Front. Agric. China 2011, 5(1): 31–34
DOI 10.1007/s11703-010-1054-2

REVIEW

Mueen Alam KHAN, Muhammad IQBAL

Breeding for drought tolerance in wheat (*Triticum aestivum* L.): constraints and future prospects

Abstract This review article is based on different aspects of wheat breeding for drought tolerance. Drought is regarded as one of the most serious threats to agriculture in Pakistan. Therefore, breeding for drought tolerance must be given top priority. Here, we try to study various options available to wheat breeders exploring the underlying mechanisms of drought tolerance. The progress made in conventional and non-conventional (molecular) based approaches with potential findings and constraints are reviewed in this article. Equipped with such information, it will be possible for breeders to further explore the mysteries of drought tolerance and to select genotypes with an improved yield under water-deficit conditions.

Keywords breeding, drought, tolerance, wheat

1 Introduction

Wheat (*Triticum aestivum* L.) is the most important cereal crop after rice to meet the food requirements of the world. Drought is considered to be the major factor among abiotic stresses that limit crop production especially of wheat in many countries. In spite of the fact that it is difficult to breed for drought tolerance (El Jaafari, 1999) due to its complex polygenic nature (Ingram and Bartels, 1996; Krishnamurthy et al., 1996), considerable breeding achievements have been made in drought susceptible areas of the world (Smith, 1987). Drought tolerance is the ability of plant to sustain itself in limited water supply (Ashley, 1993).

Early screening tests such as chlorophyll florescence are useful to evaluate drought tolerance in wheat (Sayer et al., 2008). Rauf et al. (2007) worked on seedling parameters of wheat to screen different genotypes against drought tolerance. A number of scientists have worked on physiological parameters contributing to drought tolerance (Sayer et al., 2005). Blum (1983) and Morgan (1984) found both yield and drought tolerance as complex traits controlled at different separate genetic loci.

Seventeen selected lines of Azerbaijani durum wheat were tested for drought and salt resistance with reference to the adaptability and stability (Jafar, 1999). Water, salt and thermal stress environments were applied during germination and normal growing conditions. Of the lines selected, Leucurum 242h93, Melanopus 63h93 and Apulicum 317h93 were proved to be productive and potential cultivars in stress conditions, and promising breeding material in the direction of wheat breeding for drought and salt resistance.

2 Drought tolerant mechanisms

Because drought is a complex trait, a number of factors come in to play when making the plant sustainable in drought. Mitra (2001) classified drought tolerant mechanisms of plants into three categories, i.e., drought escape, drought avoidance and drought tolerance. Drought escape is the ability of plants to complete their life cycle before the drought season begins. Drought avoidance is the plant's ability to maintain tissue water potential through increasing uptake of whatever water is available and reducing transpiration (Izanloo et al., 2008; Agbicodo et al., 2009). In drought tolerance, plants are able to tolerate the conditions of water deficiency through manipulating the biochemical and physiological parameters and thus avoiding the injurious effects of drought. Mechanisms can be best understood by considering the physiological aspects that can greatly facilitate the screening for drought tolerance and selection on that basis have indeed been proved fruitful (Turner and Nicolas, 1987; Reynolds et al., 2001; Chaves et al., 2002; Richards, 2004; Foulkes et al.,

Received July 1, 2010; accepted July 14, 2010

Mueen Alam KHAN (✉), Muhammad IQBAL
Department of Plant Breeding & Genetics, College of Agriculture & Environmental Sciences, The Islamia University of Bahawalpur, Pakistan
E-mail: mueen_1981@yahoo.com

2007; Izanloo et al., 2008; Vazifedoust et al., 2008).

Three South Australian bread wheat (*Triticum aestivum* L.) cultivars, Excalibur, Kukri, and RAC875, have been evaluated for their capacity of osmotic adjustment, which proved to be the main physiological attribute associated with tolerance under cyclic water stress enabling plants to recover from water deficiency (Izanloo et al., 2008). Varietal differences in osmotic adjustment in wheat and other cereal crops have been observed by a number of researchers as well (Morgan, 1977; Shonfeld et al., 1988). Similar findings have been reported by Lazar et al. (1995). They exploited the variation among closely related drought susceptible lines and were not able to find any correlation between certain developmental variables (anthesis date, physiological maturity, etc.) and drought susceptibility that would ultimately prove to be effective in identifying drought tolerant mechanisms in wheat.

The reduction in leaf water potential of plants exposed to drought can also be a reliable parameter for screening wheat genotypes for drought tolerance (Siddique et al., 2000). Blum (2005) argued that crops are adapted to drought conditions through the mechanism of drought avoidance rather than drought tolerance and osmotic adjustment is the major contributing trait to evaluate the performance of crops under drought conditions. A number of scientists have considered glucousness (which is the waxy coveri-ng over the cuticle) an important parameter increasing water use efficiency and drought escape and thus leading to an increase in wheat yields (Richards et al., 1986; Qariani et al., 1999). The possible physiological role of acid phosphatases in wheat was discussed by Sharma and Kaur (2008). They found an increase of acid phosphatases in the leaves and grains of drought tolerant variety C-306 under drought stress conditions. Overall stomatal resistance, relative water contents and greater osmotic adjustments are the possible factors that determine drought tolerance (El Hafid et al., 1998).

3 Selection parameters for drought tolerance

The selection efficiency can be greatly improved with the identification of biochemical markers. Lopez et al. (2003) working on dehydrins (a class of proteins and expressed in plants exposed to dehydration stress) observed a positive association of dehydrins expression with drought tolerance. A number of researchers working on the same path made similar findings (Houde et al., 1992; Labhilili et al., 1995). Nachit et al. (2000) identified some molecular markers like CDO395 and BCD1661 associated with high grain yield arguing that these and other molecular markers can greatly enhance the selection efficiency for drought tolerance through marker assisted selection (MAS). The effectiveness of *in vitro* selection in wheat was also reported by AbdElghany et al. (2004). Cseuz et al. (2002) used different selection methods like water retention ability, chemical desiccation and carbohydrate accumulation, etc., to screen different drought tolerant genotypes and lines. The selection in moisture stress environment is better for yield as compared to nonmoisture stress conditions (Golabadi et al., 2006). While selecting drought tolerant wheat genotypes, stomatal resistance is a better indicator than leaf water potential and plant resistance to water flow (Adjei and Kirkham, 1980).

4 Conventional wheat breeding and drought tolerance

Because of the complex nature of drought tolerance in wheat, conventional breeding has little success in this regard. Farshadfar et al. (2001) worked on some drought tolerance criteria and agronomic characteristics in wheat using an eight-parental diallel cross under two different regimes, i.e., rainfed and irrigated. They found an additive gene action which is a predominant factor for grain yield, harvest index, relative water content and chlorophyll fluorescence. Plainsman × Kobomugi was found to be the best specific combination for improving drought tolerance. However, the interaction of GCA and SCA with the environment proved to be nonsignificant for various parameters studied, indicating that genes controlling osmoregulation and the other physiological traits were not being affected in these varieties by different rainfed conditions. Kaul and Mundel (1987), utilizing growth as a selection parameter for drought tolerance, used a technique through which they induced slowly increasing water deficits in wheat seedlings by rooting them in damp vermiculite and growing them in a humid atmosphere. After eight weeks, drought-resistant genotypes were identified either by drought avoidance or by drought tolerance responses. Genotypes with lesser drought resistance become dormant or produce sterile spikes. However, that test did not predict the relative yield outcome of cultivars in dry field conditions.

5 Use of molecular breeding for drought tolerance in wheat

Drought tolerance has undoubtedly become a focal point for plant breeders and molecular biologists. However, the success with conventional plant breeding is limited due to the polygenic nature of drought tolerant mechanisms. Biotechnology has a potential to solve the problem. Currently, there are two major biotechnological approaches, i.e., plant genetic engineering and molecular marker technology, which focus on acquiring drought tolerance (Gosal et al., 2009). However, to get the potential benefits of these technologies, it is very important to know the molecular mechanisms of drought tolerance in plants.

As drought brings about many changes in gene expression, identification of potential candidate genes being expressed in drought stress conditions is the major strategy in this regard and the technology of microarray has been quite helpful in achieving that objective (Umezawa et al., 2006). Interestingly, the team of Zhang et al. (2005) reported a dwarf mutant of wheat named s-dwarf. It showed a remarkable low rate of transpiration with higher water use efficiency as compared to the Chinese wheat cultivar Jingdong 6. Two mutant lines DHML-50 and DHML-9 were identified through haploid breeding and mutagenesis which appeared to be promising regarding drought tolerance (Khan et al., 2001). Similarly, in search for drought resistant wheat varieties in the marginal areas of Kenya, Njau et al. (2006) used introduction, mutation and double haploid technique. The technique of double haploidy proved to be the most efficient and effective regarding breeding for drought tolerance. The genomic based approaches can ultimately help us to reach down the quantitative trait loci (QTLs) for drought tolerance making the crop survive in water limited conditions in a better way (Tuberosa and Salvi, 2006). However, despite all technological advancements, the success of molecular-based approaches in developing drought tolerant cultivars is marginal (Zhao et al., 2008).

6 Conclusion

Drought stress is one of the major limiting factors among abiotic stresses hampering wheat production. A comprehensive breeding strategy for drought tolerance is therefore needed, involving a) understanding of biochemical and physiological mechanisms, b) conventional breeding using various selection techniques, and c) biotechnology-based approaches including molecular marker techniques. The challenge for the breeders will therefore be to integrate effectively all those available strategies to get the desired level of tolerance to drought.

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