Chapter

Drought Affected Wheat Production in Bangladesh and Breeding Strategies for Drought Tolerance

Afsana Hannan, Md. Najmol Hoque, Lutful Hassan and Arif Hasan Khan Robin

Abstract

Wheat is one of the major cereal crops in Bangladesh. Over the last two decades, wheat consumption has passionately amplified in Bangladesh but its production has declined due to various stress environments. Recurrent drought event due to climate change that threatens the country's food safety has become a serious concern. To safeguard the food security, adopting suitable breeding strategies can add momentum. Developing drought tolerant wheat varieties are the definitive means of protecting the crop against hostile effects of drought. Plant breeders are exploring various breeding strategies to breed for the varieties that can cope with water deficient conditions well. Besides, breeders are consistently looking for new prospects and strategies that can boost genetic gain in yield. To endorse drought tolerance in wheat, understanding the physiological and genetic adaptation mechanisms of wheat cultivars during drought stress would provide the estimated benchmarks to adjust for suitable breeding programs. The efforts of developing drought tolerant wheat genotypes could be supported by different breeding strategies including *in vitro* haploid and double haploid protocols, polyploidization, development of various types of hybrids and induced mutants by utilizing both classical and molecular breeding techniques. The proposed book chapter shall discuss the pattern of drought-stress in the wheat growing regions, effects of drought stress on wheat production and suitable breeding strategies for developing drought tolerant genotypes in Bangladesh.

Keywords: wheat breeding, drought stress, tolerance mechanisms, breeding strategies

1. Introduction

Bangladesh is a small country geographically situated in between Himalaya and Bay of Bengal. It is among the most vulnerable countries in world to future climate change due to the flat deltaic topography, very low elevation (below 10 meters above sea level) and high population density [1–3]. Eating a lot of rice is the primary food habit of Bangladeshi people. Next to rice, wheat is the second most important cereal crops in Bangladesh for attaining food and nutritional security [4]. Although being one of the major rice producers and consumers in world [5], consumption and import of wheat in Bangladesh are growing significantly over the years [5, 6–9]. The speedy economic growth, swift urbanization, and the associated alterations in lifestyle are accountable for the increased consumption of wheat which is not going to change [8]. Instead the demand of wheat will be enhanced in near future [4]. Despite increasing yield, gradual decrease of wheat growing area make the domestic wheat production curve more or less static [10]. At present, the domestic production of the country can only encounter around 20% of total wheat consumption [11, 12] and import is the only way for meeting her demand–supply gap [6]. Several periodic natural calamities such as salinity, drought, high temperature stress, flash floods and cyclones have been accelerated due to climate change in recent years [4, 13]. Among the abiotic stresses, drought is the most prominent and prevalent limiting factors of wheat production [14–16]. Rising temperature and changing in precipitation pattern lead to increasing incidence and intensity of drought events in country like Bangladesh [17–21]. Drought employs expressively adverse effects on production of winter crop wheat in northern and central part of Bangladesh [22, 23]. Around 3.5 million ha land are vulnerable to crop production due to drought and wheat is one of the major cereal crops under the radar of this threat [24]. Considering these facts, drought should be highly preferred in future wheat improvement programs. For attaining self-sufficiency in wheat production, wheat breeders of Bangladesh have no alternatives but to develop well adapted drought tolerant varieties [22]. In spite of the polygenic nature, there are ample opportunities to increase drought tolerance of wheat through making some alterations in genetic and molecular levels. Therefore recent wheat breeding programs for drought stress should focus on utilization of both conventional as well as advanced molecular techniques.

2. Pattern and distribution of drought stress in Bangladesh

In Bangladesh, drought is defined as the period when soil moisture content is less than the required amount for satisfactory growth of a crop during a normal crop growing season [25]. According to assessment of Intergovernmental Panel on Climate Change (IPCC), by the year of 2050 about 8 million people of Bangladesh will be affected by droughts [26]. Due to tropical humid type climate, Bangladesh faces widely varying seasonal rainfall pattern, moderately warm temperatures and high humidity [27]. Irregular and varying rainfall pattern due to climate change and lack of surface water is the main reasons of recurrent devastating drought events in many areas of Bangladesh [28, 29]. Among the meteorological droughts, seasonal drought due to asymmetrical distribution of standard rainy and dry season and contingent drought due to irregular rainfall are more predominant in Bangladesh [25]. Due to high variability in pattern and distribution of rainfall, the north-western part of Bangladesh become more susceptible to droughts [30, 31]. In addition, groundwater resources are continuously abused by the farming communities causing scarcity in surface water [32, 33]. Over the last 2–3 decades, the northwestern part of Bangladesh (Barind tract) has been more exposed to recurrent drought events than the other parts [34]. Majority of the parts of greater Dinajpur, Rangpur, Pabna, Rajshahi, Bogura, Naogaon and Joypurhat districts are included in Barind Tract shown in **Figure 1** characterized by relatively less rainfall (average annual rainfall 1329 mm), shortage of surface water and high temperatures [25, 35]. One of the most vulnerable districts to droughts in Bangladesh is Rangpur [36].

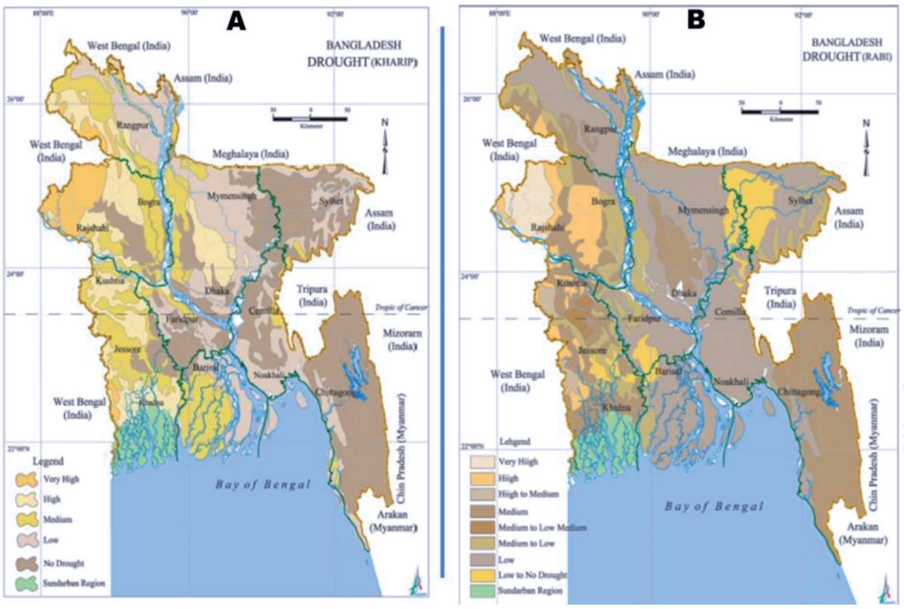

Figure 1.
Map of Bangladesh showing drought prone areas A. in kharif season B. in Rabi season [25].

Because of the extreme climate fluctuations mainly in the patterns of rainfall, Bangladesh is predicted to face increased rainfall upto 5–6% by 2030 resulting prolong flood during monsoon season and severe drought outside the monsoon season [13, 34]. Inadequate pre-monsoon shower, a delay in inception of rainy season or a quick advent of the monsoon season may accelerate the drought risk in Bangladesh [37]. Bangladesh experienced 20 different drought events over the last 50 years and among them the droughts of 1973–1974, 1975, 1978–1979, 1981, 1982, 1989, 1994–1995, 2000 and 2006 are most hazardous [34, 38]. Effects of some major historical drought events of Bangladesh are presented in **Table 1**.

In Bangladesh, the spatial pattern of pre-monsoon droughts are more recurrent in northwestern part [39]. An analysis on monthly pattern drought from 1971 to 2010 has suggested that Dinajpur, Kushtia, Rajshahi, Rangpur and Bogura are the highest drought-prone parts of the country [40]. Further drought trends investigation has revealed the declining trends in rainfall and increase in dryness at Ishurdi, Bogura, Sayedpur and Rangpur [41]. Investigation on spatiotemporal drought

Happening year	Drought impacts
1973–1974	One of the most severe drought events in the century that caused famine in 1974 in northern part of Bangladesh
1975	Affected 47% of area and half of the total population of Bangladesh
1978–1979	Affected about 42% of the cultivated land and 44% of the total population. Caused severe damage to crop production especially rice (reduced about 2 million tons production)
1981	Adversely affected crop production
1982	Caused severe reduction in rice production (reduced about 53,000 tons production)
1989	Dried up most of the rivers in north-western regions of Bangladesh with dust storms in Nawabganj, Naogaon, Nilpahamari and Thakurgaon districts
1994–1995 and 1995–1996	Caused immense crop damage, especially to the main crops of northwest Bangladesh like rice, jute and bamboo clumps. The most persistent droughts in recent times

Table 1.
Major historical droughts and its impact in Bangladesh [28].

patterns on a regional scale has exposed that higher intensities and frequencies of drought events in the northwestern part make the area more vulnerable to both drought severity and extremity [42]. Recent assessment of droughts from 1960 to 2011 in context of changing climate using drought hazard index (DHI) and drought index (DI) has disclosed that the northern part of Bangladesh are more drought-prone and there is a probability for the area of experiencing more extreme drought events in near future [43]. The studies on changing pattern of meteorological droughts indicates the rising trend of more extreme droughts in cropping season and also reveals the possibility of changing the drought occurrence pattern in both areas where it historically affected most (northwestern part) or the areas with fewer droughts (other parts) [44, 45]. Huge uncertainties are noticed in the possible future changes in droughts and also that would expand from north-western to central, western and south-western regions in Bangladesh [46, 47].

3. Cropping pattern in the drought-affected zones

Cropping pattern of an area is normally determined by its climatic parameters related to a particular time of a year. Bangladesh is situated in subtropical region giving it a suitable temperature range which makes it favorable for year round crop cultivation. However, Bangladesh has a complex and intensively diverse cropping pattern and that pattern is evolving and changing at a continuous basis [48]. Depending on cultural method, the whole crop-growing period of Bangladesh is distributed into two major seasons i.e. Kharif season and Rabi season. Beside these two, there is a transitional season named pre-kharif (shown in **Table 2**) [49]. Kharif crops like rice, jute, maize, millets etc. are grown in Kharif season and Rabi crops like wheat, mustard, chickpea, lentil etc. are grown during Rabi season [25].

In Bangladesh, all the cropping season are more or less affected by drought. But pre-monsoon and post-monsoon period are mostly prone to drought events [25]. Kharif drought negatively affects the critical reproductive stage of transplanted Aman rice where all of the Rabi crops are affected by pre-kharif/rabi droughts [4]. Assessment of drought in northern area of Bangladesh for the period between 1971 and 2008 reveals that most extreme drought conditions have been experienced in Rabi season including pre-monsoon [24]. Increasing trend in precipitation change in Bangladesh causes more rainfall in monsoon and less rainfall in winter resulting in droughts in winter season. Thus yield of various crops like HYV boro rice, aus rice, wheat, sugarcane, pulses and potatoes growing in Rabi and pre-kharif season are badly affected by droughts [35, 50]. In recent decades, the drought condition in northwestern Bangladesh severely affected the production of rice and all Rabi crops

Cropping season	Occurring month	Characteristics
Kharif or Monsoon (also known as kharif-2 or aman)	June/July to September/ October	• High rainfall, temperature and humidity • Enough moister in soil • Rain-fed crops are grown
Rabi or Winter	October/November to February/March	• Little or no rainfall during the season • Crops grown under irrigation
Pre-kharif or pre-monsoon or spring (also known as kharif-1)	March/April to May/June	• Unreliable rainfall • Intermittent moisture supply to crops

Table 2.
Major cropping seasons in Bangladesh.

(wheat, tobacco, sugarcane etc.) [25]. Rice-rice, rice-wheat and rice-maize are the dominating cropping patterns in Bangladesh in the drought regions [51, 52]. In late October to early November, certain areas of lands in Bangladesh become empty because of using short duration rice varieties which is appropriate for wheat cultivation [4]. For decades, wheat is grown in wheat-fallow-T. aman rice cropping pattern in north-western part of Bangladesh with some exceptions like wheat-jute-T. aman rice cropping pattern [53].

4. Adverse effects of drought on wheat production

Drought is one of the most limiting stress factors for crop growth and development, dry matter production and potential yield [15, 54]. The major processes required for plant growth and development are hampered by the drought condition. Water deficit conditions lessen the rate of photosynthesis by inhibiting chlorophyll synthesis, impede cellular elongation and metabolism, decline the CO_2 assimilation rates due to reduction in stomatal conductance and gaseous exchange, reduce dry matter biomass production and alter root morphology [54, 55]. As a result leaf size, stem elongation, root production and finally the rate of growth and yield are affected by drought [54].

Drought is not a static stress, it can occur at any crop growing period, its severity and frequency can vary and also it can recurrently happens in combination with other abiotic stresses, such as salinity and heat [56]. Drought stress can fluctuate diurnally (high during peak photosynthetic period and low overnight) and different organs of plants respond differently to drought stress [57]. Yield contributing traits vary according to growth stage of plant, so the level of seriousness of drought stress eventually relies on the particular growth stages that are impacted by drought. The nature of plants' response also differ depending on whether the plant is experiencing stress for the first time or after several exposures and whether they are recovering from stress after a rainfall or irrigation event [58].

Water is needed for the entire growth period of wheat but some specific stages are more sensitive to water limitations. Various morphological, physiological and biochemical alterations are occurred in plants body under drought environment (see **Table 3**). In case of wheat, the extent of drought stress may vary according to different growth stages. Specific critical growth stages of wheat plants such as germination and seedling stages [59]; tillering and stem elongation stages [60, 61]; heading, anthesis and grain filling stages [16, 59] may be more vulnerable

Drought stress in wheat	Morphological alterations	Limited plant size, ceased plant height, reduced leaf extension, lessened leaf size and number of leaves, decreased leaf area, reduced leaf longevity, prompt maturity, augmented root-to-shoot ratio, condensed total shoot length, lowered yield
	Physiological alterations	Stomata closure, reduction in photosynthesis, swift in oxidative stress, alterations in cell wall integrity, decrease in leaf water potential, lessen growth rates, reduced transpiration rates and relative water content, developed water use efficiency
	Biochemical alterations	Reduction in rubisco efficiency, decrease in photochemical efficiency, production of reactive oxygen species (ROS), increase in oxidation damage, hampered antioxidant defense system, reduced chlorophyll content

Table 3.
Effect of water-deficit stress on morphological, physiological and biochemical traits of wheat [64].

to drought stress. Long term droughts (starting from stem elongation through to maturity) cause more drastic yield reduction compared to those initiating at later stages through to maturity [62]. Although the influence of drought stress on heading and grain filling stages are more severe in terms of yield, drought can also negatively affect the multiple growth stages of wheat comprising germination, tillering, booting, heading, anthesis, and maturity [63].

5. Crop traits and mechanisms adaptive to drought stress

In drought condition, sometimes very swift growth responses are generated even due to a little water pulse that can vigorously activate plant growth and safeguard survival [65]. Constantly fluctuating nature of drought events makes it indispensible to understand the plants' aptitude to adapt and recover from the stress [66]. To overcome the harmful effects of drought stress, naturally plants are well furnished with various adaptive mechanisms. These adaptive mechanisms support plants for an optimal maintenance of growth for metabolic regulation and survival [67]. The more the extent of these mechanisms, the more will be the plants' capability to overcome stress condition. But the adaptive mechanism is not as simple as it sounds; it comprises diverse morphological, physiological and anatomical modifications in plant under stress condition. Morphological and metabolic adaptation processes of plants vary according to cultivars in response to water deficit condition. As, plants' may have unique adaptation capabilities irrespective to cultivars [68]. Different physiological processes in plant such as photosynthesis, heat dissipation and chlorophyll fluorescence are occurred in rivalry with each other in response to drought events i.e. any upsurge in the efficacy of one will bring diminution to others [69]. The normal fluctuation values of these physiological processes can denote plant fitness with the magnitude of environmental stress [55].

Drought adaptation is complicated that experiences diverse anatomical and morpho-physiological and biochemical amendments in plants such as alterations in leaf traits or canopy cover, leaf water relations with modification of growth rates, reduction of stomatal opening and associated components [70, 71]. The plants' response to water deficit condition has been extensively studied to recognize tolerance mechanisms [72]. So, detailed knowledge about underlying behavior of plants under drought stress is required to develop drought tolerant plants. Although being complex, mainly three kinds of drought-resistance mechanisms are exhibited by plants to evade the resulting devastating effects of droughts: (i) drought escape (ii) drought avoidance and (iii) drought tolerance [73]. Drought escape happens when plants grow quickly and reproduce before severe drought conditions. In this mechanism, plants evades drought season by modifying flowering time thus they try to complete their life cycle before drought condition. In drought avoidance mechanism, plants avoid water-deficit situation by enhancing their water-use efficiency (WUE) through closure of stomata, reduction of transpiration, limitation of vegetative growth, or by increment in root growth. In case of drought tolerance, drought stress is fought by plants at cellular level through osmotic adjustment by developing antioxidants and production of molecules that stabilize proteins [73].

Wheat plants exhibit a tight network of morpho-physiological and photoprotective mechanisms to alleviate the drought stress [66]. To escape reproductive failure from severe drought stress, plants displayed phenological alterations of earlier anthesis and maturity [66]. Previous literature revealed constitutive traits that confer dehydration avoidance mechanisms in plants include leaf waxy layer, leaf rolling and osmotic adjustment [74], high root length density [75] and high fine roots with small diameters [76], a deep root system and the number of seminal roots [77–79],

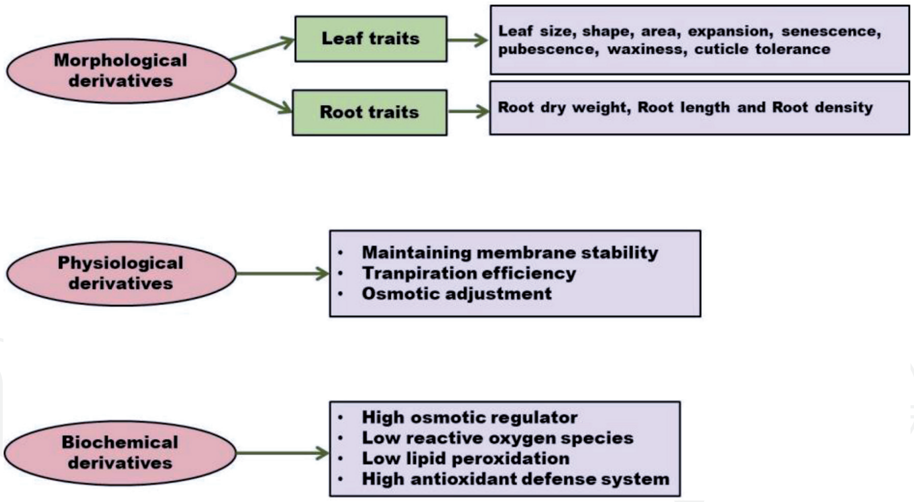

Figure 2.
Morpho-physiological and biochemical derivatives of drought tolerance in wheat.

high total root length and total root surface area [80, 81], root-to-shoot dry matter ratio [82] and root partitioning of assimilates to shallow or depth roots in response to drought [83]. There are range of morphological, physiological and biochemical derivatives of drought tolerance in wheat [64] (shown in **Figure 2**). Water use, water use efficiency, biomass yield and flag leaf relative water contents are the important drought tolerance traits in wheat [84, 85]. Selection of wheat plant with high transpiration efficiency, high percentage of relative water contents and cell membrane thermo-stability and greater osmotic adjustment capacity leads to produce drought tolerant plants [64, 86]. When drought stress is imposed on seedling stage of wheat, cell membrane thermo-stability, fresh and dry weight of seedlings are considered major traits to govern drought responses under stress conditions [87]. Therefore, greater morphological adaptation with limited down-regulated physiological activities followed by high recovery in wheat cultivars designate its capability to effectively endure drought events [66].

6. Prospects of breeding for drought tolerance in wheat

Plant breeders around the world have to deal with great challenges to work with drought stress. Polygenic nature of drought makes the breeding efforts more complicated than other abiotic stresses [88]. Global climate change will result in frequent drought events as per predicted in country like Bangladesh [89]. So, for improving wheat production in Bangladesh, research priority should be focused on breeding new high yielding drought tolerant wheat varieties. Majority of the studies under drought stress focus on the response of natural drought in field conditions where drought events are ambiguous and irregular using conventional techniques. Generally the conventional breeding techniques such as introduction, selection, hybridization and mutation are being used by the breeders of Bangladesh. Whereas throughout the globe, wheat breeders are now using different novel breeding methods including *in situ* and *in vitro* techniques. Under drought stress, several morpho-physiological and biochemical mechanisms are activated in plant body to withstand the stress. But poor conceptual knowledge about the developmental and physiological basis of yield related traits under water-deficit environments make the drought stress more complex [90]. Therefore, better understanding about the detailed physiological and genetic adaptive strategies of wheat cultivars during water-deficit stress would offer the appraised benchmarks of breeding methods for pursuing drought tolerance in wheat [64]. Hence, selection procedures based on physiological traits have potentiality to improve the final productivity of wheat under drought stress [66].

In recent times, as part of empirical breeding based programs, breeders have been embracing replicated, multi-locational and multi-year variety testing for finding out the best adaptive varieties to stress environments. Expanding grain yield under drought stress can be performed to a limited extent through selection process [91, 92]. For being recurrent and season indefinite stress event, trait evaluation under drought condition may cause losing of potential genetic resources which perform better in normal wheat-growing environments [89]. This may ultimately hamper the variety development process. Therefore, evaluation including diverse testing environments including both normal and stressed conditions will be more suitable and competent for the development of high yielding, stable varieties amended to water-deficit conditions [89].

7. Breeding strategies for drought tolerance in wheat

It is very challenging for the plant breeders of Bangladesh to develop drought-tolerant wheat varieties [22]. For ensuring future food security of Bangladesh, the scientists of Wheat Research Center (WRC) of Bangladesh Agricultural Research Institution (BARI) are trying hard to develop wheat varieties that can be suited well in abiotic stress environments [4]. But alongside using a range of conventional breeding strategies for developing stress tolerant variety, breeders always search to produce new genetic variant to increase of genetic gain through advanced molecular approaches.

For maintaining the consistency of wheat production in Bangladesh adaptive to future climate change, the wheat varieties of next generation should possess high yield potentially even under stressed conditions. Yield potentiality can be enhanced through strategic crosses depending upon pyramiding yield potential traits and related physiological traits to stress tolerance in well adapted genotypes [4]. Breeding for drought tolerance in wheat initially requires satisfactory amount of variability among the source populations. Conventional hybridization is the most widely used breeding procedure in wheat, where genetic variability is created through combination and recombination of desirable genes in the background of diverse adapted genotypes followed by a selection of desirable plants in subsequent generations to develop improved varieties for the target environment [4]. Generally grain yield is the primary basis for selection for drought tolerance but indirect selection based on related yield-contributing and physiological traits can be more effective for developing drought tolerant varieties [89, 93–95]. In this connection, several wheat lines collected from various national and international sources especially CIMMYT (International Maize and Wheat Improvement Center) are evaluated for their performance in diverse growing environments of Bangladesh [4]. Screening of drought tolerant wheat genotypes has been commenced at Barind area of Rajshahi region of Bangladesh where incorporation of related traits to drought tolerance into adapted varieties is also undergoing [4]. Although being the main breeding procedures with some advantages, conventional techniques are slow, labour-intensive and economically unfeasible [96].

In contrast to time-consuming conventional breeding methods for accomplishing homozygous lines to develop wheat varieties, double haploid breeding instantly enables development of homozygous lines from a crop plant. Hence, double haploid breeding can be also an effective method in wheat breeding since selection efficiency relies on uniform homozygous line production. But, unwanted genetic modifications due to gametoclonal variation negatively affect the selection of population [97–99]. Interspecific crosses can also produce double haploids of wheat. Recently, WRC of BARI (now, Bangladesh Wheat and Maize Research Institute) has embraced the double haploid breeding technique through cross-pollinating wheat and maize [4]. For speeding up the variety release process, scientists are being trained for efficient targeted crosses to produce double haploid plants [4]. Mutation breeding offers another way to produce drought tolerant wheat varieties in Bangladesh. Induced mutations by gamma-ray is very efficient in augmenting genetic variability which provide a great opportunity for the wheat breeders to select for drought tolerance in M_2 (mutant generation 2) and next mutated generations [100–102]. Recently, in bread wheat, drought tolerant mutants are formed using gamma rays that lead to the release of 26 varieties worldwide [103]. Incorporating with several improved traits, these varieties can survive the stress environments. Thus, high potentiality of developed wheat mutants for direct release and inclusion in hybridization breeding programs is the major benefit of mutation breeding [104].

Molecular mechanism of drought tolerance is very complicated to understand. Numerous drought-responsive genes are involved in making plant drought tolerant, furthermore expressions of these genes also differ with various plant growth stages [74, 105]. Various genes and their related enzymes and proteins including late embryogenesis abundant (lea), responsive to abscisic acid (Rab), rubisco, helicase, proline, dehydrins, vacuolar acid invertase, glutathione-S-transferase (GST) and carbohydrates provide the molecular basis for drought tolerance in wheat [64]. It points towards challenges and uncertainties remain in breeding for drought tolerance. Hence, inclusion of innovative molecular and biotechnological methods like molecular marker methods, quantitative trait loci (QTL) mapping strategies, expression patterns of genes and genetic engineering should be practiced for the development of drought tolerant wheat genotypes. Currently, molecular markers are extensively used for detecting the location of drought-induced genes. Genome mapping and tagging of various traits aided by molecular markers are utilized in Marker-assisted breeding in wheat for developing drought tolerance [106]. Marker techniques allow indirect selection independent of crop developmental stage specially when dealing with polygenic trait like drought tolerance. In the previous few decades, molecular markers like isozymes, SDS-protein and sequence based DNA markers are exploited in wheat breeding for assessing gene diversities, precise mapping of their respective QTLs on chromosomes and finally for selecting quantitative traits like drought tolerance [107–111]. Even though large genome size of wheat, polygenic nature of the trait, instability of some QTL ultimately make the mapping process very challenging to execute for drought tolerance [106, 112, 113].

Now-a-days, modern biotechnological approaches have been involved in developing transgenic plants that can withstand the severity caused by drought. Since, these biotechnological strategies enable more understanding about the drought responses of crops at the entire plant and molecular levels [114]. It is evident from previous study that in field conditions, genetically modified wheat exhibits high tolerance to drought [115]. Plant tissue culture, hydroponic culture, *in situ* techniques and *in vitro* techniques such as somaclonal variants selection, protoplast culture should be employed for breeding under drought stress [116]. Further novel technologies like genome editing [117], high throughput phenotyping (HTP) and next generation sequencing (NGS) may be employed to explore innovative possibilities for improving drought tolerance in wheat plants [89, 118–120].

8. Conclusions

As it is an urgent call for upgrading wheat production under increasing potentiality of drought events, wheat breeders of Bangladesh need to emphasize on integrating more breeding techniques to make drought tolerant varieties. Majority of the breeding approaches here are concentrating on conventional techniques. So, it is high time to combine the conventional breeding methods with the modern techniques to develop wheat genotypes for the next generation. New advanced screening, hybridization and selection techniques shall need to be incorporated with conventional techniques. To maximize the breeding efficiency for drought tolerance in wheat, advanced precision phenotyping accompanied by genetic and molecular approaches should be integrated in breeding programs.

Conflict of interest

"The authors declare no conflict of interest."

Funding

This research was supported by the University Grants Commission of Bangladesh (Grant No. 2019/829/UGC).

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References

[1] Ahmed AU. Bangladesh climate change impacts and vulnerability. A synthesis; climate change cell; department of environment, comprehensive disaster management programme: Dhaka, Bangladesh, 2006.

[2] Shahid S, Behrawan H. Drought risk assessment in the western part of Bangladesh. Natural Hazards. 2008; 46:391-413. DOI: 10.1007/s11069-007-9191-5

[3] World Bank Bangladesh – country assessment strategy FY 2011-2014. Bangladesh Country Management Unit, South Asia Region, The World Bank Office, Dhaka, 2009.

[4] Barma NCD, Hossain A, Hakim MA, Mottaleb KA, Alam MA, Reza MM, Rohman MM. Progress and challenges of wheat production in the era of climate change: a Bangladesh perspective. In Wheat Production in Changing Environments. Springer, Singapore. 2019. p. 615-679. DOI: 10.1007/978-981-13-6883-7_24

[5] Food and Agriculture Organization of the United Nations (FAO). Data domain: production: crops. FAO, Rome. Available from: http://www.fao.org/faostat/en/#data/QC. [Accessed: 2018-07-18]

[6] Timsina J, Wolf J, Guilpart N, Van Bussel LG, Grassini P, Van Wart J, Hossain A, Rashid H, Islam S, Van Ittersum MK. Can Bangladesh produce enough cereals to meet future demand?. Agricultural Systems. 2018; 163:36-44. DOI: 10.1016/j.agsy.2016.11.003

[7] Mottaleb KA, Rahut DB, Kruseman G, Erenstein O. Wheat production and consumption dynamics in an Asian rice economy: The Bangladesh case. The European Journal of Development Research. 2018; 30:252-275.

[8] Mottaleb KA, Rahut DB, Kruseman G, Erenstein O. Changing food consumption of households in developing countries: a Bangladesh case. Journal of International Food & Agribusiness Marketing. 2018; 30:156-174. DOI: 10.1080/08974438.2017.1402727

[9] Mottaleb KA, Rahut DB, Kruseman G, Erenstein O. Evolving food consumption patterns of rural and urban households in developing countries. British Food Journal. 2018; 20:392-408. DOI: 10.1108/BFJ-12-2016-0620

[10] Bangladesh Bureau of Statistics (BBS). Statistical year book of Bangladesh. Dhaka: Statistics Division, Ministry of Planning, Government of Peoples Republic of Bangladesh; 2018.

[11] United States Department of Agriculture (USDA). FAS Home/Market and trade data/PSD online. USDA, Foreign Agricultural Service, Washington, DC; 2018. Available from: https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery. [Accessed: 2018-09-28]

[12] Barma NCD. An overview on variety development program of WRC. Presented in WRC Internal research review and planning workshop 2017-18, held on 15 July 2018 at BARI seminar room, BARI, Joydebpur, Dhaka.

[13] Intergovernmental Panel on Climate Change (IPCC). Climate change 2007. Synthesis report. In: Pachauri RK, Reisinger AJ editors. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. Geneva, 2007. p. 104. Available from: https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-4-1.html. [Accessed: 2018-08-15]

[14] Daryanto S, Wang L, Jacinthe PA. Global synthesis of drought effects on maize and wheat production. PloS one. 2016; 11:e0156362. DOI: 10.1371/journal.pone.0156362

[15] Zhang J, Zhang S, Cheng M, Jiang H, Zhang X, Peng C, Lu X, Zhang M, Jin J. Effect of drought on agronomic traits of rice and wheat: a meta-analysis. International Journal of Environmental Research And Public Health. 2018; 15:839. DOI: 10.3390/ijerph15050839

[16] Sarto MVW, Sarto JRW, Rampim L, Rosset JS, Bassegio D, da Costa PF, Inagaki AM. Wheat phenology and yield under drought: a review. Australian Journal of Crop Science. 2017; 11:941. DOI: 10.21475/ajcs17.11.08.pne351

[17] Shahid S, Wang XJ, Harun SB, Shamsudin SB, Ismail T, Minhans A. Climate variability and changes in the major cities of Bangladesh: observations, possible impacts and adaptation. Regional Environmental Change. 2016; 16:459-471. DOI: 10.1007/s10113-015-0757-6

[18] Khan N, Shahid S, Ismail T, Ahmed K, Nawaz N. Trends in heat wave related indices in Pakistan. Stochastic Environmental Research and Risk Assessment. 2019; 33:287-302. DOI: 10.1007/s00477-018-1605-2

[19] Khan N, Shahid S, bin Ismail T, Wang XJ. Spatial distribution of unidirectional trends in temperature and temperature extremes in Pakistan. Theoretical and Applied Climatology. 2019; 136:899-913. DOI: 10.1007/s00704-018-2520-7.

[20] Ahmed HGMD, Sajjad M, Li M, Azmat MA, Rizwan M, Maqsood RH, Khan SH. Selection criteria for drought-tolerant bread wheat genotypes at seedling stage. Sustainability. 2019; 11:2584. DOI: 10.3390/su11092584

[21] Shiru MS, Shahid S, Chung ES, Alias N. Changing characteristics of meteorological droughts in Nigeria during 1901-2010. Atmospheric Research. 2019; 223:60-73. DOI: 10.1016/j.atmosres.2019.03.010

[22] Hossain A, Teixeira da Silva JA. Wheat production in Bangladesh: its future in the light of global warming. AoB Plants. 2013; 5. DOI: 10.1093/aobpla/pls042

[23] Abhinandan K, Skori L, Stanic M, Hickerson N, Jamshed M, Samuel MA. Abiotic stress signaling in wheat–an inclusive overview of hormonal interactions during abiotic stress responses in wheat. Frontiers in Plant Science. 2018; 9:734. DOI: 10.3389/fpls.2018.00734

[24] Alam K. Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh. Agricultural Water Management. 2015; 148:196-206. DOI: 10.1016/j.agwat.2014.10.011

[25] Banglapedia, National Encyclopedia of Bangladesh. Available from: http://en.banglapedia.org/ index.php?title=Drought [Accessed: 2020-10-10].

[26] Huq S. Lessons of climate change, stories of solutions: Bangladesh: adaptation. Bulletin of the Atomic Scientists. 2011; 67:56-59. DOI: 10.1177/0096340210393925

[27] Shahid S. Rainfall variability and the trends of wet and dry periods in Bangladesh. International Journal of Climatology. 2010; 30:2299-2313. DOI: 10.1002/joc.2053

[28] Selvaraju R, Baas S. Climate variability and change: adaptation to drought in Bangladesh: A resource book and training guide. Food & Agriculture Organization; 2007.

[29] National Drought Mitigation Center (NDMC). What is drought?

Understanding and defining drought. Available from: http://www.drought.unl.edu/whatis/concept.htm [Accessed: 2017-09-25]

[30] Shahid S. Spatial and temporal characteristics of droughts in the western part of Bangladesh. Hydrological Processes: An International Journal. 2008; 22:2235-2247. DOI: 10.1002/hyp.6820

[31] Shahid S, Behrawan H. Drought risk assessment in the western part of Bangladesh. Natural hazards. 2008; 46:391-413. DOI 10.1007/s11069-007-9191-5

[32] Shahid S, Hazarika MK. Groundwater drought in the northwestern districts of Bangladesh. Water Resources Management. 2010; 24:1989-2006. DOI: 10.1007/s11269-009-9534-y

[33] Dey NC, Alam MS, Sajjan AK, Bhuiyan MA, Ghose L, Ibaraki Y, Karim F. Assessing environmental and health impact of drought in the Northwest Bangladesh. Journal of Environmental Science and Natural Resources. 2011; 4:89-97. DOI: 10.3329/jesnr.v4i2.10141

[34] Habiba U, Shaw R, Takeuchi Y. Farmer's perception and adaptation practices to cope with drought: Perspectives from Northwestern Bangladesh. International Journal of Disaster Risk Reduction. 2012; 1:72-84. DOI: 10.1016/j.ijdrr.2012.05.004

[35] Habiba U, Shaw R, Takeuchi Y. Drought risk reduction through a socio-economic, institutional and physical approach in the northwestern region of Bangladesh. Environmental Hazards. 2011; 10:121-138. DOI: 10.1080/17477891.2011.582311

[36] Khatun M. Climate Change and Migration in Bangladesh: Golden Bengal to Land of Disasters. Bangladesh e-journal of Sociology. 2013; 10.

[37] Shafie H, Halder SR, Rashid AK, Lisa KS, Mita HA. Endowed wisdom: knowledge of nature and coping with disasters in Bangladesh. Dhaka: Center for Disaster Preparedness and Management. 2009.

[38] Ramamasy S, Baas S. Climate variability and change: adaptation to drought in Bangladesh. A resource book and training guide. FAO: Rome, Italy. 2007; p. 68.

[39] Alamgir M, Shahid S, Hazarika MK, Nashrrullah S, Harun SB, Shamsudin S. Analysis of meteorological drought pattern during different climatic and cropping seasons in Bangladesh. JAWRA Journal of the American Water Resources Association. 2015; 51:794-806. DOI: 10.1111/jawr.12276

[40] Rahman MR, Lateh H. Meteorological drought in Bangladesh: assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data. Environmental Earth Sciences. 2016; 75:1026. DOI: 10.1007/s12665-016-5829-5

[41] Nury AH, Hasan K, Dustegir M, Alam MJ. Drought assessment using standardized precipitation evaporation index and its association with southern oscillation index in the Northwestern Bangladesh. International Journal of Water. 2017; 11:132-158. DOI: 10.1504/IJW.2017.083766

[42] Miah MG, Abdullah HM, Jeong C. Exploring standardized precipitation evapotranspiration index for drought assessment in Bangladesh. Environmental Monitoring and Assessment. 2017; 189:547. DOI: 10.1007/s10661-017-6235-5

[43] Kamruzzaman M, Rahman AS, Ahmed MS, Kabir ME, Mazumder QH, Rahman MS, Jahan CS. Spatio-temporal analysis of climatic variables in the western part of Bangladesh. Environment, Development and

Sustainability. 2018; 20:89-108. DOI: 10.1007/s10668-016-9872-x

[44] Mondol M, Haque A, Ara I, Das SC. Meteorological drought index mapping in Bangladesh using standardized precipitation index during 1981-2010. Advances in Meteorology. 2017; 2017. DOI: 10.1155/2017/4642060

[45] Mohsenipour M, Shahid S, Chung ES, Wang XJ. Changing pattern of droughts during cropping seasons of Bangladesh. Water Resources Management. 2018; 32:1555-1568. DOI: 10.1007/s11269-017-1890-4

[46] Planning Commission, GOB and UNDP Bangladesh. Policy study on climate change on poverty and economic growth and the options of coping with adverse impact of climate change in Bangladesh. Support to Monitoring PRs and MDGs in Bangladesh: Dhaka. 2009.

[47] Mortuza MR, Moges E, Demissie Y, Li HY. Historical and future drought in Bangladesh using copula-based bivariate regional frequency analysis. Theoretical and Applied Climatology. 2019; 135:855-871. DOI: 10.1007/s00704-018-2407-7

[48] Timsina J, Connor DJ. Productivity and management of rice–wheat cropping systems: issues and challenges. Field Crops Research. 2001; 69:93-132. DOI: 10.1016/S0378-4290(00)00143-X

[49] Ahammed SJ, Homsi R, Khan N, Shahid S, Shiru MS, Mohsenipour M, Ahmed K, Nawaz N, Alias NE, Yuzir A. Assessment of changing pattern of crop water stress in Bangladesh. Environment, Development and Sustainability. 2019; 1-9. DOI: 10.1007/s10668-019-00400-w

[50] Ahmed AU. Bangladesh climate change impacts and vulnerability. A synthesis; climate change cell; department of environment, comprehensive disaster management programme: Dhaka, Bangladesh. 2006.

[51] Timsina J, Jat ML, Majumdar K. Rice-maize systems of South Asia: current status, future prospects and research priorities for nutrient management. Plant and Soil. 2010; 335:65-82. DOI: 10.1007/s11104-010-0418-y

[52] Timsina J, Buresh RJ, Dobermann A, Dixon J. Rice-maize systems in Asia: current situation and potential. IRRI, Los Banos, Philippines. 2011. p. 235.

[53] Kabir MJ, Islam MM. Study on agronomically and economically dominant cropping patterns in some selected areas of Barisal district. Bangladesh Journal of Agricultural Research. 2012; 37:55-65. DOI: 10.3329/bjar.v37i1.11177

[54] Anjum SA, Xie XY, Wang LC, Saleem MF, Man C, Lei W. Morphological, physiological and biochemical responses of plants to drought stress. African Journal of Agricultural Research. 2011; 6:2026-2032. DOI: 10.5897/AJAR10.027

[55] Liu H, Sultan MARF, Liu XL, Zhang J, Yu F, Zhao HX. Physiological and comparative proteomic analysis reveals different drought responses in roots and leaves of drought-tolerant wild wheat (*Triticum boeoticum*). PLoS One. 2015; 10:e0121852. DOI:10.1371/journal.pone.0121852

[56] Suzuki N, Rivero RM, Shulaev V, Blumwald E, Mittler R. Abiotic and biotic stress combinations. New Phytologist. 2014; 203:32-43. DOI: 10.1111/nph.12797

[57] Tardieu F, Granier C, Muller B. Water deficit and growth. Co-ordinating processes without an orchestrator?. Current Opinion in Plant Biology. 2011; 14:283-289. DOI: 10.1016/j.pbi.2011.02.002

[58] Vadez V, Kholova J, Zaman-Allah M, Belko N. Water: the most important

'molecular' component of water stress tolerance research. Functional Plant Biology. 2013; 40:1310-1322. DOI: 10.1071/FP13149

[59] Akram M. Growth and yield components of wheat under water stress of different growth stages. Bangladesh Journal of Agricultural Research. 2011; 36:455-468. DOI: 10.3329/bjar.v36i3.9264

[60] Saeidi M, Abdoli M. Effect of drought stress during grain filling on yield and its components, gas exchange variables, and some physiological traits of wheat cultivars. Journal of Agricultural Science and Technology. 2015; 17:885-898.

[61] Wang X, Vignjevic M, Liu F, Jacobsen S, Jiang D, Wollenweber B. Drought priming at vegetative growth stages improves tolerance to drought and heat stresses occurring during grain filling in spring wheat. Plant Growth Regulation. 2015; 75:677-687. DOI: 10.1007/s10725-014-9969-x

[62] Shamsi K, Kobraee S. Bread wheat production under drought stress conditions. Annals of Biological Research. 2011; 2:352-358.

[63] Ihsan MZ, El-Nakhlawy FS, Ismail SM, Fahad S. Wheat phenological development and growth studies as affected by drought and late season high temperature stress under arid environment. Frontiers in Plant Science. 2016; 7:795. DOI: 10.3389/fpls.2016.00795

[64] Nezhadahmadi A, Prodhan ZH, Faruq G. Drought tolerance in wheat. The Scientific World Journal. 2013; 2013:1-12. DOI: 10.1155/2013/610721

[65] Chen D, Wang S, Cao B, Cao D, Leng G, Li H, Yin L, Shan L, Deng X. Genotypic variation in growth and physiological response to drought stress and re-watering reveals the critical role of recovery in drought adaptation in maize seedlings. Frontiers in Plant Science. 2016; 6:1-15. DOI: 10.3389/fpls.2015.01241

[66] Abid M, Tian Z, Ata-Ul-Karim ST, Wang F, Liu Y, Zahoor R, Jiang D, Dai T. Adaptation to and recovery from drought stress at vegetative stages in wheat (*Triticum aestivum*) cultivars. Functional Plant Biology. 2016; 43:1159-1169. DOI: 10.1071/FP16150

[67] Izanloo A, Condon AG, Langridge P, Tester M, Schnurbusch T. Different mechanisms of adaptation to cyclic water stress in two South Australian bread wheat cultivars. Journal of Experimental Botany. 2008; 59:3327-3346. DOI:10.1093/jxb/ern199

[68] Khanna-Chopra R, Selote DS. Acclimation to drought stress generates oxidative stress tolerance in drought-resistant than-susceptible wheat cultivar under field conditions. Environmental and Experimental Botany. 2007; 60:276-283. DOI: 10.1016/j.envexpbot.2006.11.004

[69] Maxwell K, Johnson GN. Chlorophyll fluorescence – a practical guide. Journal of Experimental Botany. 2000; 51:659-668. DOI: 10.1093/jexbot/51.345.659

[70] Galmés J, Flexas J, Savé R, Medrano H. Water relations and stomatal characteristics of Mediterranean plants with different growth forms and leaf habits: responses to water stress and recovery. Plant and Soil. 2007; 290:139-155. DOI: 10.1007/s11104-006-9148-6

[71] Ali A, Syed AAW, Khaliq T, Asif M, Aziz M, Mubeen M. Effects of nitrogen on growth and yield components of wheat (report). Biological Sciences. 2011; 3:1004-1005.

[72] Kantar M, Lucas SJ, Budak H. miRNA expression patterns of *Triticum*

dicoccoides in response to shock drought stress. Planta. 2011; 233:471-484. DOI: 10.1007/s00425-010-1309-4

[73] Ludlow MM. Strategies of response to water stress. In: Kreeb KH, Richter H, Hinckley TM, editors. Structural and functional responses to environmental stresses: water shortage. SPB Academic, The Hague; 1989. p. 269-281.

[74] Blum A. Plant breeding for water-limited environments. Springer Science & Business Media, New York. 2010.

[75] Comas L, Becker S, Cruz VM, Byrne PF, Dierig DA. Root traits contributing to plant productivity under drought. Frontiers in Plant Science. 2013; 4:442. DOI: 10.3389/fpls.2013.00442

[76] Henry A, Cal AJ, Batoto TC, Torres RO, Serraj R. Root attributes affecting water uptake of rice (*Oryza sativa*) under drought. Journal of Experimental Botany. 2012; 63:4751-4763. DOI: 10.1093/jxb/ers150

[77] Manschadi AM, Christopher J, deVoil P, Hammer GL. The role of root architectural traits in adaptation of wheat to water-limited environments. Functional Plant Biology. 2006; 33:823-837. DOI: 10.1071/FP06055

[78] Lilley JM, Kirkegaard JA. Benefits of increased soil exploration by wheat roots. Field Crops Research. 2011; 122:118-130. DOI: 10.1016/j.fcr.2011.03.010

[79] Ali ML, Luetchens J, Singh A, Shaver TM, Kruger GR, Lorenz A. Greenhouse screening of maize genotypes for deep root mass and related root traits and their association with grain yield under water-deficit conditions in the field. Euphytica. 2016; 207:79-94. DOI: 10.1007/s10681-015-1533-x

[80] Ayalew H, Ma X, Yan G. Screening wheat (*Triticum* spp.) genotypes for root length under contrasting water regimes: potential sources of variability for drought resistance breeding. Journal of Agronomy and Crop Science. 2015; 201:189-194. DOI: 10.1111/jac.12116

[81] Li R, Zeng Y, Xu J, Wang Q, Wu F, Cao M, Lan H, Liu Y, Lu Y. Genetic variation for maize root architecture in response to drought stress at the seedling stage. Breeding Science. 2015; 65:298-307. DOI: 10.1270/jsbbs.65.298

[82] Siddique KHM, Belford RK, Tennant D. Root: shoot ratios of old and modern, tall and semi-dwarf wheats in a Mediterranean environment. Plant and Soil. 1990; 121:89-98. DOI: 10.1007/BF00013101

[83] Ehdaie B, Layne AP, Waines JG. Root system plasticity to drought influences grain yield in bread wheat. Euphytica. 2012; 186:219-232. DOI: 10.1007/s10681-011-0585-9

[84] Richards RA, Rebetzke GJ, Condon AG, Van Herwaarden AF. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Science. 2002; 42:111-121. DOI: 10.2135/cropsci2002.1110

[85] Rampino P, Pataleo S, Gerardi C, Mita G, Perrotta C. Drought stress response in wheat: physiological and molecular analysis of resistant and sensitive genotypes. Plant, Cell & Environment. 2006; 29:2143-2152. DOI: 10.1111/j.1365-3040.2006.01588.x

[86] Faisal SU, Mujtaba SM, Khan MA, Mahboob WA. Morpho-physiological assessment of wheat (*Triticum aestivum* L.) genotypes for drought stress tolerance at seedling stage. Pakistan Journal of Botany. 2017; 49:445-452.

[87] Ahmed HG, Zeng Y, Yang X, Anwaar HA, Mansha MZ, Hanif CM, Ikram K, Ullah A, Alghanem SM. Conferring drought-tolerant wheat genotypes through morpho-physiological

and chlorophyll indices at seedling stage. Saudi Journal of Biological Sciences. 2020; 27:2116-2023. DOI: 10.1016/j.sjbs.2020.06.019

[88] Zhu M, Shabala S, Shabala L, Fan Y, Zhou MX. Evaluating predictive values of various physiological indices for salinity stress tolerance in wheat. Journal of Agronomy and Crop Science. 2016; 202:115-124. DOI: 10.1111/jac.12122

[89] Khadka K, Earl HJ, Raizada MN, Navabi A. A Physio-morphological trait-based approach for breeding drought tolerant wheat. Frontiers in Plant Science. 2020; 11:715. DOI: 10.3389/fpls.2020.00715

[90] Khan MM, Khan MSI, Mondal RS, Rashid MH, Faruq G, Rahman MM, Barma NCD. Performance of some selected wheat genotypes in southern Bangladesh. WRC Internal Research Review Report 2017-18 (Crop Management). Wheat Research Center, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur-5200, Bangladesh. 2018.

[91] Cattivelli L, Rizza F, Badeck FW, Mazzucotelli E, Mastrangelo AM, Francia E, Marè C, Tondelli A, Stanca AM. Drought tolerance improvement in crop plants: an integrated view from breeding to genomics. Field Crops Research. 2008; 105:1-14. DOI: 10.1016/j.fcr.2007.07.004

[92] Sserumaga JP, Beyene Y, Pillay K, Kullaya A, Oikeh SO, Mugo S, Machida L, Ngolinda I, Asea G, Ringo J, Otim M. Grain-yield stability among tropical maize hybrids derived from doubled-haploid inbred lines under random drought stress and optimum moisture conditions. Crop and Pasture Science. 2018; 69:691-702. DOI: 10.1071/CP17348

[93] Reynolds MP, Pellegrineschi A, Skovmand B. Sink-limitation to yield and biomass: a summary of some investigations in spring wheat. Annals of Applied Biology. 2005; 146:39-49. DOI: 10.1111/j.1744-7348.2005.03100.x

[94] Reynolds MP, Trethowan RM. Physiological interventions in breeding for adaptation to abiotic stress. In: Spiertz JHJ, Struik PC, van Laar HH, editors. Scale and complexity in plant systems research: gene-plant-crop relations. Cham: Springer; 2007. p. 129-146. DOI: 10.1002/anie.199315241

[95] Dolferus R, Thavamanikumar S, Sangma H, Kleven S, Wallace X, Forrest K, Rebetzke G, Hayden M, Borg L, Smith A, Cullis B. Determining the genetic architecture of reproductive stage drought tolerance in wheat using a correlated trait and correlated marker effect model. G3: Genes, Genomes, Genetics. 2019; 9:473-489. DOI: 10.1534/g3.118.200835

[96] Wieczorek A. Use of Biotechnology in Agriculture-Benefits and Risks. University of Hawaii, Biotechnology, BIO-3, Honolulu, Hawaii, USA, 2003.

[97] Huang B. Gametoclonal variation in crop improvement. In: Jain SM, Sopory SK, Veilleux RE, editors. In vitro haploid production in higher plants. vol 2. Kluwer, Dordrecht; 1996. p. 73-91.

[98] Raina SK. Doubled haploid breeding in cereals. In: Janick J, editor. Plant breeding reviews. vol 15. Wiley, New York; 1997. p. 141-186.

[99] Ma H, Busch RH, Riera-Lizarazu O, Rines HW, Dill-Macky R. Agronomic performance of lines derived from anther culture, maize pollination and single-seed descent in a spring wheat cross. Theoretical and Applied Genetics. 1999; 99:432-436.

[100] Sobieh SS. Induction of short culm mutants for bread wheat by using gamma rays. Arab Journal of Nuclear Sciences and Applications. 2002; 35:318-328.

[101] Al-Naggar AM, Ragab AE, Youssef SS, Al-Bakry RI. New genetic variation in drought tolerance induced via irradiation and hybridization of Egyptian cultivars of bread wheat. Egyptian Journal of Plant Breeding. 2004; 8:353-370.

[102] Al-Naggar AM, Atta MM, Shaheen AM, Al-Azab KF. Gamma rays and EMS induced drought tolerant mutants in bread wheat. Egyptian Journal of Plant Breeding. 2007; 11:135-165.

[103] FAO/IAEA. Mutant variety database. Cereals and legumes. FAO/IAEA, Vienna. 2012. Available from: http://mvgs.iaea.org

[104] Sakin MA, Gokmen S, Yildirim A. Investigation of mutants induced in durum wheat (*Triticum durum* Desf.) for yield and some agronomic and quality traits. Asian Journal of Plant Sciences. 2005; 4:279-283.

[105] Ahmed HG, Khan AS, Khan SH, Kashif M. Genome wide allelic pattern and genetic diversity of spring wheat genotypes through SSR markers. International Journal of Agriculture & Biology. 2017; 19:1559-1565. DOI: 10.17957/IJAB/15.0463

[106] Ashraf M. Inducing drought tolerance in plants: recent advances. Biotechnology advances. 2010; 28:169-183. DOI: 10.1016/j.biotechadv.2009.11.005

[107] Powell W, Morgante M, Andre C, Hanafey M, Vogel J, Tingey S, Rafalski A. The comparison of RFLP, RAPD, AFLP and SSR (microsatellite) markers for germplasm analysis. Molecular Breeding. 1996; 2:225-238. DOI: 10.1007/BF00564200

[108] Russell JR, Fuller JD, Macaulay M, Hatz BG, Jahoor A, Powell W, Waugh R. Direct comparison of levels of genetic variation among barley accessions detected by RFLPs, AFLPs, SSRs and RAPDs. Theoretical and Applied Genetics. 1997; 95:714-722.

[109] Davila JA, Loarce Y, Ferrer E. Molecular characterization and genetic mapping of random amplified microsatellite polymorphism in barley. Theoretical and Applied Genetics. 1999; 98:265-273.

[110] Ibrahim SE, Schubert A, Pillen K, Léon J. QTL analysis of drought tolerance for seedling root morphological traits in an advanced backcross population of spring wheat. International Journal of Agricultural Science. 2012; 2:619-629.

[111] Ahmad MQ, Khan SH, Khan AS, Kazi AM, Basra SMA. Identification of QTLs for drought tolerance traits on wheat chromosome 2A using association mapping. International Journal of Agriculture and Biology. 2014; 16: 862-870.

[112] Kumar U, Joshi AK, Kumari M, Paliwal R, Kumar S, Röder MS. Identification of QTLs for stay green trait in wheat (*Triticum aestivum* L.) in the 'Chirya 3'×'Sonalika'population. Euphytica. 2010; 174:437-445. DOI: 10.1007/s10681-010-0155-6

[113] Sharma RK. Does low yield heterosis limit commercial hybrids in wheat?. African Journal of Agricultural Research. 2013; 8: 6663-6669. DOI: 10.5897/AJAR2013.8108

[114] Gosal SS, Wani SH, Kang MS. Biotechnology and drought tolerance. Journal of Crop Improvement. 2009; 23:19-54. DOI: 10.1080/15427520802418251

[115] Kereša S, Barić M, Horvat M, Habuš Jerčić I. Drought tolerance mechanisms in plants and their genetic base in wheat. Sjemenarstvo. 2008; 25:35-45.

[116] Mahpara S, Hussain ST, Farooq J. Drought tolerance studies in wheat (*Triticum aestivum* L.). Cercetari Agronomice in Moldova. 2015; 47:133-140. DOI: 10.1515/cerce-2015-0011

[117] Wang K, Riaz B, Ye X. Wheat genome editing expedited by efficient transformation techniques: progress and perspectives. The Crop Journal. 2018; 6:22-31. DOI: 10.1016/j.cj.2017.09.009

[118] Mir RR, Zaman-Allah M, Sreenivasulu N, Trethowan R, Varshney RK. Integrated genomics, physiology and breeding approaches for improving drought tolerance in crops. Theoretical and Applied Genetics. 2012; 125:625-645. DOI: 10.1007/s00122-012-1904-9

[119] Kosova K, Vitamvas P, Urban MO, Kholova J, Prášil IT. Breeding for enhanced drought resistance in barley and wheat-drought-associated traits, genetic resources and their potential utilization in breeding programmes. Czech Journal of Genetics and Plant Breeding. 2014; 50:247-261. DOI: 10.17221/118/2014-cjgpb

[120] Choudhary AK, Sultana R, Vales MI, Saxena KB, Kumar RR, Ratnakumar P. Integrated physiological and molecular approaches to improvement of abiotic stress tolerance in two pulse crops of the semi-arid tropics. The Crop Journal. 2018; 6:99-114. DOI: 10.1016/j.cj.2017.11.002