International Journal of Advanced Multidisciplinary Research (IJAMR)
ISSN: 2393-8870
www.ijarm.com

Review Article

Exploring the drought tolerance potential in different wheat varieties: A review

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Keywords

Wheat,
varieties,
drought stress,
phonological and
physiological characters.

Abstract

Wheat is an important staple food of the inhabitants of Pakistan. Its production is largely hampered due to drought prevalence. The adverse effects of drought on growth and development of crop plants are of multifarious nature. However, it varies to different degrees in different varieties differently. Drought can affect growth rate and phonology of wheat depending on its time, duration and intensity. They may be in the form of inhibited cell expansion and reduced biomass production. Drought can cause different metabolic changes in plants, reduce or even inhibit activities of enzymes, ionic imbalance and disturbances in solute accumulation or a combination of all these mechanisms. Nutrient uptake is reduced due to non availability of moisture particularly nitrogen. The drought caused marked reduction in photosynthesis, water potential, leaf water contents, osmotic potential, leaf area and chlorophyll contents in different wheat varieties in varying degree. The water stress during vegetative and reproductive development is equally injurious to wheat for final crop yield. Drought during tillering stage reduces number of tillers per seed. It means less number of plants per unit area. Drought during jointing stage accelerates tiller death (senescence) and reduces spikelets per spike which causes reduction in number of grain per spike. As the grain yield is the product of grain weight and grain numbers per unit area and there was reduction in number of grains per spike which finally reduce the final yield. Drought employed at anthesis stage in wheat crop reduces pollination and thus less number of grains per spike is formed which results in the reduction of grain yield. It is therefore suggested that there should be exploration of the potential of varieties for drought tolerance keeping in view their phonological and physiological characters.

Introduction

Food security in the world is challenged by increasing food demand and threatened by declining water availability. The main stay of Pakistan's economy is based on agriculture. Wheat being the staple food for the people of Pakistan is very important and its yield in rain fed area is approximately one half as compared to irrigated area (Govt. of Pakistan, 2010). It is mainly consumed in the form of flat breads (*chapatti, naan, roti*) which is served as a staple diet to the inhabitants of this region (Zwart and Bastiaanssen, 2004).

Pakistan is predominantly an agricultural country. In spite of favorable conditions of soils, irrigation water and climate, agriculture in the country suffers from under - production both in terms of yield per hectare and production per farm worker. The country is heavily dependent on agriculture for food and fiber requirements of the ever increasing population. In order to cope with these requirements, it is essential to increase food and fiber production not only to attain self sufficiency but also to the extent of exportable surplus for earning foreign exchange (Rauf *et al.*, 2006).

Drought (Water stress or water deficit) is an inevitable and recurring feature of world's agriculture. It has been estimated that about one third of the world's potentially arable land suffers from water shortage and on most of reminder, crop yields are often reduced by drought. Drought is an important issue of the day in Pakistan, as silting of dams has curtailed their storage capacity to alarmingly low levels. Thus production of wheat like other field crops is being hampered in irrigated areas of Pakistan. In rain-fed areas too, storage of moisture is one of the major factors limiting wheat production (Khan, 2003).

Wheat is one of the most important food grain crop grown in the world and is staple food of about one third of the world's population. Mainly grown under irrigated conditions, wheat water requirements ranged from 20-24 inch per acre. It ranks first in the world cereal crops. It is also a principal source of carbohydrates both for human beings and animals. Wheat grain contains about 15.4% protein, 1.9% fat, 68% carbohydrates and 12.2% dietary fiber (Anjum *et al.,* 2005). Its straw constitutes an essential part of livestock feed as well as it is used for paper making. Wheat grain is consumed in several ways in a number of industrial and commercial products such as baking ingredients, pizza, biscuits, burger, cookies, noodles, crackers and commercial bread. Due to its immense and multipurpose use in daily life, the prosperity and well being of Pakistan depends upon good harvest of wheat crop.

Wheat *(Triticum aestivum* L.*)* belongs to family poaceae and ranks first in the world among cereal crops. It not only meets the major dietary requirements of human being but also used as feed for animals. It contributed 14.4 % to agriculture and 3.1 to GDP of Pakistan. In Pakistan total area under wheat cultivation was 9042 thousand hectares with production of 25.00 million tones during 2009-10 (Govt. of Pakistan, 2010).

Average yield (2639 kg ha^{-1}) of existing approved cultivar of wheat is much lower than the potential yield 7200 kg ha^{-1} (Govt. of Pakistan, 2010). The production of this yield level of wheat can be increased by bringing more area under cultivation or by increasing its per hectare yield. Currently, it is impossible to increase area due to other competing crops, limited supply of irrigation water and reduction in cropped area due to expanding cities and industries.

The present situation of wheat production in Pakistan is much better than the past, yet there is need to improve its productivity. Since the introduction of short statures and well fertilizer responsive wheat cultivars and recent advances in production technology of wheat, we can reach to the threshhold levels of self sufficiency. Unfortunately, inspite of initial momentum, wheat production has almost stagnated and not kept pace with rapidly increasing population. At present, total production of wheat is increasing gradually, but the rate of increase in grain yield per acre is less than that of desired level.

Water deficit affects every aspect of plant growth and modifies the anatomy, morphology, physiology, biochemistry and finally the productivity of a crop. Soil moisture at the earlier stages of growth is essential to establish the optimum plant population which triggers substantial increase in crop yield. Moisture stress during spike emergence and anthesis has been reported to reduce grain yield up to 20% mainly through reduction of individual grain weight. Drought may cause reduction in translocation of the nutrients and thus affect the uptake and mobility of mineral element in plant that ultimately reduce the plant growth and development (Thompson and Chase, 1992).

Moisture stress during spike emergence and anthesis reduced yield from 7.0 to 3.3 tons ha^{-1} through reduction in spike m^{-2} (37%), individual grain weight (15%) and number of grain per spike (13%). Stress during grain filling had reduced yield by 20% mainly due to 16% reduction in individual grain weight (Singh and Diwivedi, 2002).

Water stress experienced by a wheat crop during growth is known to have cumulative effects expressed as a reduction in total biomass as compared to well watered conditions. Decreased growth rate is caused primarily by reduction in radiation use efficiency when drought occurred at various growth stages such as tillering, booting, earing, anthesis and grain development (Jamal *et al.,* 1996).

The availability of less irrigation water, poor quality seed, improper time of sowing, low and imbalance use of fertilizers, presence of weeds are the major causes of low yield in Pakistan. Therefore the yield of wheat can be increased by better crop management. Among various factors responsible for low yield, drought is perhaps the main factor limiting crop production world wide (Sajjad, 2001*).* Due to unavailability of good quality irrigation water and harsh environment, it is necessary to develop drought tolerant varieties that have the ability to withstand water stress environment. Under water deficient conditions, management practices can help to reduce yield loss, but greater progress can also be attained through genetic improvement in field crops (Sun *et al.,* 2006).

Better performance of the crop depends upon availability of water. Plant which faced drought showed certain morphological and biochemical changes which ultimately caused either functional damage to plant organs or loss of plant parts. Severe water deficit during the vegetative stages results in reduced leaf area and this in turn affects tillering and spike size (Jones and Corlett, 1992*).* Water stress at anthesis stage reduces pollination and number of grains per spike which results in reduction of grain yield *(*Zhang *et al.,* 1998).

It is an imperative to develop drought tolerant wheat genotypes to ensure sustainable and productive wheat production under adverse environmental conditions. Major challenge to modern crop husbandry is to maintain field crops yield under adverse environmental conditions (Sinclair *et al.,* 2004).

1.1 Water stress effects on crop plants

Water deficit is the most important stress among the abotic stresses which is often encountered by the plants. It causes severe loss to crop productivity in dry land as well as in irrigated agriculture. Its effects are rigorous in semi-arid environments where drought is capricious and cause instability in crop production. There are many strategies to encounter the adverse effects of drought on plants including management practices, improved irrigation system and drought tolerant of crop varieties etc. Much research has been focused on increasing yield performance under suboptimal moisture conditions through selection and development of drought tolerant field crop genotypes. Potential drought resistance in cereal crops has been observed (Cabez and Kumar, 1999).

Research into the plant response to water stress is increasingly becoming important. The most climate change scenarios suggest an increase in aridity in many areas of the world. On a global basis, drought (assumed to be soil and/or atmospheric water deficits) with high temperature and radiation pose the most important environmental constraints to plant survival and crop productivity. Crop plants are frequently subjected to water stress during the course of their life cycle. However certain stages, such as germination, seedling growth, crown root initiation and flowering are the most critical for wheat for water stress damages (Hagyo *et al.,* 2007).

Drought is a very important limiting factor affects all stages of plant growth and development including germination. Drought reduces growth and agriculture productivity more than any other factor (Greenway and Munns, 1980). Water deficit is a global issue to ensure survival of agricultural crops and sustainable food production. Agriculture is a major user of water resources in many regions of the world. With increasing aridity and a growing population, water in the near future will become a scarce commodity in the third world countries like Pakistan. Even though in viable agriculture severe water deficits are rare events (Ahmad,2002). A better understanding of the effects of drought on plants is vital for improved management practices in agriculture and for predicting the fate of natural vegetation under climatic change. That is why this problem has been studied by numerous researchers and in a large number of crops such as tomato, rice and various grass mixtures (Kisana, 2003).

The adverse effects of drought on growth and development of crop plants are of multifarious nature. They may be in the form of inhibited cell expansion and reduced biomass production. Drought can cause different metabolic changes in plants, reduce or even inhibit activities of enzymes, ionic imbalance and disturbances in solute accumulation or a combination of all these mechanisms (Mudassar, 2005).

Water is very essential at every stage of plant growth from seed germination to plant maturation. Water stress reduces crop yield regardless of the growth stage at which it occurs, so any degree of water imbalance may produce deleterious effects on crop growth and development. In general, shoot growth is more sensitive to water deficit than that of root growth. The reduction in above ground growth can be considered as an advantage because it limits transpiration and conserves soil water. Direct inhibition of shoot growth by water deficit also contributes to soluble accumulation and eventually to osmotic adjustment (Passioura, 2007).

The impact of water stress at early stages of germination and immediately following radical emergence has been well documented. Germination rate is reduced considerably under water stress of -0.4 MPa and the emergence of shoot is faster on account of better availability of soil moisture (Sairam *et al.,* 1990). The reduction in germination percentage both in tolerant as well as sensitive genotypes of wheat has also been reported by Singh *et al.* (1986) even at water potential of -0.1 MPa in drought sensitive genotypes of wheat.

Water is very essential for plant growth and makes up 75 to 95 percent of plant biomass. Plants use water and carbon dioxide to form sugars and complex carbohydrates. Water acts as a carrier of nutrients and also a cooling agent (Ashraf and Harris, 2005). Water stress limited crop production depends on the intensity and the pattern of drought which vary from year to year. In sub tropical country like Pakistan however, there is high probability that crop water deficits increase in severity as the season progresses, due to lack of rainfall and to high evaporative demand (Shahryari *et al .,* 2008).

Among the morphological traits required to resist early drought, a deep and dense rooting system is probably the most important one, because roots absorb soil water for the crop and also partly control development of leaf area by hormonal signals in presence of water stress. Roots play a primordial role in sensing soil water deficit. Sustained root growth under moderate level of water stress results from rapid adjustment that allows partial turgor recovery and maintenance of the ability to loosen cell walls. Field observation has generally shown that more extensive root systems under drought is associated with improved performance of wheat genotypes (Ford and Thorne, 2001).

During drought, water loss is minimized by decreasing canopy leaf area through reduced leaf growth and shedding of older leaves. Leaf growth inhibition is among the earliest responses to drought. It has also been observed that small leaves are well adapted to high light and high temperature that prevail in most arid regions as their size permits greater sensible heat dissipation and an efficacious control of water loss by stornatal closure (Nagarajan *et al.,* 1999*).* Water shortage reduces the growth of plants by decreasing photosynthetically active leaf area. In wheat, drought reduced dry weight as compared to normal irrigations (five or six) applied at different growth stages (Chaves *et al.,* 2002).

Drought can affect growth rate and phonology of wheat depending on its time, duration and intensity. A study of five durum wheat genotypes grown in contrasting soil moisture regimes concluded that moisture stress resulted in lower rates of dry matter accumulation, irrespective of the time the stress occurred (Rafiq *et al.,* 2005).

Song *et al.* (1995) in pot experiment determined the effect of drought on leaf water status in cultivars of maize. Drought tolerant cultivars had a higher relative water contents, water potential and osmotic potential and lower rates of transpiration. Drought tolerance cultivar also showed smaller effects of drought on protoplasmic structure than did drought sensitive cultivars.

Rashid *et al.* (2003) performed a pot experiment in which four wheat genotypes i.e. Inqlab-91, Chakwal-97, Rawal-87 and Kohsar-95 were tested against four irrigation levels imposed at different growth stages including control, terminal drought, pre-anthesis drought and post-anthesis drought. Wheat plants subjected to terminal and pre-anthesis drought were severely damaged and died before the final harvest. Flag leaf area and peduncle length of wheat exhibited a significant reduction of 14% and 36% respectively, under drought. The reduction in yield was 40% at pre-anthesis to 98% in the post-anthesis stage depending upon the extent and degree of stress. Wheat plants could withstand and tolerate drought only before anthesis stage but thereafter water stress results in a complete death and failure of crop. It could be deduced that critical period for moisture in wheat started 60 days after sowing, which becomes more severe at 90 days i.e. anthesis stage. Among genotypes Inqlab-91 was found more tolerant to drought.

Rauf *et al.* (2006) evaluated sixteen wheat genotypes for their drought tolerance ability at germination and seedling stages. They used PEG-6000 to create water stress. The date on germination percentages, germination rates index, shoot length, root length, fresh weight of shoot, dry weight of shoot, fresh weight of root, dry weight of root, shoot/root ratio showed that the genotypes differed significantly in response to the moisture stress. There were highly significant differences for all these parameters. Cultivar PK-18199 showing the maximum germination percentage, germination rate index, shoots length root length, coleoptiles length, fresh shoot weight, dry shoot weight, fresh root weight, dry root weight and shoot/ root ratio under all four moisture stress levels was considered as drought resistant.

The development of root system increases the water uptake and maintains requisite osmotic pressure through higher praline levels in *Phoenix dactylifera* (Djibril *et al.*, 2005). The root dry weight was decreased under mild and severe water stress in *popuhus species*. An increase in root to shoot ratio under drought conditions was related to ABA content of roots and shoots. An increased root growth due to water stress was reported in sunflower and *Catharanthus roseus* (Jaleel *et al.*, 2008 b).

Availability of soil moisture influences many aspects of crop growth and yield (Akram *et al.*, 2004). High yields of cereals and other crops were associated with larger values of leaf area duration under better irrigation management. Better performance of the crop depends upon availability of water, especially at various growth stages. According to Jamieson *et al.* (2000), non- availability of water at tillering stage caused reductions in the amount of intercepted photosynthetically active radiation and radiation use efficiency. In wheat, adequate water at or after anthesis not only allowed the plant to increase photosynthetic rate but also give extra time to translocate the carbohydrates in grains, which enhanced grain size and ultimately causes higher grain yield (Mirbahar *et al., 2009).*

1.2 Water Stress and Nutrient Uptake

Remobilization of Nitrogen N from vegetative organs in to grain differs in different cultivars. Much N must be accumulated in vegetative organs and allocated to more active photosynthetic organs until anthesis and more N must be absorbed from soil during earlier grain filling phases and then translocated to grains during the final grain filling phase (Takahashi *et al.*, 1996). Shah *et al.* (1996) studied the effect of NP supply on grain yield differences in three wheat varieties. They observed increase in grain yield with increased NP supply in all three wheat cultivars LU-26S, Pasban-90 and Inqulab-91.

N uptake during grain filling did not show any correlation to N applied in barley but it was markedly correlated in wheat. Thus, wheat required high N fertilization to optimize yield (Delogu *et al.*, 1998). N accumulated in culms and leaves was maximum from tillering to anthesis stage and the rate of N translocation decreased readily from anthesis till maturity in different types of high yielding winter wheat. Absorption rates of three nutrients (N, P and K) took the form of multipeak curves during the growth period in winter wheat. The maximum rate of N and P absorption was from tillering stage to booting stage, while that of K was from tillering stage to flowering stage (Guang *et al.*, 1998).

N was absorbed after anthesis in two wheat cultivars with contrasting maturity appearance and by the application of N, the demand for N from leaves for grain protein accumulation reduced. During the first two weeks of grain filling the N content of leaves was decreased slowly due to its transport to grains. The N accumulation in grains remained slow. Yield potential was limited due to low N content in leaves at anthesis, less N uptake and quick export of leaf N during grain filling (Guohua *et al.*, 1999).

When N supply and water availability were variable, there exists a common relationship between Kernel per plant (KNP) and plant growth rate (PGR). The relationship between KNP and PGR obtained for treatments in which PGR was varied through plant density and shading also could predict KNP for condition in which PGR was affected by water stress (Andrade *et al.*, 2002). High temperature aggravated the effect of drought and significantly reduced kernel dry weight and duration of grain filling (Yang *et al.*, 2001).

Nutrient input under scarce precipitation and drought occurrence has different results, depending on the degree of water deficit and timing of fertilization. It has been found that with the increase of available P in soil, plant took up more P in a wide range of soil water contents. However, fertilization causes over consumption of water by producing abundant vegetative growth at early stages, and can lead to a significant reduction in seed yield (Wang *et al.*, 2004). Song and Li (2006) conducted a field experiment on maize to determine the effect of water movement and root took uptake of nutrients on

NO_3^-N and NH_4-N transfer with four treatments with limiting irrigation, NO_3-N concentration at all point measured were small with difference of 6.5 mg kg $^{-1}$ between the highest and lowest. This indicated that NO_3-N could be transferred as solute to plant root systems with water movement. Without irrigation, NO_3-N concentration sharply decreased from one point to another and the difference between the highest and the lowest was 26 mg N kg $^{-1}$.

Li (2007) showed N allocation in wheat grain through mass flow by irrigation in a lysimeter experiment and revealed that wheat seeds obtained much higher N by the contribution of mass flow with irrigation compared to that without irrigation. This indicates that water could significantly transfer N from other organs to seeds. Drought significantly decreased the growth and mineral nutrition of wheat (*Triticun aestivum* L.), chickpea (*Cicer arietinum L.*) and lentil (*Lens culinaris M.*) (Gunes *et al.,* 2007).

1.3 Drought and Plant Water Relations

A reduction in plant water relation parameters (like water potential, osmotic potential, turgor pressure and relative water contents) under water stress conditions have been well reported in literature. Shimshi *et al.* (1982) reported that in wheat plants subjected to varying degree of water stress by withholding irrigation, from 2 to 12 days before the date of sampling and determination resulted in reduction in leaf water potential from -1.2 MPa to -2.4 MPa and lost more than half of its tissue water and retained lower relative water contents. Drought tolerant cultivars had higher relative water contents, water potential and osmotic potential and lower rates of transpiration, and showed smaller effects of Drought on protoplasmic structure than drought susceptible cultivars. Plants try to maintain turgor potential and relative water contents RWC throughout the whole growth period but this ability is higher at the grain filling stage than the earlier growth stages and they play an important role in photosynthetic maintenance under low soil water potential (Xu *et al.,* 1996).

Hafid *et al.* (1998) evaluated the response of six spring durum wheat cultivars to early season drought under four water regimes: well watered and three different water deficits ranging from emergence until the onset of tillering or at the end of tillering. Relative water content (RWC) remained high and stable for both water-stressed and unstressed plants, ranging between 94% and 97% until the fifth day of progressive water deficit. During this period soil water content (SWC) of water stressed treatment pots dropped from 100% to 70% of its maximum retention capacity between 5th and 9th day of experiment, RWC dropped from 96% to 78% for water stressed plants, while SWC dropped from 70% to 40% .

Drought causes reduction in relative water content (RWC) of wheat. Under moderate Drought, RWC was 82.4% and under hard Drought RWC was 75.1% and Drought causes acceleration in flowering and ripening processes (Molnar *et al.*, 2002). Plants water status changes with the change of soil water availability resulting in lowering of leaf water potential and in cereals specially the water potential of flag leaf. There are reports in literature of significant decrease in water potential of flag leaf in wheat and barley under water deficit conditions. Severe water stress imposed during either early or mid grain filling, and maintained until maturity decreased photosynthesis as judged by leaf water potential, leaf senescence and total plant dry weight in maize (*Zea mays L.*) leaves (Farooq *et al.,* 2009). There are reports of relationship between the leaf water potential and biomass production in wheat.

Ashraf and Khan, (1993) reported that the drought imposed at vegetative stage of ten wheat varieties showed that Sarsabz, Pak-81, S-232, V-8001 and Pak-15794 produced lower biomass of shoots with the exception of varieties Lu-265, Sarsabz and Pak-81, which had lower leaf water potential than others. On the other hand, high biomass yielding varieties, M-54, Pak-15800 and Barani-83 showed high water potential.

The drought caused marked reduction in photosynthesis, water potential, osmotic potential, leaf area and chlorophyll contents in two brassica cultivars (Sharma *et al.,* 1993). The increased frequency of irrigation generally resulted in higher water contents, leaf water potential, leaf osmotic potential, leaf turgor potential, leaf diffusive conductance, leaf area index, evapotranspiratioon, photosynthesis and yield in sorghum, maize and pearl millet. Leaf turgor potential in N starved cotton plants was lower than N supplied cotton plants exposed to water and N deficits during the pre flowering stage. The decline of leaf water potential relative to soil water content was greater in N under water deficit (Sandhi, 2007).

Relative water content (RWC) of wheat remained high and stable for both water-stressed and unstressed plants, ranging between 94% and 97% until the fifth day until the progressive water deficit. During this period soil water contents (SWC) of water stressed treatment pots dropped from 100% to 70% of its maximum retention capacity between 5th and 9th day of experiment, RWC dropped from 96% to 78% for water stressed plants, while SWC dropped from 70% to 40%. During the same period, RWC of unstressed plants diminished 97% to 93%. The day after re-irrigation both water-stressed and unstressed plants had RWC equal to 97% (Depererira *et al.,* 1999).

Bayoumi *et al*. (2008) reported high relative water content and accumulation of proline in wheat were good characteristics for drought tolerant varieties. They evaluated nine wheat genotypes: seven local varieties with newly introduced genotypes from International Center for Agriculture Research in Dry Areas (ICARDA) for drought tolerance ability in a field experiment. The superior genotypes which gave higher relative water content (RWC) accumulated more free proline and had lower drought susceptibility index values, whereas genotypes having the lowest RWC, proline accumulation and had the highest susceptibility index values which indicated that accumulated. Proline acts as a compatible solute regulating and reducing water loss from the cell during water deficit.

The rate of photosynthesis was reduced to 38% when rape seed plants were subjected to water stress. The drought resistance character of rape seed plant pod was due to low specific area and succulence. Low stomatal conductance resulted in only a slight decrease in water potential during soil drying and maintenance of high relative water contents during severe drought (Mogensen *et al.,* 1997). Leaf water potential was lower in *Brassica juncea* than in *Brassica napus* due to decline in leaf osmatic potential. *Brassica napus* was found to produce less dry matter and yield than *Brassica juncea* in water deficit conditions (Wright *et al.*, 1997).

Drought causes a significant reduction in leaf osmotic potential of sorghum lines. There exist a positive relationship between drought resistance and osmatic adjustment and a negative relationship between drought resistance and water retention capability in all four lines of sorghum (Ashraf and Ahmad, 1998).

The correlation between percentage yield depression and osmatic adjustment between irrigated and non-irrigated treatment in *Brassica napus* and *Brassica juncea* showed that the group with no osmotic adjustment had 15 to 40% yield depression. On the other hand, the group with significant osmotic adjustment had only 0 to 12% yield reduction (Niknam and Turner, 2001). Exposure of plants to drought led to decrease in leaf water potential and relative water content with a concurrent increase in leaf temperature in four wheat cultivars; Kanchan, Sonalika, Kalyasona and C-306 subjected to four levels of water stress at vegetative or anthesis stage or both. Drought plants displayed high canopy temperature than well-watered plants at both vegetative and anthesis stages.

Drought caused a significant decrease in leaf water potential, relative water contents and osmotic potential of three Egyptian corn (*Zea mays L*.) genotypes; viz; GIZA2, TWC310 and TWC320. These genotypes were subjected to four levels of water stress at vegetative stage and tassel emergence stage. Under drought plants maintained 0.47 MPa osmotic potential which was lower than controls treatment. This decrease in water potential and RWC was associated with lower stomatal conductance and photosynthetic rate. The results of current study indicated that tassel emergence stage was more sensitive to drought than vegetative stage which according reduced grain yield (Atteya, 2003). Water deficit condition reduced 35% leaf area index (LAI) and 8% solar radiation interception in eight genotype of cotton, which had okra type normal leaf. Dry land plant leaves of cotton had 6% greater CO_2 exchange rates (CER) and 9% higher light adopted photosystem 11 (PH11) quantum efficiency than irrigated leaves of cotton. In the morning however, water potential of dry land plants of cotton decreased during afternoon (Pettigrew, 2004).

1.4 Drought and Plant Growth

The duration and timing of drought is an important factor in determining the effect of water stress on plant growth and development. Al-Khafaf *et al.* (1988) in wheat applied water stress for 15 days after germination stage, 50 days after booting stage and 70 days after anthesis stage. They observed the maximum reduction in grain yield in plants stressed for 70 days after anthesis stage indicating decreasing trend of dry matter accumulation with an increase in the duration of drought. Islam (1992) reported that intermittent drought was more harmful than continuous water stress and stress at heading (45-60 DAS) days after sowing affected dry matter production more than stress at (15-30 DAS). Irrigation enhances the total dry matter production (TDM) and mean crop growth rate (CGR) over the non irrigated crops. The fully irrigated treatment show more LAI which leads to more yield of the crop.

Musik *et al*. (1980) studied the effect of planting date and water deficit on development and yield of irrigated winter wheat. They found that plant water stress limits leaf area and tiller development during vegetative growth. Drought during jointing stage accelerates tiller death (senescence) and reduces spikelets per spike which causes reduction in number of grain per spike. As the grain yield is the product of grain weight and grain numbers per unit area and there was reduction in number of grains per spike which finally reduce the final yield.

Drought employed at anthesis stage in wheat crop reduces pollination and thus less number of grains per spike are formed which results in the reduction of grain yield (Nazir *et al.*, 1987). Adequate water at or after anthesis period not only allows the plant to increase photosynthetic rate but also give an extra time to translocate the carbohydrates in grains which enhanced grain size and thereby lead to increase grain yield (Zhang *et al.*, 1998).

Mosaad *et al.* (1995) studied the response of four cultivars each of *Triticum aestivum* L. and *Triticum durum*, and conducted that by increasing moisture stress leaf area decreased. *Triticum durum* cultivars flowered later, and had an average one leaf more than *Triticum aestivum* L. with similar leaf appearance rates.

During grain filling stage, when there is association among the agronomic aspects and assimilates, a positive relationship also exists between the harvest index and dry matter mobilization efficiency. Under moderate water deficit conditions, pre-anthesis assimilates move to the grains during grain filling. It results to increase the grain yield and WUE in varieties of winter wheat and is also related to longer duration of maturity and a high dry matter mobilization efficiency which finally improves the harvest index (Zhang *et al.*, 2008).

Application of normal irrigation irrigation enhanced the grain yield by improving the growth of the crop thus enabling it to intercept more radiation over non irrigated crops (Sharif, 1999). The water stress imposed on plants led to a considerable loss in photosynthetic rate, stomatal and mesophyll conductance and increased the intercellular CO_2 concentration of four wheat cultivars (Siddique *et al.,* 2000). Leaf area index (LAI) mainly contributed in proper growth and plant development. According to a field experiment drought at vegetative stage of four wheat cultivars and resulted in less leaf area index while drought at reproductive stage decreased number of fertile tillers per matter square, number of grains per spike and 1000-grain weight which ultimately reduce the final grain yield of crop. The water stress during vegetative and reproductive development is equally injurious to wheat for final crop yield (Qadir *et al.,* 1999).

The highest yields were found in the non stressed treatment and the lowest in the non irrigated treatment when wheat was given different irrigation treatment to produce different degree of stress (Sezen and Yazar, 1996). Two levels of water stress imposed until maturity in soybean showed that the moisture stress reduced yield by reducing seed size (8-20) and seed number (18) and seed size (14-32%) (De-Souza *et al*., 1997). Irrigation during seed filling (IDSF) and irrigation during the period from the start of flowering to the start of seed filling compared with a non irrigated (IR) and a season long, irrigated as needed (WI) treatment showed that the water stress during the flowering period did not reduce seed quality more than WI, and reduce seed yield slightly. Water stress during seed filling decrease seed yield but the effect on seed quality was not significantly.

The number of kernels per spike and 1000- kernels weight were more sensitive to Drought in 30 wheat cultivars and 21 land races subjected to optimum and drought conditions. The number of spikelets per spike and plant height differed in cultivars while these traits did not differ in land races under Drought compared to near optimum conditions (Dencic *et al.,* 2000). The water stress significantly reduced the stem height, stem diameter, leaf area, days to complete and grain yield flowering of maize cultivar YH-202 (Khan *et al.,* 2001).

Yang *et al.* (2001) studied that a hormonal change may mediate the effect of water deficit that enhances whole plant senescence and speed up grain filling. In well watered and water stressed treatments were imposed for nine days at post anthesis to maturity. Results showed that water stress increased partitioning of fixed CO_2 in to grain, accelerated the grain filling but shortened the grain filling period. Cytokinin, indole-3-acetic and Gibberillins contents in the grain increased at early grain filling stage and WS treatment reduce their contents at the late grain filling stage.

The experiment was conducted on wheat grown at day/night temperature of either 18/20 ^{0}C (moderate temperature) or 27/2 ^{0}C (chronic high temperature) at the time of anthesis showed that in non-drought plants, shading following anthesis reduced kernel dry weight of remaining kernel of droughted plants. At high temperature following effect of drought, kernel dry weight may be reduces and there is a reduction in the duration of grain filling period (Wardlaw and Ian, 2002).

1.5 Effect of Water Stress on Yield and Yield Components

The effect of drought on plant growth and development ultimately reduced grain yield. Hochman (1982) determined the effect of water stress applied at different growth stages on grain yield in wheat. He observed reduction in grain filling. Grain weight and number of grains per spike were also reduced by drought. The plant under water stress matured a week earlier at earing stage whereas water stress applied at seedling and booting stage delayed the maturity by one week as compared with control. Booting stage was found to be most critical for grain yield. Among three cultivars, Pak-81 proved to be somewhat better to water stress condition (Illahi *et al.,* 1986).

Drought causes reduction in the efficiency of key physiological processes like photosynthesis and respiration (Pessarakali, 1999). Under limited water supply water potential of wheat leaves was less negative which is likely to reflect a lower water consumption of these plants. Tambussi *et al.* (2000) reported that drought caused partial breakdown of the photosynthetic apparatus and electron transport was also severally affected.

Setter *et al.* (2001) reported that water deprivation decreased kernel set, photosynthesis, stomatal conductance and carbohydrate accumulation. In another study it was observed that water potential of roots sampled was lowered immediately after given water stress.

The reduction in plant height was associated with a decline in the cell enlargement and more leaf senescence in *A. esculentus* under drought. Development of optimal leaf area is important to photosynthesis and dry matter yield (Wellscleger *et al.,* 2005).

The greatest adverse effect of water stress on yield and WUE was observed during stress from jointing stage to flowering in wheat comprising three levels of water stress viz. -0.5 and -1.5 MPa water potential (Singh *et al.*, 1986). The experiment conducted to study the effect of water and temperature on apex differentiation, spike and spikelet development and number of spikelets in a controlled environment using; Sinyion; hard red spring wheat (HRSN) showed that the plant exposed to water stress starting 12 days after seedling emergence required the same duration to develop the double ridges as the control, but stressed plant shorter spikelet development stages, resulting in fewer spikelets per spike (Frank *et al.,* 1987).

The date and rate of formation of additional fertile tillers were major factors in grain yield under drought. The drought starting from stem extension or heading in different varieties and strains of spring barley caused reduction in yield (Kaminska and Mazgalska, 1992). Moisture stress in wheat during spike emergence and anthesis reduced grain yield from 7.0 to 3.3 t ha^{-1} 37% reduction in spikes m^{-2}, 15% reduction in individual grain weight and 13% reduction in grain number per spike. Application of drought during grain filling decreased yield by 20% by decrease in individual grain weight. The dry matter production, plant height, leaf area duration (LAD) of grain filling period and protein contents were significantly influenced by the irrigation treatment (Thompson and chase, 1992).

Wheat crop was most sensitive to moisture deficit at tillering stage and least sensitive at least sensitive at flowering stage. Number of tillers per unit area, spikelets per spike and number of grains per spike were reduced when stress was applied at tillering and flowering stage respectively (Waheed *et al.*, 1998).

The yield reduction under water stress environment is attributed to the decrease in productive tillers per plant, fertile spikelets per plant, number of grains per plant and reduce individual grain yield (Pal, 1992). The grain yield of wheat cultivar Hauyutaka improved with the increase in the number of effective spikes per unit area which was more affected by deficit irrigation applied different growth stages (Matsunaka *et al.*, 1992). The water stress affected grain yield components particularly the number of fertile ear per unit area and grain number per ear of durum wheat (Giunata *et al.*, 1993).

Crop varieties respond differently to drought. Yasin *et al*. (1993) in a study to response of different wheat varieties to water stress observed that under drought among all varieties, LYP-73 proved to be most tolerant one as it gave maximum yield. Water stress caused large differences in yield of four cultivars of wheat. Stress applied at either tillering or heading gave similar results but effect was more pronounced when stress was applied at heading stage. The water stress imposed on bread wheat by cessation of watering for 9-17 days starting at the 4 to 5 leaf stage showed that the emergence of tiller was delayed. Formation of the secondary tillers was the most sensitive to water shortage, because their number and size was greatly reduced (Moustafa *et al.*, 1996).

Shehizadi et al. (1999) conducted an experiment to see the effect of different water regimes on growth, yield and anatomy of wheat. She found that plant height, number of tillers, number of spikelets per ear, ear length, and 1000-grain weight, grain yield per plant and biomass per plant showed decreased response to drought.

Water stress inhibits cell enlargement more than cell division. It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, ion uptake, and carbohydrates, nutrient metabolism and activity of growth promoters (Jaleel *et al.*, 2008a). The reactions of plants to water stress differ significantly at various organizational levels depending upon intensity and duration of stress as well as plant species and its stage of growth (Jaleel *et al.*, 2008b).

Understanding of plant response to drought is of great importance and also a fundamental part for making the crops stress tolerant (Zhao *et al.*, 2008).Water stress suppressed cell expansion and cell growth due to the low turgor pressure. Osmotic regulation enables the maintence of cell turgor for survival or to assist plant growth under severe drought conditions in Pearl millet (Shao *et al.*, 2008).

The leaf growth was more sensitive to water stress in wheat than in maize. Water deficit stress mostly reduced leaf growth and finally the leaf area in many species of plants (Wellschleger *et al.*, 2005). In *Vigna unguiculata* and sunflower both stomatal and non-stomatal limitation were the major determinant of reduced photosynthesis under drought (Manivannan *et al.*, 2008).

The plant height, number of tillers, number of spikelets per ear, ear length, 1000 grain weight, grain yield per plant and biomass per plant decreased under water stress in wheat. The irrigation requirement of wheat tested at 35, 50, 65 and 80 % depletion levels of plant available moisture. Durum varieties, *Kronos* and *Westbred* 881 showed that grain yield averaged over the two varieties were 6787, 6494, 5460 and 3067 lbs/acre for the 35, 50, 65 and 80% depletion levels respectively. The irrigation at 50% soil water depletion or less is optimal for wheat grain yield (Husman *et al.*, 2000).

Dencic *et al.* (2000) conducted a two year experiments in which they tested 30 wheat cultivar and 21 land races under near optimum and drought conditions. They found that number of kernels per spike, 1000 kernels weight and especially yield were more sensitive to drought. In cultivars, plant height and number of spike lets per spike differed while in land races these traits did not differ under drought as compared to near optimum conditions.

Husman *et al.* (2000) studied the optimum irrigation timing based on depletion of plant available water in the soil. A field experiment was conducted in which two durum wheat varieties wheat Kronos and Westbred 881 were tested at at 35%, 50%, 65%, and 80% depilation of plant available water. Average grain yield of two varieties were 6787, 6494, 5460 and 3067 lbs/acre at the 35, 50, 65 and 80% depletion levels, respectively. The results of this study indicate irrigating at 50% soil water depletion or less is optimal for wheat grain yield.

The grain filling processes in wheat under drought conditions are limited by low substrate availability and low solute potential within the sink i.e. an unfavorable seed environment and reduced synthetic capacity of the sink (Ahmadi and Baker, 2001). The drought at anthesis stage reduced yield in nine wheat varieties. The differential responses of varieties to drought water stress condition indicate the drought tolerance ability of wheat varieties. Varieties Parwaz-94, Pasban-90 and Punjab-96 showed high yield potential and stability against drought, so these varieties could be further tested for their drought tolerance characteristics (Ahmad, 2002).

Siddique *et al.* (2000) studied the effect of drought on the water relations of four wheat cultivars Viz, Kanchan, Sonalika, Kalyasona and C-306. They were subjected to two levels of water stress at vegetative and anthesis stages. Exposure of plants to drought led to noticeable decrease in leaf water potential and relative water content by a constant increase in leaf temperature. Drought plants displayed high canopy temperature than well-watered plants.

Kang *et al.* (2002) conducted a field experiment for winter wheat to evaluate the effect of limited irrigation on crop yield and water use efficiency (WUE). The result showed that evapotranspiration, grain yield, biomass, WUE and harvest index depend on soil water content. High moisture treatment gave the greatest evapotranspiration and biomass but did not produce the highest grain yield and gave relatively low WUE. Stress caused an average grain yield reduction of 79.7%: and a harvest index reduction 45.2% in 26 durum wheat genotypes. Drought susceptibility index proved useful to compare genotypes under droughted conditions. Number of kernels per spike and 100 kernel weight had the largest direct effect on grain yield, under both stressed and non-stressed conditions. On the basis of absolute grain yield, cultivar Barani-83 was found to be the most drought tolerant due to the better osmotic adjustment and Inqilab-91 the most sensitive one as it suffered maximum loss in grain yield (Akram *et al.*, 1998).

The evaluation of comparative growth and yield behavior of 7 wheat varieties viz; *Bahawalpur*-79, *Faisalabad*-85, *Punjab*-85, *Pasban*-90, *Inqulab*-91, *Watan*-93 and *Parwaz*-94 showed that the maximum numbers of grains per spike (59.07) were produced by Inqalab-91, which was statistically different from one another. The grains yield was higher (46.33 q ha^{-1}) (Hussain, 1997). The evaluation of twelve spring wheat genotypes grown under two irrigation levels (well-watered and moisture-stressed) imposed between tillering and anthesis with a line-source sprinkler irrigation system showed that Klasic consistently had the highest canopy temperature under moisture stressed conditions, while Bannock and Pondera had the lowest. Bannock, Yecora Rajo and Klasic had the warmest canopies under well-watered conditions, while Vandal, Amidon and Rick had the coolest. Plot to plot variation in canopy temperature under water stress condition was evident for differences in grain yield. Significant correlations between canopy temperature and yield under moisture-stress conditions and drought susceptibility index values indicated the potential for screening wheat genotypes for drought tolerance (Ahmad, 1999).

Ashraf (1998) reported that earlier water deficit reduced grain yield and yield component in all cultivars, but cv. Ckakwal-86, DS-4 and Barani-83 gave higher yield and yield component than all other cultivars. Drought from sowing was the most damaging treatment: there was no difference between pre and post anthesis drought.

Chang and Suo (2007) studied the effects of water stress on grain yield of wheat. They subjected wheat to moderate water stress during early growth stages. Interruption of irrigation at an early growth stage resulted in reduced stem height and a smaller number of spikes, while spike weight and crop yield were influenced if irrigation was interrupted before heading and after pollination. Water deficiency before heading resulted in severe yield loss.

Esmail (2001) simulated the growth of durum wheat cultivar grown under water stress condition by interruption of irrigation at different growth stages. Interruption of irrigation at an early growth stage resulted in reduced stem height and a smaller number of spikes, while spike weight and crop yield were decreased when irrigation was interrupted before heading and after pollination. Water deficiency before heading resulted in severe yield loss (73%).

Ozturk (1999) reported decreased growth and yield of winter wheat cv. Dogu-88 due to water stress. Fully irrigated (FI), rainfed, early drought (ED), late drought (LD) and continuous drought drought (CD) treatments were checked for growth and yield of wheat. Reduction in grain number per unit area (44.4%), reduction in 1000-grain weight (6.9%), and reduction in grain yield (40.6%) was observed as compared with FI. In LD treatment shorter green area duration of 27.5 days, lighter 1000-grain weight (3.8g) and lower grain yield (24.0%) were also recorded. Continuous drought treatment decreased grain number per unit area by 54.9%, 1000 grain weight by 19.9% and grain yield by 65.6% compared with FI. Early drought limited primarily grain number per unit area while LD affected grain weight. The negative effect of ED on grain yield was more significant than LD.

The evaluation of 30 diverse genotypes of bread wheat for seed vigor index, germination percentage, root length, shoot length, root-to-shoot length ratio, coleoptiles' length and osmotic membrane stability under laboratory conditions indicated that the seed vigor index was the most sensitive trait, followed by shoot length, germination percentage and root length. The root-to-shoot length ratio, however, increased under osmotic stress. All the characters except germination percentage shoot length and coleoptiles' length showed considerable genetic variability. These parameters used as screening criteria against drought (Dhanda *et al.*, 2004).

Pirdashi *et al.* (2004) conducted the field experiment to evaluate the effect of water stress on the yield and yield components of four rice cultivars Khazar, Tarom, Fajr and Nemat in Mazandranan, Iran. Water stress was imposed during vegetative, flowering and grain filling stages. Water stress at vegetative stage significantly reduced plant height and water stress during vegetative, flowering and grain filling stages reduced mean grain yield by 21%, 50% and 21%, respectively, as compared to control.

Gupta *et al.* (2001) conducted a pot experiment were they imposed drought at booting and anthesis stages and observed that water stressed wheat plants exhibited significantly higher leaf diffusive resistance in both the genotypes. Wu and Li (2001) subjected four wheat genotypes to water stress and found that drought decreased stomatal conductance and degree of inhibition in it was 22.40% less in drought resistant cultivars than the drought sensitive ones.

Water stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Desiccation is much more extensive loss of water, which can potentially lead to gross disruption of metabolism and cell structure and eventually to the cessation of enzyme catalyzed reactions (Jaleel *et al.*, 2007). Drought is characterized by reduction of water content, diminished leaf water potential and turgor loss, closure of stomata and decrease in cell enlargement and growth. Severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of plant parts occur (Jaleel *et al.*, 2008c).

Specht *et al.* (2001) studied the relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. Spring wheat cultivars were subjected under two moisture-deficit regimes. They reported that moisture deficit differentially and significantly influenced cultivars test weight, and yield. The overall moisture deficit induced reduction in yield was due to reduction in kernel weight, Effects of moisture deficit on yield of specific cultivars were due less number of kernels per spike. During irrigation management studies on wheat, it was noted that water stress at critical growth stages significantly decreased wheat grain yield. Moisture stress reduced seed size as well as final yield.

The evaluation of vegetative growth, water use, physiological development, biomass accumulation and grain yield of five wheat cultivars under irrigated and water stressed treatments showed that high tillering capacities and apparent vigorous root system was favored in some cultivars, even in irrigated treatment. The vegetative drought resistance did not infer the final grain yield (Brisson *et al.,* 2001).

Under drought conditions, path coefficient analysis on 27 wheat genotypes revealed that biological yield had the highest positive direct effect on grain yield followed by harvest index, spikelets per spike, 1000-grain weight. Spikes per spike had the highest positive direct effect on grain yield followed by harvest index, 1000-grain weight, days to maturity and plant height. Therefore, indirect selection for these plant traits should be exercised in selecting drought tolerant genotypes of wheat (Muhammad, 1995).

The yield components like grain number and grain size were decreased under pre anthesis Drought treatment in wheat (Erward and Wright, 2008). In some other studies on maize, Drought greatly reduced the grain yield, which was dependent on the level of defoliation due to water stress during early reproductive growth. Water stress for more than 12 days at grain filling and flowering stage of maize (grown in sandy loam soil) was the most damaging in reducing the seed yield (Khan *et al.,* 2001).

Singh *et al*. (2003) studied the genetic variability and path coefficient analysis of 45 wheat varieties under semi-arid conditions. He observed that number of grains per spike and harvest index gave the highest phenotypic (21.78 and 20.35) and genetic (18.71 and 18.05) coefficients of variation. The number of grains per spike exhibited the most direct effect on the yield of grains (0.54), followed by spike length (0.42) and 1000-grain weight (0.30). The results indicated that the number of grains per spike, spike length, and 1000-grain weight were the main yield contributing factors.

Genotypic variation in water utilization assimilates partitioning, growth and yield parameters were also studied in wheat crop. A field trial was conducted to study the growth, development, radiation use efficiency (RUE) and yield of different wheat cultivars. Results showed that there were significant differences in RUE and total dry matter production in all the wheat cultivars. Among the cultivars, C-306 produced maximum number of ears per m^{-2} (181.5), seeds per ear (37.9), thousand grains weight (38.6g). Its root development, water uptake (154 mm), water use efficiency (13.75 kg ha^{-1} mm^{-1}) was also maximum from all other cultivars (Naseem, 2007).

If water deficit condition occurs during grain filling stage then photosynthesis will be low which reduces the production of final grain yield. To compensate the grain yield and to prevent the severe losses, pre-anthesis assimilates (stored in stem) are efficiently utilized. This assimilates increase during the one leaf up to grain filling stage. Under water deficit conditions during floral initiation to grain filling stage, dry matter translocation and its efficiency is also decreased. When water stress occurs during grain filling stage, the remobilization and contribution of pre-anthesis assimilates is increased by 20% as compared to optimum irrigation (Ali *et al.,* 2009).

Conclusion

There is lot of potential in phenotypical and physiological traits of different varieties of wheat with reference to their tolerance to drought. However, there is need to explore it.

Acknowledgments

The authors are thankful to Dr. Safdar Hussain and Dr. Anser Ali, Department of Agronomy, Faculty of Agriculture, Ghazi University, Dera Ghazi Khan, Pakistan for their technical collaboration in writing the manuscript of this review article

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