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ADVANCES IN BREEDING FOR SOIL SALINITY TOLERANT WHEAT VARIETIES IN INDIA

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Abstract: Soil salinity constitutes an important abiotic stress for wheat production systems in India. The salinity tolerance research posses layered challenges in the form of tedious field screening of the wheat lines, non-availability of ample genetic diversity for the complexly inherited trait and tolerance in itself being a trait of traits and difficult to dissect genetically. The area under salinity has been predicted to increase in the coming future in the country and the inbuilt genetic resistance to the natural and anthropologically induced salinity in the predicted scenario should be a much sought after trait in otherwise commercially successful varieties with excellent agronomic attributes. The Indian Wheat Improvement Programme has kept sturdy pace with this challenge and have succeeded in development of many salt tolerant wheat varieties, mainly by conventional breeding approaches. However, this is time that the breeding for soil salinity tolerance in wheat be complemented by the biotechnological tools available for rapid and enhanced genetic gains for the trait. The present paper presents with the importance of soil salinity in Indian context, elucidates upon the prevalent breeding strategy and the products developed as a result.

INTRODUCTION

India ranks second in wheat production after China with a record production of 107.59 million tonnes in the year 2020 with an average national productivity of 3508 kg/ha (ICAR-IIWBR, 2020). A record production was achieved in the year 2021 with an all-time highest production of 112 million tonnes from an area of 31.3 million hectares (about 14% of the global area). It is a staple food in northern and northwestern states of the country and accounts about 8.7% of the total wheat production in the world, 36% of the cereal grains produced in India (Sendhil et al., 2019) with 13% of total cultivated area dedicated to cultivation of this crop in the country.

At regional level, Uttar Pradesh (31.88), Punjab (17.85), Madhya Pradesh (15.91), Haryana (11.16) and Rajasthan (9.19) are the top five wheat producing states of India as per 2017-18 wheat production statistics. During the past six decades, a steady increase in the production and productivity of wheat in India has mainly indicated the green revolution impact. In the year 2030 the population of India will be 1.43 billion and the food grain requirement will be 311 mt which will increase to 350 mt in the year 2050 when the population of the country will swell to 1.8 billion strong (Kumar and Sharma, 2020). The role of wheat in total food production is very important and the goal of producing 350 million tonnes of food grains can be achieved by achieving a steady increase in the wheat production of the country which in turn is mired by many challenges at various levels.

It is evident that the gains in agricultural output provided by green revolution have

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reached their ceiling whereas the population of India is expected to reach nearly 1.8 billion by 2050. The recent plateau in genetic gain in productivity of crops also indicates that possibly the attainable maximum productivity of crops with traditional methods of crop improvement even with all the favourable factors for crop growth in place for high productivity zones has already been reached. Therefore, in addition to increasing the yield of crop plants in normal soils, there is an absolute need to enhance productivity and stability of crop yield in less productive lands, including salt affected areas. This is more relevant to highly populated countries such as India where an estimated 6-7 million hectares of land is affected by salinity/alkalinity (out of the total 147 million hectares of degraded land) and about 2.0 million hectare of salt affected land is being reclaimed (Kumar and Sharma, 2020). Further, it is being predicted that salt affected area is likely to increase to an extent of 16.2 million ha by 2050. Mainly due to expansion in irrigated area, intensive use of natural resources responsible for second generation problems and also due to predicted climate change. The projection made by other organizations even foresees a large area affected by the twin problems of water logging and soil salinity. During the period between 1997 to 2047, there could be a two fold increase in saline lands (11.0 to 22.0 million ha) (Gupta and Bundela, 2017). Water logging adversely affects bread wheat production in about 4.7 million ha of irrigated land in Northern India which include 2.5 m ha of sodic soils and 2.2 m ha affected by seepage from irrigation canals in rice wheat cropping system. Salinity, alkalinity and waterlogging are the major stresses restricting crop stand and yield. Alone in India, 2.5 million ha of alkaline soils of the Indo-Gangetic plains planted with wheat may experience saturated or temporary waterlogging (WL) conditions every year due to excess rains or mismanagement of water drainage from the farmers' fields. Among all the crops, wheat suffered the highest production loss of 4.06 million ton along with monetary loss of Rs. 56.49 billion due to salt stress. In this context, concerted efforts to improve salt tolerance in wheat cultivars is highly crucial for enhancing the productivity in land affected by soil salinity, alkalinity and poor quality of waters. In addition, there is a need to consider wheat improvement for multiple stresses in view of climate change.

The suitability of each type of soil for agricultural crops is different and some soils are also a serious challenge for agricultural production. One such type of soil which presents a serious challenge in terms of increasing agricultural production is saline soil. Saline soil refers to soil rich in natural salt. A soil type whose saturated paste has an electrical conductivity greater than 4 dS/m and a pH value less than 8.5, falls under the category of saline soil. There are two types of soil salinity. Salinity arising from natural causes is called primary soil salinity. It arises mainly due to erosion of salt present in the maternal rock and its mixing in the soil through ground water. On the other hand, secondary soil salinity comes into existence through anthropological activities. The main reason for this is irrigation of the land with highly saline water. Due to more irrigation in areas with less rainfall, the water surface rises and the soil salts come to the surface through water. Due to lack of proper drainage in areas with excess rainfall, the surface salts dissolve in the water and the salt layer is left on the surface when the water evaporates. In such lands, Sodium, Magnesium, Calcium, Potassium and Chlorine elements and their compounds are predominant. If the pH of the soil is high due to the predominance of Sodium only, then such land is classified as alkaline land and the condition as alkalinity.

The productivity of the saline/alkaline soil is often very low. Both the primary and secondary soil salinity in the regions of the Green Revolution in India, presents a challenge in increasing the production of wheat. The high yield varieties deployed in the Green Revolution required intensive irrigation, and therefore, areas of water-borne salinity are often found in these states, particularly Punjab, Haryana, Western UP and Northern Rajasthan. Agricultural crops are classified on the basis of their salinity resistance and wheat has been found to be a moderate type of salinity crop. It can successfully yield in soils with electrical conductivity up to 8 dS/m.

Soil salinity mainly leaves its negative impact on crop plants in two ways. It reduces the availability of water to the plant by increasing the amount of salt in the root area and causes more salt to enter the plants causing salt-toxicity. A variety of methods including mechanical (leaching, subsurface drainage,) chemical (gypsum etc.) and biological methods (Phytoremediation, crop cycle, crop selection, green manure etc.) have been developed to improve such soils. In spite of that, the breeding of salt tolerant wheat varieties remains a relatively inexpensive and logistically easier way to take good production in salt affected soils.

There are three major strategies of developing a salinity tolerant variety:

1. **Germplasm evaluation and selection:** Wheat is bestowed with tremendous genetic diversity for tolerance to major biotic and abiotic stresses and indigenous as well as exoticgermplasm is constantly augmented and evaluated for trait identification contributing in tolerance to stresses including salinity. For trait demarcation,the available germplasm is tested under control as well as natural field conditions and stresstolerant lines suitable for the ecological nichesare selected. This strategy is by far a simple and quick method to obtain a salt tolerant variety. However, this suffers from that the variety selected might not be the best one or better to the already released wheat varieties. Therefore, this strategy is more beneficial when utilized as a part of pre-breeding for identification of salinity tolerant germplasm for the actual breeding process.
2. **Varietal breeding and development:** Evidently high yield potential and salinity tolerance might not be present in the same line. Therefore, conventional and molecular breeding approaches need to be applied for transferring the desirable traits therough executing a well-planned breeding programme spanning over years. Presently most of the wheat varieties are being developed by pedigree/bulkselection method, predominantly. The shuttle breeding i.e. taking two generations of segregating generations in one year to reduce the time in developing of the wheat varieties is a part of this scheme.
3. **Genetic modification through biotechnology:** In this method, recombinant DNA technology is used to transfer a salinity tolerant gene from another line or species through genetic transformation. Although low transformation rates, and the choice of the genes are the limitations of this method. During the last decades, a gene called *AtNHX1* was successfully transferred in wheat lines from the Arabidopsis plant, which showed better salinity tolerance compared to the lines lacking this gene under salinity conditions. Similarly, the transfer of a gene called *P5CS* in a variety of wheat has also led to better performance in sodium dominant salinity.

Through the mentioned methods of breeding, several salinity tolerant wheat varieties were developed during the last five decades, combinatorial approach has been used to bred all the existing varieties possessing salt tolerance and the major successful varieties are described below:

1. **Kharchia-65:** The first salinity tolerant wheat variety, Kharchia-65 was developed by Rajasthan Agricultural University, Bikaner in 1978 from the indigenous landrace *Kharchia local*. Kharchia-65 is a relatively late maturing (149 days) and tall (110.5 cm) variety. In saline soils (EC: 6 dS m^{-1} and pH: 9.5), this variety has the potential to yield up to 40 quintals per hectare. Although, this variety is now out of cultivation, mainly due to the development of susceptibility to many diseases such as yellow and brown rust, Karnal bunt etc.
2. **KRL1-4:** This variety was developed by the ICAR-Central Soil Salinity Research Institute, Karnal in the year 1990 through conventional breeding approach, using Kharchia-65 and WL-711 as parents and was recommended for salt affected agro-ecosystems under North-Western Plains Zone (NWPZ) as well as North-Eastern Plains Zone (NEPZ) of India under normal sown conditions (5 to 20

November). It matures in an average of 132 days with an average height of 89 cm. Its medium size and light brownish-yellow grains contain up to 12 % protein. It is resistant to all three rusts and also tolerant to lodging. This variety can be successfully grown in salt affected soils having the stress intensity of 7dSm^{-1} and a pH of 9.3 with the average grain yield of 40 quintal per hectare.

3. **KRL19:** This variety was also developed by ICAR-Central Soil Salinity Research Institute, Karnal, in the year 2000 by conventional breeding method (bulk selection) using salt tolerant KRL1-4 and PBW255 as parents. It is a relatively short statured variety with an average height of 85 cm and matures in an average of 132 days. This variety has been recommended for cultivation in salt affected agro-ecosystems of NWPZ and NEPZ under normal sown conditions (5 to 20 November). Its grains are medium sized and the protein content is 12 percent. The average yield of KRL19 is up to 35 quintals per hectare under saline soils having the stress intensity of EC: 7 dSm^{-1} and/or pH:9.3. Whereas, under normal soils, it has the potential to yield up to 52 quintals per hectare.
4. **KRL210:**It is most popular salt tolerant wheat variety in India, developed through conventional breeding approach using PBW65 and Pastor as parents by the ICAR-Central Soil Salinity Research Institute, Karnal in the year 2010. It matures in an average duration of 143 days. It can tolerate a pH of up to 9.3 and EC: 7.20 dS m^{-1}.the average yield of 52 quintal per hectare under normal conditions and up to 35 quintal per hectare in saline/alkaline soils has been recorded. The grains are bold and it is recommended for normal sowing time in salt affected agro-ecosystems of NWPZ and NEPZ of the country.
5. **KRL213:** This variety has been recommended for normal sowing time in salt affected agro-ecologies of the country. It is developed by the ICAR-Central Soil Salinity Research Institute in the year 2010. It matures in an average of 145 days and can tolerate a salt stress intensity of EC 6.4dS m^{-1} and a pH of 9.2. It has an average length of 97 cm and has been recorded an average yield of 60 quintal per hectare under normal conditions and up to 35 quintal per hectare under saline/alkaline conditions.
6. **KRL 283:**A new salt tolerant wheat variety KRL 283 has been recommended in the year 2018 for salt affected soils of Uttar Pradesh. KRL 283 has shown good yielding ability and salt tolerance with superiority in grain yield in comparison of ruling check varieties. Under normal conditions, its yield potential is 5.8-6.2 t ha^{-1} while in sodic soils (pH 9.0-9.3) it gives 4.5-4.8 t ha^{-1}. In future, it could be evaluated for potential as climate resilient variety because of inherent multiple stresses tolerance. It takes 128-133 days for maturity and can tolerate salinity up to 6.7 dS m^{-1} and sodicity up to pH 9.3. It is also resistant to stripe rust/ brown rust/ stem rust/Karnal bunt/aphid and shoot fly.

In addition to the above five varieties, three genetic stocks namely; KRL35, KRL99 and KRL 3-4 tolerant to salinity and alkalinity have been identified by ICAR-CSSRI, Karnal and registered with the ICAR-National Bureau of Plant Genetic Resources, New Delhi. These genetic stocks are well established and are being utilized in introgression breeding for the development of wheat varieties for salt tolerance including genome-wide association studies, marker trait associations and validation of salt-responsive markers in wheat (Mehta et al., 2021).

With the onslaught of the global climate change, the incidence of drought and water requirement of the crops might increase, which will necessitate frequent irrigations leading to enhanced salinity of the soils. This calls on the continuation and consolidation of the breeding programmes aimed at development of salt tolerant wheat varieties for different agro-ecological zones. The recently released popular varieties of the ICAR-Indian Institute of Wheat and Barley Research, Karnal such as DBW222, DBW187 and DBW303 could be potentially evaluated for tolerance to salinity/alkalinity for speeding up the breeding pipeline against this important abiotic stress of wheat crop. Apart from this, the cutting edge biotechnology tools such as linkage disequilibrium mapping which involves non-structured populations to be explored at genomic levels for identification of regions conferring salinity tolerance needs to be exploited for broadening of the genetic base of the salt tolerant wheat varieties. Further the genome editing systems such as CRISPR/Cas9 have huge potential in up or down regulating of the genes involved in salinity tolerance or susceptibility, respectively as has been shown by Zheng et al., (2021) in case of histone acetyltransferase TaHAG1 enhancing the salt tolerance in hexaploid wheat. The salinity tolerance research in wheat cannot be overemphasised when wheat is becoming integral part of human diet in the demographically expanding globe craving for food and nutritional security.

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