International Journal of Plant & Soil Science
6(1): 1-9, 2015; Article no.IJPSS.2015.091
ISSN: 2320-7035

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Physiological Responses of Wheat (*Triticum aestivum* L.) to Drought Stress

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Authors' contribution

All authors have equally contributed in the current manuscript. The Idea was designated by authors MKNS and MA. Authors MKN and MK collected all the relevant material/literature. Authors MKN and MSI compiled and drafted the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2015/9587
Editor(s):
(1) Mirza Hasanuzzaman, Department of Agronomy, Sher-e-Bangla Agricultural University, Bangladesh.
(2) Samuel Agele, Federal University of Technology, Nigeria.
(3) Peter A. Roussos, Agricultural University of Athens, Greece.
Reviewers:
(1) Anonymous, Iran.
(2) Anonymous, India.
(3) Anonymous, Malaysia.
(4) Anonymous, Iran.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=953&id=24&aid=7885

Review Article

Received 18th February 2014
Accepted 11th November 2014
Published 26th January 2015

ABSTRACT

Drought is serious problem in many parts of the world in circumstances of rapid change in climatic conditions especially for rainfed agriculture. Among prevailing abiotic stresses, it is the most significant and severe factor inhibiting plant growth and production. Water deficiency in plant impairs the numerous physiological and metabolic functions. Selection of wheat genotypes that can tolerate water scarcity would be helpful tools for breeding program aiming to development of drought tolerant variety under water limited regions. Rapid development of new wheat varieties with the help of analytical breeding would be the most attractive approach. In this review paper, after the brief introduction about the present scenario of food insecurity, the impact of drought and about the targeted approaches for drought stress, we briefly review the already work done to deal with this environmental calamity (drought). We discussed in detail the important physiological traits (viz. proline content, relative water content, chlorophyll content, cell membrane stability and canopy temperature) having important role in wheat to estimate the drought tolerance and to improve the

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efficiency of crop breeding. This review paper highlights the role of physiological traits in enhancing the crop yield and their tolerance to water deficiency. The analytical breeding approach followed by the conventional strategies has already been engaged and more need to be employed in future for improving and developing the new wheat varieties, which should be perform better under drought condition. Analytical (physiological) breeding should become an important component of modern wheat breeding research.

Keywords: Drought; Physiological Phenotyping; Analytical Breeding; Wheat.

1. INTRODUCTION

Wheat is an important food crop of world and a source of food and livelihood for over one billion people in developing countries. It is reckoned among the “big three cereal crops” viz. rice, wheat and maize. Approximately 35% of the world population feed on it [1]. Nutrition profile of wheat employs that more than one third of the world’s population used it as staple food [2]. Wheat grain used to make flour, breads, biscuits, cakes, cookies, pasta, noodles and also for beer, other alcoholic beverages or biofuel [3]. Today wheat is grown on more than 200 million hectares of the world's cultivated land and is the most important agricultural commodity in international trade [1]. An enormous increase in food production is necessary to supply sufficient food for a rapid growing world population. World Agriculture, report of Food and Agriculture Organization states that “Further increment in population will create inadequate food consumption levels, pressuring for further increases of food supplies”. To feed the rapidly growing population of the world, food production should be heightened. Efforts have been made for a long time to develop such crop cultivars which could cope against biotic and abiotic stresses and give more production.

Among all the stress factors either biotic or abiotic factors, drought plays a significant role for reduced wheat production and performance upon a great extent. It is recognized that almost 50% of wheat cultivated land in the developing world is under rainfed condition [4]. Drought is a worldwide problem constraining global crop production seriously [5,6] as in world map (Figure 1) demonstrated the drought prone areas. Drought, being the important environmental stress, severely impairs plant growth and development [7,8]. The severe effects of drought are numerous, including: reduce crop yield, decreased availability of fodder and feed. Wheat yields are reduced 57% from their potential because of drought spell on at least 60 million hectare in the developing world [9]. Water stress at all stages of plant growth affects the grain yield but when it takes place in critical stages of growth, grain yield is sharply decreased [10,11,12]. KulKarni [13] reported that crop yield is reduced by 70-80% due to a drought spell during the reproductive stage. Therefore, it has now become important to evaluate the new high yielding wheat varieties, tolerant to the severe climatic conditions peculiar to drought [14].

Considering the importance of drought in wheat yield reduction, a number of breeding strategies and methods have been formulated. To overcome the problem of drought stress and develop the new varieties which can perform well under stress condition. Genetic gains through the use of empirical or conventional breeding approach have been difficult [15]. Now scientists look forward modern or analytical breeding approaches to evaluate the complex phenomena of drought with the help of secondary (physiological) traits. Physiological changes of crop plants to water stress are useful tool to understanding the mechanisms of drought tolerance. Improvement in wheat crop growth and production can be attained by adopting the physiological strategies, evaluate the plant at molecular level [16]. Physico-morphic approaches have a great importance in order to understand the complex responses of plants to water deficiency and to sustain the plant productivity. In this review, importance of physiological and morphological traits and who they response to water deficient conditions are discussed in detail.

2. DROUGHT AND PLANT GROWTH

Drought is the most prevalent environmental condition, severely impairs the plant growth and field crops production more than other environmental stresses [17,18,19,20]. It differs from other abiotic stresses in a way that the effects of drought often accumulate slowly over a considerable period of time. Because of this,

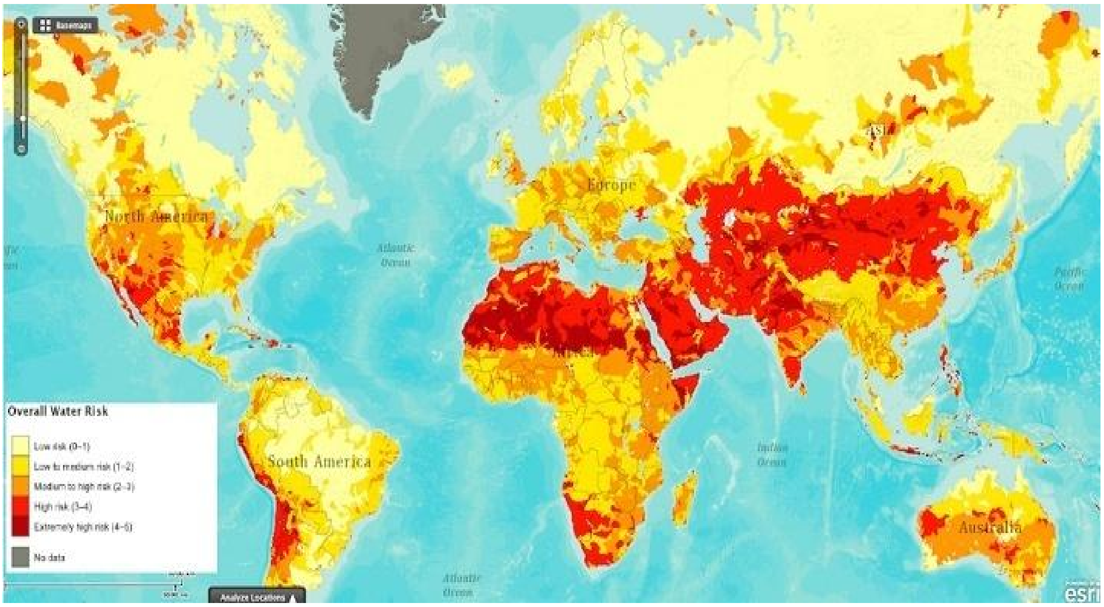

Fig. 1. World map demonstrating the drought prone areas (SPEI 2014)

drought is termed as a "Creeping phenomena". Its impacts are apparent to a lesser extent and are spread over large geographical areas with greater damages that result from other natural stresses. Drought is a worldwide problem, decreases the global crop production seriously and recently global climate change has made this situation more serious [21]. Estimates indicated that 25% of the world's agricultural land is now affected by high levels of water stress [22]. While it affects the 50% of wheat production area worldwide [23]. In arid and semiarid regions, wheat crop usually experience drought during the grain filling period. Drought stress at grain filling period causing grain shriveling ultimately reduces grain yield. In rainfed agriculture, water limitation may prove to be a critical constraint to primary productivity under arid climates [24]. In these areas drought spell is expected at any critical stage of plant growth [10,11,12]. Water shortage at earlier stage of crop i.e. seedling and tillering leads to abnormal germination and poor crop stand [25,26]. Drought stress at anthesis stages caused severe reduction in yield of wheat [27]. Also it badly impact on embryonic development and seed fails to germinate properly.

3. WHEAT RESPONSE TO DROUGHT

The capability of plant to maintain itself in water scarce conditions is important in the world of agriculture. Wheat plant is drought tolerant and need less water to sustain the growth and production. The water requirement of wheat plant varies by the stage of crop development and environmental conditions in which it grows [28]. In case of dryer and hotter environmental conditions, the more water wheat plant requires. Wheat plants adopt various mechanisms including their morphological, physiological, biochemical and molecular responses at cellular level to tackle drought stress. These mechanisms are categorized into following drought response strategies: escape, avoidance and tolerance to sustain under dry environment [29]. In case of escape, wheat plants complete the life cycle during the sufficient water supply before the onset of drought stress e.g. early maturity [30]. Different studies [31,32] concluded that in wheat early maturity avoid the late season water scarce period to attain higher yield. The drought avoidance mechanism is associated with the ability of a plant to enhanced water uptake and reduced water loss [33,34] involves the strategies of wheat plants to maximization of water uptake by long and thick root network [35] and reducing the water loss by leaf and stomatal characteristics like decrease in the transpiration of the leaf area, leaf rolling, leaf shedding, lower canopy temperature and maintaining relative leaf water content [36,37,38]. Dehydration tolerance enables the wheat plants to survive periods of water deficit and re-grow when rain falls. Dehydration tolerance may also allow wheat plant, to maintain metabolic activity for longer time, to withstand under drought stress with low tissue water potential and tackle the injurious effects of drought by initiating various defense mechanisms i.e. osmotic adjustment, enhanced anti-oxidative capacity and physical desiccation tolerance by maintaining membrane integrity [39,40,8,41].

4. PHYSIOLOGICAL RESPONSES

The study of physiological responses of wheat varieties to water stress is a useful tool to understanding the mechanisms of drought resistance. Drought induces significant alterations in wheat physiology. Some wheat genotypes have a set of physiological adaptations that allow them to tolerate water stress conditions. Researchers linked various physiological responses of wheat plant to drought with their tolerance mechanisms, such as: high chlorophyll content, high relative water content, cell membrane stability, high proline content and lower canopy temperature. Almeselmani [42] reported significant reduction in physiological, yield and yield contributing traits were recorded in the drought susceptible wheat varieties compared to other varieties. Positive and significant association between the physiological and yield traits was observed. It is obvious from the results that all these parameters explained the drought tolerance mechanisms. These drought tolerance mechanisms help in understanding the physiological responses that enable plants to maintain growth and productivity during stress period. Ultimately, indicated the importance of these traits in breeding programs for screening and selection of tolerant genotypes. Zaharieva [43] reported that physiological traits are helped in the selection of best performing drought resistant wheat genotypes in arid areas.

5. PROLINE CONTENT

Water scarcity mostly affects accumulation of some organic compatible solutes in wheat plants which adjust the intercellular osmotic potential [44]. Accumulation of organic compatible solutes causes increase in solute potential that prevent the loss of water. It is the early reaction of wheat plants to water stress. Wheat plants accumulate the proline in greater extent than the other osmoregulators in water scarce condition [45]. Proline is also common and important osmoregulator that is produced in response to stresses. It is an amino acid known for its sensitivity to drought. It also protects cells against damage induced by ultraviolet radiation. In plants accumulation of cellular proline due to increased synthesis under a variety of stress conditions such as salt and drought had been documented in many plant species. Wheat response to water stress by accumulating proline is a useful tool to understand the mechanisms of drought tolerance. Rate of proline accumulation observed high in drought conditions [45]. A positive correlation exists between the degree of proline accumulation and drought tolerance. Wheat genotypes having more accumulation of proline under drought have ability to bear drought. This phenomenon varies among the wheat genotypes because different genotypes have variable water stress threshold. Hence, proline accumulation is a useful trait for selecting drought tolerant wheat genotypes [46].

6. RELATIVE WATER CONTENT

Relative water content is an important character which related to drought stress. Water deficiency was found to reduce the relative leaf water content. The high relative water content and low excised leaf water loss had been suggested as important indicators of water status [47]. Lugojan and Ciulca [48] proposed that relative water content is more important indicator of water status than water potential in wheat under drought conditions. Naroui Rad [49] reported that relative water content is exhibited the continuous variation in wheat under drought stress because it is controlled by multiple genes with additive effect. Relative water content had positively correlated with total grain yield per plant, biological yield per plant and harvest index in wheat [50]. Hence, relative water content is a useful character for selecting drought tolerant wheat genotypes [46,51,52].

7. CHLOROPHYLL CONTENT

Severe drought stress inhibits the photosynthesis of plants by changes in chlorophyll content, affecting chlorophyll components and damaging the photosynthetic apparatus. Total chlorophyll content is found to reduce under water stress conditions. A decrease in chlorophyll content is faster in drought sensitive than in drought tolerant genotypes [53]. The chlorophyll content in flag leaves reflect photosynthetic activity and yield potential of wheat plants. High chlorophyll content in different plant leaves was considered as a favorable trait in crop production under drought stress [54,55]. Some studies show that leaf chlorophyll content is positively correlated with photosynthetic capacity. It is reasonable to assume that high chlorophyll capacity of wheat plants under drought conditions could be identified by selecting breeding materials with high chlorophyll capacity [46,49]. Chlorophyll content was an indicator of drought tolerance and it could be used as screening tool for drought tolerance in wheat. Resistant genotypes of wheat had higher chlorophyll content than sensitive genotypes under the drought [46]. The wheat genotypes with high chlorophyll content can produce high yield under moisture-stressed conditions and there was a significant positive correlation between chlorophyll content and yield [56].

8. CELL MEMBRANE STABILITY

Cell membrane stability (CMS) is one of the key indicators of drought tolerance and the rate of injury to cell membrane by drought can be estimated through measurement of electrolyte leakage from the cells. Cell membrane stability asses either by natural drought stress or artificially induce by polyethylene glycol (PEG-6000) of dehydrated leaf tissues. The degree of cell membrane stability had been used to evaluate drought tolerance of some plant species [57]. Drought tolerant wheat genotypes had higher cell membrane stability as compared to intermediate and susceptible genotypes. The wheat genotypes with higher cell membrane stability (71-80%) have been observed to tolerate better under drought condition [58]. Significant positive correlation was found between cell membrane stability with grain yield in the stress condition [59]. Hence cell membrane stability measurements were important criteria for selecting drought tolerant wheat genotypes [60].

9. CANOPY TEMPERATURE

Canopy temperature is as a useful trait which is used for screening drought tolerant wheat genotypes, as it reveals the different physiological responses [61]. Relatively lower canopy temperature in drought stressed crop plants indicates a relatively better capacity for taking up soil moisture and for maintaining a relatively better plant water status by various plant adaptive traits [62]. Low canopy temperature under drought is associated with drought tolerance in wheat. Canopy temperature measurements had been widely used to study genotypic response to drought [61]. Blum [63] evaluated the wheat genotypes for stable performance under various environmental conditions on the basis of canopy temperatures. Significant correlations were evaluated between canopy temperature and yield under moisture-stress conditions and drought susceptibility index. Relatively lower canopy temperature is positively correlated with final yield under stress. Wheat genotypes with a low canopy temperature could produce high yield under moisture-stressed conditions [56]. These findings revealed the potential of this trait for screening the wheat genotypes for drought response.

10. MORPHOLOGICAL TRAITS

Improving crop yield under drought condition is the most important challenge for the plant breeders [64]. The development of cultivars for water limited environments would involve selection and incorporation of both physiological and morphological mechanisms of drought resistance through traditional breeding programmes. Considerable progress for rapid screening methods in both directions has been already made [65]. Andarab [66] investigated the affecting traits on yield and yield components of five wheat varieties under water stress and irrigated conditions. The results indicated that wheat genotypes could be selected under irrigated and stress conditions on the basis of traits which have high correlation with grain yield. Correlations among morphological traits such as plant height, grains per spike, grain yield per plant, flag leaf area and spike fertility were generally reliable indicators for screening drought tolerant wheat cultivars and potentially with higher yields [67]. Various morphological traits are frequently used for screening drought tolerant genotypes under drought. Gupta [68] reported positive correlations among plant height, leaf area and gain yield in wheat cultivars. Nouri-Ganbalani [69] suggested the presence of positive significant correlations between grain yield, 1000 grain weight and tillers per plant. Tolerant genotypes have the larger leaf area and produced more total dry matter maturity. Under drought condition, flag leaf area had positive direct effects on grain yield [70]. Ivanova and Tsenov [71] reported the relation of grain yield with the number of productive tillers, plant height, 1000 grain weight and number of grains per spike was higher under stress.

11. CONCLUSION

Our knowledge of drought avoidance mechanism has been heightened by research programmes emphasizing specific physiological aspects of drought tolerance and its impact on yield.

Selection solely on the basis of empirical approach has not led to an increase in tolerance. Although the hypothesis of combine the empirical and physiological approaches have been already proposed. But few research programmes have implemented this integrative approach in their breeding programmes. The great strength of physiological analysis in wheat has been ability to screen large population and well developed field phenotyping capabilities. Latest developments in physiological approaches have created the opportunity to tackle the specific components of drought tolerance. Morphological phenotyping has now become the costly and time consuming steps in the evaluation of drought tolerance. The development of rapid and cheap physiological procedures to evaluate the drought response will be important.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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