developed under different climatic conditions. Most often, these soils are result of irrigation mismanagement. Evaporation allows the salt dissolved in water to concentrate in the root zone of the crops, which eventually results in deterioration of productive land around the globe (Table 1) to as much as 50% in some of the countries (Table 2). Thus, salinity exists globally, is a menace for agricultural productivity, and a burden on economy, health and civic liberties.It is complex and difficult to handle every where.

The problem of salinization developed with irrigated agriculture about 6000 years ago. In Mesopotamia, irrigation was the basis for a highly productive and successful agrarian society located on Tigris-Euphrates Rivers. It was developed with the provision of drainage system. With the passage of time, ground water came above the surface and salts dissolved in it starred accumulating in the rhisosphere of crops. The impact of this process is available in archeological record (Jacobsen 1982). It is because of this process that cropping pattern was switched from wheat to barley (the latter being more salt tolerant) despite the fact that wheat was the major staple. The salinity kept increasing to the extent that it salted-out barley and the powerful agrarian society declined and lost in the history.

Table 1. Extent of salt affected sols by continent and sub-continents

| Region | Salt affected area (mil. ha) |
|---|---|
| Africa | 80.5 |
| Australia | 357.3 |
| Europe | 50.8 |
| Mexico and Central America | 2.0 |
| North America | 15.7 |
| North and Central Asia | 211.7 |
| South America | 129.2 |
| South Asia | 87.6 |
| South East Asia | 20.0 |
| Total | 954.8 |

Source of data for Table 1 and 2: Data Table 19.3 of World Resources 1987, a report by International Institute of Environment Development and the World Resources Institute, published by Basic Book Inc, New York

Table 2. Estimates of irrigated land affected by salinization in selected countries

| Country | % salt affected | Country | % salt affected |
|---|---|---|---|
| Algeria | 10–15 | India | 27 |
| Egypt | 30–40 | Iran | < 30 |
| Senegal | 10–15 | Iraq | 50 |
| Sudan | > 20 | Israel | 13 |
| USA | 20–25 | Jordan | 16 |
| Colombia | 20 | Pakistan | > 40 |
| Peru | 12 | Sri Lanka | 13 |
| China | 15 | Arab Republic | 30–35 |

## THE CURRENT SITUATION

Today, standing exactly at the middle of the first decade of the 21st century, humanity is still facing not the same but the worst situation compared to that prevailing 6000 years ago. Yield and growth rates have fallen to the level below those needed to both substantially alleviate the serious malnutrition and poverty in the developing world as well as to protect the non-cropped area. We are faced with special challenges of uncertainty surrounded by GMOs, by inevitable but poorly predictable climate change and by perceived inequity in access to the essential IPR for crop research. Today we can anticipate that increased salinization of arable land is expected to have devastating global effects that can result in 30% of land loss within next 25 years and 50% by the year 2050 (Bray *et al*. 2000). Degradation of arable land is taking place concomitant with a burgeoning population demanding more food. The current population is 6 billion which is expected to be over 8 billion in 2025 of which 6.8 billion would be living in developing countries (Anonymous 1998). Wheat and wheat based products are the major stable cereal in most of the developing countries especially in south and south east Asia where intake of calories will increase by more than 13% by 2010 (Table 3). For example, in east Asia, during the period of 1961–1992 (30 years) the increase in intake of calories obtained largely from cereals was about 53% (1.8% increase per year) to which another 14% increase (~0.8% per year) is expected during by 2010. Assuring food security for this population would require a further increase in agriculture production of 40–50% during next 30 years. This is an uphill task and can be achieved only by increasing wheat yield especially on saline lands.

### Types of salinity and of saline lands

Generally, saline soils are of four types which include slightly saline soils, porous saline, saline sodic soils, severely saline sodic soils, and saline soils irrigated with subsoil water. Slightly saline soils possess electrical conductivity (EC) in the range of 6–10 dS/m. These soils exist as patches that can be cultivated with high yielding salt tolerant germplasm. Porous saline and saline sodic soil are usually found in the conductivity level of EC 10–15 dS/m. These soils are often found saline sodic throughout the root zone, are pervious to water, possess good physical qualities and require wheat/rice rotation. Soils with EC >20 dS/m are often known as severely saline or sodic soils. These soils are loamy, dense, and impervious to water and have high water table. Reclamation of such soils requires engineering approach. Soils that became saline due to irrigation with subsurface saline water usually possess high concentration of carbonates and bicarbonates. These soils require saline agriculture comprising cultivation with salt tolerant trees, bushes, shrubs, grasses and plants which need to produced/evolved.

## The potential in *Triticeae* for all types of saline soils

### a. Salt tolerance in perennial *Triticeae*

The tribe *Triticeae* with almost 350 species is an excellent source of gene pool for certain abiotic stresses like salinity, alkalinity and disease. These species are mostly perennial grasses possessing excellent forage quality and are distributed into various genera including *Agropyron, Pseudoroegnaria, Psathyrostachys, Thinopyrum, Elytrigia, Elymus, Leymus* and *Pascopyrum* (Table 4).

Studies to know salt tolerance potential of these grasses began in 1960 when Dewey tested 25 strains of tall wheat grasses and found *Agropyron elongatum* host. (*Elytrigia pontica* Pod. Holub.) to be the most salt tolerant with significant interspecific variations. Such variations were also observed when other wheat grasses like *A. intermedium* and *A. cristatum* were tested (Dewey 1962; Hunt 1965). Later studies on salt tolerance of different wheat grasses repeatedly confirmed the high potential of *E. pontica* (Elzam & Epstein 1969; Moxley *et al*. 1978; Shannon 1978). McGuire and Dvorak (1981) tested different accessions belonging to *A. elongatum* (*E. elongate*), *A. intermedium* (*E. intermedia*) and *A junceum* (*E. junciformis*) and found species of the *elongatum* complex (*E. pontica* and *E. scirpea*) and *junceum* complex (*A. junceum*) the most salt tolerant. Gorham *et al*. (1985) tested and found another salt tolerant diploid species that is *Thinopyrum bessarabicum* which can withstand prolonged exposure to 350 mol $m^3$ NaCl. The most salt tolerant genera (*A. junceum* and *A. elongatum*) have now been combined into one genus i.e. *Thinopyrum* (Dewey 1984). Farooq *et al*. (1988) also tested about 100 different accessions of various perennial genera and found species of genera *Leymus* (*L. kerelenii*), and *Thinopyrum* (*Th. scripeum* and *Th. junceum*) as most salt tolerant. These species showed 100 % and 83% survival at EC 54 dS/m, which was never reported earlier.

The mechanism imparting salt tolerance to perennial *Triticeae* has also been thoroughly investigated. Studies by Gorham *et al*. (1984, 1985) have indicated that salt tolerance in *Thinopyrum* and *Leymus* is achieved by i) strictly controlling the influx of $Na^+$ and $Cl^-$ to the shoot and not the exclusion of these inorganic ions as in other glycophytes, ii) attaining high glycine betaine concentration which mainly contributes to osmotic adjustment and plays a major role in salt tolerance of *Thinopyrum* as in some other *Agropyron* species (Hitz & Hanson 1980), iii) reduced transpirational rate coupled with constant water use efficiency under salt stress and iv) maintenance of high $K^+/Na^+$ ratio in leaves.

The genetics of some of the main mechanisms controlling salt tolerance in these species is only partly known. For example, the genes controlling $K^+/Na^+$ ratio are generally located on long arm of chromosome 4D of *Ae. tauschii* (Shah *et al*. 1987) and of *Triticum aestivum* (Gorham *et al*. 1990). In perennial species, these genes are located on several chromosomes (Zhong & Dvorak 1995). The genes for $Na^+$ and $Cl^-$ exclusion are located on chromosomes 5J of *Th. junceum* (Forster *et al*. 1988) and can be transferred to wheat for salt tolerance improvement. Accumulation of compatible solutes such as betaines, however, is a widespread response of plants that protect them against environmental stress. Genetically engineered plants are being studied for the enzymes that catalyze the synthesis of various compatible solutes including glycine betaine the mechanism of which is not yet fully understood (Chen & Murata 2002).

## Practical utilization of salt tolerance available in perennial *Triticeae*

The first successful attempt to transfer salt tolerance from decaploid *E. pontica* was made by

Table 3. Food distribution in the world (calories/day)

| Region | 1960–1961 | 1990–1992 | 2010 | Percent increase | |
|---|---|---|---|---|---|
| Developing countries | 1960 | 2520 | 2730 | 28.53 | 8.33 |
| Sub-Saharan Africa | 2100 | 2014 | 2170 | –3.00 | 6.37 |
| East Asia | 1750 | 2670 | 3040 | 2.57 | 13.86 |
| South Asia | 2030 | 2300 | 2450 | 13.30 | 6.52 |
| Industrialized countries | 3020 | 3330 | 3470 | 10.26 | 4.20 |
| World | 2300 | 2700 | 2860 | 17.39 | 5.92 |

Source: Anonymous (1998)

Table 4. The habitat and significance of some important genera of the tribe *Triticeae*

| Genus | Habitat | Significance |
|---|---|---|
| *Agropyron* | saline and arid rangeland | tolerant to drought and cold |
| *Pseudoroegnaria* | rangeland and rocky hills | txtremely tolerant to alkalinity |
| *Psathyrostrachys* | arid rangeland and rocky hills | tolerant to alkalinity and drought |
| *Thinopyrum* | coastal inlands | tolerant to inland salinity |
| *Elytrigia* | coastal saline regions | tolerant to moderate salinity |
| *Elymus* | moderately saline and alkaline soils | moderately tolerant to salinity and alkalinity |
| *Leymus* | saline and alkaline soils | extremely tolerant to salinity and alkalinity |
| *Pascopyrum* | heavily saline and alkaline soils | extremely tolerant to salinity and alkalinity |

Source: Dewey (1960)

Jan Dvorak and his group (1985). They were able to select hybrid plant derivatives which showed superior salt tolerance compared to wheat parents in hydrponics. In addition to decaploid *E. pontica*, diploid *E. elongata* has also been hybridized with wheat cultivar Chinese spring and the hybrid tested for salt tolerance (Storey *et al*. 1985). It was noticed that at 4mM NaCl, amphiploid behaved more like wheat and showed high affinity for salt but at higher external NaCl concentaration (120mM), it behaves like *Elytrigia* which is known to restrict salt accumulation in shoots. The amphiploid was grown in saline conditions for only three weeks. Hence its performance at maturity and yield data was not reported. However, study did indicate that salt tolerance of *E. elongata* can be transferred to hexaploid wheat. This was re-confirmed by Dvorak and Ross (1986) by growing amphiploid of

Table 5. Percent survival of species of various genera of the tribe *Triticeae* after exposure to different salinity levels

| Genus/Species | Electrical conductivity (dS/m) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Leymus cinerius* | 100 | 83 | 83 | 33 | 16 | – | – | – |
| *L. kerelenii* | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| *L. arenarius* | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 67 |
| *L. subulosus* | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 67 |
| *L. recemosus* | 100 | 100 | 100 | 100 | 100 | 83 | 67 | – |
| *L. angustus* | 100 | 100 | 100 | 100 | 100 | 83 | 67 | – |
| *Thinopyrum junceum* | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 83 |
| *Th. intermedium* | 100 | 100 | 100 | 100 | 67 | 17 | – | – |
| *Th. podperae* | 100 | 100 | 100 | 67 | 17 | – | – | – |
| *Th. bassarabicum* | 100 | 100 | 100 | 100 | 100 | 83 | 67 | 33 |
| *Th. curvifolium* | 100 | 100 | 100 | 83 | 50 | 50 | 50 | 17 |
| *Th. caespitosum* | 100 | 100 | 100 | 83 | 50 | – | – | – |
| *Th. scirpeum* | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| *Th. nodosum* | 100 | 100 | 83 | 67 | 17 | – | – | – |
| *Th. ponticum* | 100 | 100 | 100 | 83 | 50 | – | – | – |
| *Elymus canadensis* | 67 | – | – | – | – | – | – | – |
| *Elytrigia repens* | 67 | 50 | 33 | 17 | – | – | – | – |
| *Pseudoroegnaria stipifolia* | 17 | – | – | – | – | – | – | – |
| *P. tauri* | 50 | 50 | 17 | 17 | – | – | – | – |
| *Triticum aestivum* | 100 | 83 | 67 | – | – | – | – | – |

Source: Farooq *et al*. (1988)

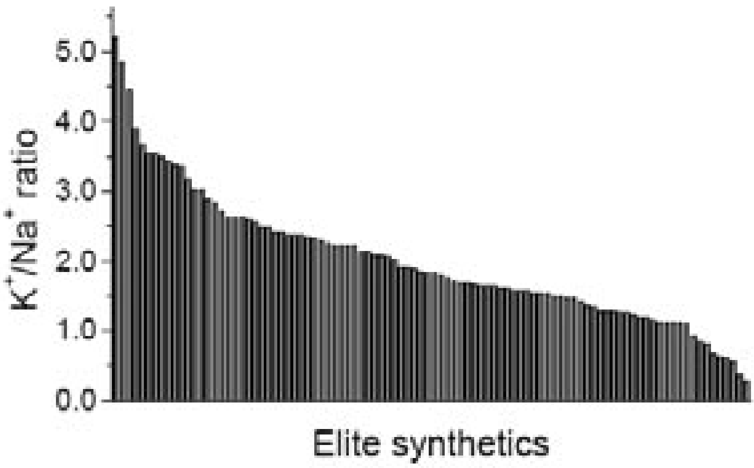


Figure 1. $K^+/Na^+$ ratios of elite synthetic hexaploid wheat genotypes grown at 100 mM NaCl for 35 days showing the range of variation within the population. Genotypes are ranked from the highest (left) to the lowest (right) discrimination ratio (Source of data: CIMMYT)

*E. elongata* and Chinese spring in a solution of NaCl, KCl, $MgSO_4$, $K_2SO_4$ and in sea water. Addition lines of *E. elongata* (*Th. elongatum*) were also tested confirming that several chromosomes contribute towards salt tolerance (Dvorak *et al*. 1988). None of these studies showed field performance of the material developed by transferring salt tolerance form *Th. elongatum.*

Attempts have also been made to transfer salt tolerance from diploid *A. junceum* (*Th. bassarabicum*) to wheat (Alonso & Kimber 1980; Forster & Miller 1985; Mujeeb-Kazi *et al*. 1987). The amphiploid survived but produced nonviable seeds at a salt concentration (250mM NaCl solution) lethal to wheat (Forster *et al*. 1987). Later studies (Dvorak *et al*. 1988) indicated that gene(s) responsible for ion regulation in *Thinopyrum* species have been transferred to wheat. These genes were found on chromosomes 5J and 2J of *Thinopyrum*. Line 5J survived at 200mM NaCl and produced shriveled grains which indicated that chromosomes 5J carries major gene(s) for ion regulation, which is amenable to transfer to wheat (Gorham *et al*. 1986).

Genes were also transferred from *Th. bassarabicum* to tetraploid wheat (King *et al*. 1997). The fertile amphiploid (*Tritipyrum*) survived at 150mM NaCl and performed better than any of the salt tolerant wheats. *Lophopyron elongatum* was used to transfer salt tolerance to hexapoloid wheat (Omielan *et al*. 1991). Its amphiploid with Chinese spring and disomic substitution line (3E) when tested under saline field appeared more tolerant than Chinese spring.

Salt tolerance has also been transferred from hexaploid *Th. junceum* (Charpentier 1992). Upon testing for salt tolerance, one of the addition lines (AJDAj5) survived at EC 42 dS/m (Wang *et al*. 2003) and showed the salt tolerance comparable to that of amphiploid. The addition line AJDAj5 is reported to have a pair of chromosomes ($E^bE^b$) from *Th. junceum* ($2n$ = 42: $E^bE^bE^e$). In order to introduce salt tolerance from this addition line it was crossed with hexaploid wheat carrying the $Ph^1$ gene. Three F5 families were selected and tested for salt tolerance of which two lines (4909 and 4910) showed salt tolerance greater than AJDAj5 and can be used as gene source for breeding salt tolerant wheat cultivars (Wang *et al*. 2003).

There could be several other examples of transferring salt tolerance from perennial wheat grasses. They might have proved even more salt tolerant than examples quoted here, but is any one of them has reached farmer's field? If not, then why not? The answer to this "why" is a big challenge for all those working with *Triticeae.*

**b. Salt tolerance in annual** *Triticeae*

Salt tolerance in annual *Triticeae* has been investigated very extensively. Shah *et al*. (1987) have indicated that hexaploid wheat is more salt tolerance than diploid wheats (*T. monococcum*) which is the AA genome contributor to hexaploid and tetraploid wheats. Durum wheat that lacks the DD genome, tends to accumulate more $Na^+$ and less $K^+$ than bread wheat under salinity stress. The high tolerance of bread wheat compared to durum wheat was found to be related with $K^+/Na^+$ discrimination factor which is genetically controlled (Gorham *et al*. 1990) and the gene(s) are located

Table 6. Description and survival of various *Aegilops* species after salt tolerance screening at EC 30 dS/m

| Species | Genome | Chromosome No. | No. of accessions | No. of accessions with 100% survival |
|---|---|---|---|---|
| *Ae. squarrosa* | DD | 14 | 55 | 45 (82) |
| *Ae. ovata* | CuCuMoMo | 28 | 21 | 6 (29) |
| *Ae. cylindrical* | CCDD | 28 | 15 | 9 (60) |
| *Ae. triuncialis* | CuCuCC | 28 | 3 | 3 (100) |
| *Ae. variabilis* | CuCuSvSv | 28 | 3 | 2 (67) |
| *Ae. bicornis* | SbSb | 14 | 2 | 1 (50) |
| *Ae. longissima* | SiSi | 14 | 2 | 0 (0) |
| *Ae. umbellate* | CuCu | 14 | 1 | 0 (0) |
| *Ae. sharonensis* | CiSi | 14 | 1 | 0 (0) |

Figures in parentheses indicate percent of total accessions used. Source: Farooq *et al.* (1989)

on long arm of chromosome 4D of *Ae. squarrosa* (*Ae. tauschii*).

Salt tolerance in *Aegilops* species is known since 1989 when Farooq *et al*. tested more than 100 different accessions of various species and found *Ae. squarrosa* (*Ae. tauschii*) the most salt tolerant (Table 6). *Ae. squarrosa* that contributes DD genome to hexaploid wheat (Kimber & Zhao 1983), is more tolerant than *Ae. speltoide.* The latter is one of the probable BB genome donors to hexaploid and tetraploid wheats (Alanso & Kimber 1983).

No significant progress has so far been made to transfer salt tolerance from *Aegilops* species to bread or durum wheats. However, synthetic hexaploids have been produced by crossing various accessions of *Ae. tauschii* (*Ae. squarrosa*) with durums via bridge crosses technology (Schachtman *et al*. 1991). In this method, *T. turgidum* ($2n = 4x = 28$: AABB) was crossed with *Ae. tauschii* ($2n = 2x = 14$: DD) to produce F1 hybrid having 21 chromosomes (ABD) which are doubled using colchicine to produce hexaploid wheat with 42 chromosomes. Approximately 800 such synthetic hexaploids have been produced at CIMMYT of which about 95 have been studied for various characteristics including tolerance to abiotic stresses (Mujeeb-Kazi *et al*. 1996).

It is clear in Figure 1 that tremendous variations exist for $K^+/Na^+$ ratio in these synthetics which can be used for transferring this character to bread wheat. Those with $K^+/Na^+$ ratios above 4 could be particularly useful. This material has been tested under saline field in various countries including Pakistan. However, till todate, neither any of these

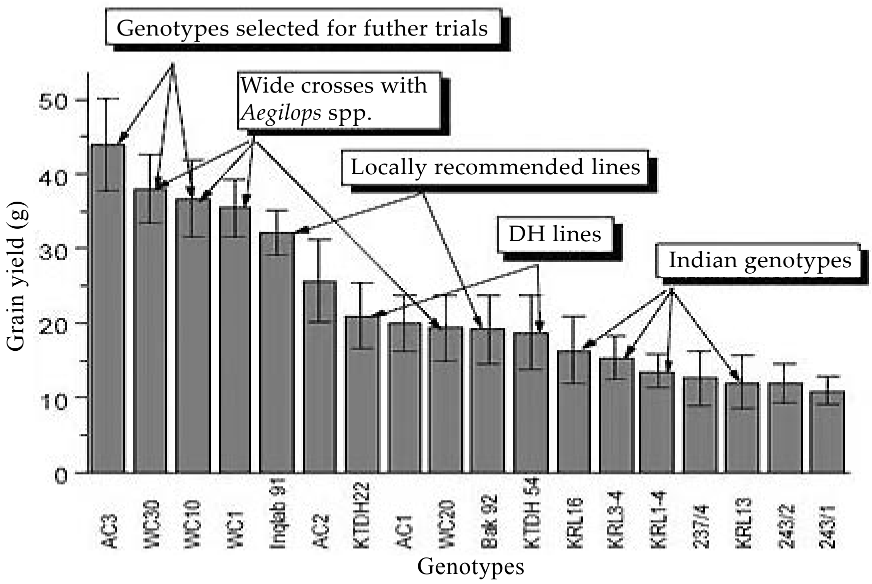


Figure 2. Yield performance of salt tolerant wheat selections, including WC-30; WC-10; WC-1 and WC-20 (the material produced at NIAB through transferring genes from *Ae. cylindrica*) compared to other known salt tolerant wheat varieties/lines. (Source of data: CSSRI, Karnal, India)

synthetics or its derivatives have officially or unofficially been released for commercial cultivation nor it has reached to the farmer's field despite the fact that the material has proven drought tolerance as well (Trethowan *et al*. 2000).

**How to tackle salinity?**

Salinity is a complex global problem solution of which depends upon the gravity of the situation, priorities of the agriculture sector, resources of the countries, climatic conditions and social acceptance of the approach in terms of economic benefits. A strategic approach is therefore, required that can meet these challenges.

In Pakistan, we have about 6.8 million hectares of salt affected land while country's first priority in agriculture sector is to achieve wheat production target of 26.43 million tones by 2010 through a growth rate of 2.93% per annum. We have about 4.1 million small farmers possessing 5–10 hectares of land that is being degraded at a rapid pace due to salinity and drought. Presently, water availability is 30% less than that in 2000–2001, and is further diminishing (Anonymous 2000). The farmers want to see their land productive with minimum possible inputs and that too without sacrificing food and social security of their families.

To cope with this situation, a multidisciplinary research programme is in place at the authors' Institute (NIAB) to cultivate saline lands with wild species through which new genetic resources were to be identified for their possible integration into existing breeding system. We selected *Aegilops* speices because these are liked by goats and are excellent fodder especially in winter when the supply is scarce. Approximately 22 *Aegilops* species are available mostly with zerophytic habits and salinity tolerance. These species are distributed in climatic region ranging from Mediterranean to Central Asia and thus can be used for a wide range of breeding programmes in different climatic conditions. Some of these like *Ae. cylindrica, Ae. tauschii,* and *Ae. geniculata* can be found along the Pak-Afghan border. The species also possess excellent resistance to several rusts including *Puccinia graminis*, *P. striiformis*, *P. hordei* and *P. reconditea*. Resistance for smut diseases_like *Tilletiaceae* and *Ustilaginaceae* and *Erysiphe graminis* have also been reported in Aegilops species (Gill *et al*. 1989; Farooq *et al*. 1998). These species can also be used

Table 7. Description of existing salt tolerant wheat germplasm

| Material | Description and developed by |
|---|---|
| DH line | Kharchia-65 (Rajisthan) × TW 161 (Sod. Excel)* |
| Lu-26 | Khushal × Blue silver (Univ. Agric. Faisalabad, Pakistan) |
| Lu-26 | Selections of LU-26 |
| KRL (4 lines) | Kharchia-65 × WL711 (a land race native to Pakistan, India and Afghanistan**) |
| Muir | Australian Tricale for water logging |
| *T. aestivum* | Gene transfer from *E. pontica* (Dvorak *et al*. 1985) |
| *T. aestivum* | Gene transfer from *Elytrigia elongata* (Dvorak & Ross 1986) |
| *T. aestivum* | Gene transfer from *Th. bassarabicum* (*A. junceum*); amphiploid and addition lines (Foster *et al.* 1987, 1988) |
| CIMMYT | Mostly from *Agropyron* (Mujeeb-Kazi *et al*. 1989) |
| *T. aestivum* | Gene transfer from *Ae. cylindrica* (Farooq *et al*. 1990a, b, c) |
| *T. turgidum* | K/Na discrimination from *T. aestivum* (Dvorak & Gorham 1992) |
| *T. aestivum* | Gene transfer from *Ae. tauschii* *** (Schachtum *et al*. 1991) |
| *Tritipyrum* | Gene transfer from *A. junceum* (King *et al*. 1997) |
| *T. aestivum* | Gene transfer from *Th. junceum* (Wang *et al*. 2003) |

Source: Farooq *et al*. (2004)
DH – Doubled haploid line; *Developed in UK has poor adaptability and is susceptible to disease; **Developed in India; ***Developed after Farooq *et al*. (1989) reported salt tolerance in *Aegilops* species. No gene for salt tolerance transferred from *Ae. cylindrica* has been reported except Farooq *et al*. (1992, 1993, 1995)

for improving disease resistance as gene transfer is possible from *Aegilops* species to *Triticum*, *Secale*, *Dasypyrum* and *Elytrigia*. In addition to that, *Aegilops* species possess considerably higher protein (> 18%) and lysine (>3.65%) contents compared to that in bread wheat and durum wheat (Maqbool *et al*. 1997). *Aegilops* species like *Ae. geneculata*, *Ae. umbellulata, Ae. speltoides, Ae. triunciallis. Ae. neglecta* and *Ae. longissima* possess considerable tolerance to drought (Rekika *et al*. 1997) and salinity (Farooq *et al*. 1989) and can be grown at salinity levels ranging from 20–40 dS/m (e.g. *Ae. cylindrica* and *Ae. geneculata* synomous *Ae. ovata*). The most important characteristics of *Aegilops* species is that these are progenitors to wheat (BB and DD genome) and characterized by profuse tillering thereby provide green cover to the otherwise saline barren land in addition to high biomass.

As one of the strategies adopted by NIAB, we transferred salt tolerance for the first time (Table 7) from *Ae. cylindrica* ($2n = 4x = 28$ CCDD) to hexaploid wheat cultivars LU-26 and Pak-81 (Farooq *et al*. 1992). The objective was to produce stress tolerant germplasm of wheat using tolerant gene(s) available in wild species and to provide to the farmers, new practices and technologies that are economically viable, environment friendly, and socially acceptable.

The germplasm thus produced have its stress tolerance increased many fold. It survived up to maturity at EC 25 dS/m under gravel culture, and between EC 15–20 dS/m under saline fields (Farooq *et al*. 1995). Wheat lines WL-1076 and WL-41 out yielded LU-26: the salt tolerant local check and one of the parents of these lines (Farooq *et al*. 1992). These lines require only three irrigations instead of six given to the commercial cultivars and half the recommended dose of both urea and phosphate fertilizers. This material is being used in national and international field trial and has out performed most of the locally recommended and other known salt tolerant genotypes (Figure 2). It is being used by the farmers especially those residing in the areas beset with water shortage and by the resource poor farmers who cannot afford to purchase expensive fertilizers. It is anticipated that cultivation of such germplasm will reduce the import especially of phosphate fertilizer thus relieving the burden on the economy, and the less use of nitrogenous fertilizer will improve the environment. The lesser number of irrigations will help saving the precious commodity like water that can be used for some other purposes.

The material is also being cultivated in the southern Punjab, which is a cotton belt, and farmers cannot vacate the fields before January, which is not a normal wheat sowing time. After having the stress tolerant material produced at NIAB, they are cultivating wheat inside standing cotton, which again is not a normal practice. During recent field trials, farmers in the southern Punjab have produce grain yield equal 3300–4000 kg/ha and demonstrated that (a) diversity in agriculture does play dividends and that (b) for sustainable agriculture, diversity must be created, collected, characterized, and utilized continuously. This is essential in order to meet the ever-changing demand of present day agriculture and unforeseen requirements of future. NIAB is the only institution in the country working on its indigenous programme of creation of stress tolerant wheat germplasm through transferring gene(s) from annual *Triticeae.*

## CURRENT SITUATION

The current emphasis in the field of salinity is on i) studying molecular basis of abiotic stress tolerance (Krishna 2002), ii) identifying regulatory genes (Wangxia *et al*. 2003) the function of which is still unknown and metabolic engineering of compatible solute, and iii) making transgenic plants for osmotic adjustment and Na exclusion (Datta 2002). Generally, *Arabidopsis* is being used for such studies while in *Triticeae*, application of molecular markers is more common compared to genetic engineering with few exceptions. The most notable among these exceptions are the efforts made at Oklahoma State University to develop salt and drought tolerant transgenic wheat. In these studies, mannitol-producing chimerical gene derived from corn and two common bacteria were introduced into wheat. Transgenic wheat plants that accumulated mannitol in leaf tissues showed improved productivity under salinity and water stress. The field trials are being conducted since 2004. If the plants perform well in the field, it will take at least a decade to incorporate the traits into varieties available to the farmers (Abebe *et al*. 2003).

There exists an optimism as well as pessimism about genetically engineered crops especially for drought and salinity tolerance in which many different genes are involved. The optimism is largely based on theoretical success of various engineered genes expressing in salt and drought tolerant plants grown in the green houses (Anonymous 2004) that have yet to see the light of day and the harshness of the environment under field conditions. Whether such transgenic plants would ultimately contribute to the struggle against world hunger, is questionable because of the many different genes involved in drought and salinity tolerance mechanism. Conversely, there exists many different "farmers varieties" that show high tolerance to adverse environmental conditions such as water deficit and salinity. There also exists huge genetic diversity in traditional crop plants with these properties developed over hundred of years by traditional farmers. Despite this, a salt tolerant wheat has not yet been produced that can go to the farmer's field. There could be many factors responsible for this bottleneck. It could be the differences in type of salinity, climatic conditions, sources of irrigation, agricultural practices, and disease/pest incidence in different regions of the world or it could be the polygenetic nature of salinity where each and every gene interacts differently. Nevertheless, it is understood that interaction of all these factors with various genes controlling the salinity tolerance would probably require a variety of crops for different saline areas.

In *Triticeae*, there exists a huge genetic variability for salinity tolerance. Also, extensive breeding efforts made over the years have produced many different varieties that show desired traits in regionally adapted farmer's crops. These varieties are in harmony with local environment and its ecology. Salt tolerant varieties have been, are being and will perhaps be produced in similar way till the time when farmers witness the wonders of GMOs which may be possible in the next five or ten years.

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