

CHAPTER I

GENERAL INTRODUCTION

Food security is facing new challenges due to the increase of world population and the impacts of climate change on agriculture and food supply now-a-days. An enormous increase in food production is necessary to supply sufficient food for a rapid growing world population. FAO (2013) states that the further increment in population will create inadequate food consumption levels, pressuring for further increase of food supplies. Therefore, to feed the rapidly growing population of the world, food production should be heightened.

Wheat (*Triticum aestivum* L.) is a staple food for more than 35% of the world's population, and a source of food and livelihood for over one billion people in developing countries (Metwali *et al.* 2011). Wheat grain used to make flour, breads, biscuits, cakes, cookies, pasta, noodles and also for beer, other alcoholic beverages or biofuel (Knott *et al.* 2009). 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 (FAO 2010). It is recognized that almost 50% of wheat cultivated land in the developing world is under rainfed condition (Reynolds *et al.* 2014). Abiotic stresses are serious problem in many parts of the world especially for rainfed agriculture in circumstances of rapid change in climatic conditions. Among prevailing abiotic stresses, drought is the most significant and severe factor inhibiting plant growth and production (Naeem *et al.* 2015). Wheat yields are reduced 57% from their potential because of drought spell on at least 60 million hectare in the developing world (Hlavinka *et al.* 2009). 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 (Subhani 2012, Hanif *et al.* 2013, Zamurrad *et al.* 2013). KulKarni *et al.* (2008) 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 particular to drought (Mahmood *et al.* 2013).

Water stress reduces plant growth and manifests several morphological, physiological and biochemical alterations leading to massive loss in yield (Farooq *et al.* 2009). Water stress tolerance is seen in almost all plant species but its extent varies from species to species and even within species due to differences in phenological, morphological, biochemical, physiological and molecular adaptive mechanisms (Nakayama *et al.* 2007). Drought tolerance does not exist as a unique and easily quantifiable plant attribute, it is a complex physiological, morphological and molecular character connected with relative water content (RWC), relative water loss (RWL), chlorophyll fluorescence and cell membrane stability (CMS) (Farshadfar *et al.* 2008). According to the previous studies, there is a link between various physiological responses of crop plants to drought and their tolerance mechanisms such as high relative water content and water potential (Datta *et al.* 2011), membrane stability (Gholamin and Majid Khayatnezhad 2010), and pigment content stability under stress (Ghobadi *et al.* 2011). The high RWC and low excised leaf water loss (RWL) have been suggested as important indicators of water status (Gunes *et al.* 2008, Ghobadi *et al.* 2011). Almeselmani *et al.* (2011a) reported that membrane stability index is the best indicator for screening wheat varieties for drought stress particularly at advance stages of plant growth. Total chlorophyll content and the Chl a/b ratio were found to reduce under water stress conditions. A decrease in this index was faster in drought sensitive than in drought tolerant genotypes (El-Tayeb 2006). According to (Zivcak *et al.* 2009) chlorophyll, fluorescence measurement appears very promising for screening of genotypes for improved tolerance to drought and high temperature. The improvement of tolerance to drought has been a principal goal of the majority of breeding programmes for a long time, as a water deficit in certain stages of wheat growth is common for many wheat growing regions of the world (Farshadfar 2012). To overcome the low response to direct selection for yield under drought conditions,

substantial efforts have been targeted on manipulation of physiological traits influencing drought resistance through an escape, avoidance and tolerance mechanism (Blum 1997).

Concept about the drought tolerance is one of the most indistinct in literature. Many tolerance mechanisms have been evolved, such as dehydration tolerance level using genetic engineering techniques under laboratory condition (Jenks *et al.* 2007, Nelson *et al.* 2007), reactive oxygen species (ROS) detoxification under stress condition (Lee *et al.* 2007, Yang *et al.* 2007, Zhu *et al.* 2007), and facilitating the drought avoidance mechanism with hormonal balance (Rivero *et al.* 2007). Nutritional status of the plant is the indicator of its response to environmental stress. Besides various adaptive mechanisms, additional potassium (K) application under drought condition can improve the tolerance of crop plants to various types of abiotic stresses, and it also improved subsequent growth and yield. Cakmak (2005) reported that potassium enhanced drought tolerance in plants by mitigating harmful effects by increasing translocation and by maintaining water balance. K regularizes physiological processes like photosynthesis, translocation of cations into sink organs, regulation of turgor pressure and enzymes activation (Mengel and Kirkby 2001). Cakmak (2005) reported that plant suffering from drought stress required more internal K. During stress condition, ROS formation was induced and oxidative damage to cells occurred and requirement for K was increased (Foyer *et al.* 2002). This enhanced need for K by plants suffering from drought stress showed that K is required for photosynthetic and CO₂ fixation, because water deficit caused stomatal closure and decreased the CO₂ fixation. By the studies of Jiang and Zhang (2002), it is documented that the impairment in photosynthesis increased the ROS production and carbohydrate metabolism was also disturbed. Mengel and Kirkby (2001) observed that due to low K concentration, ROS production was induced during water deficit which caused disturbance in stomatal opening. In legumes damaging effects of drought can be diminished by ample K supply (Sangakkara *et al.* 2000). Low grain yield resulting from water deficit could be overcome by increasing K supply (Damon and Rengel 2007).

Foliar application of 1% potassium at all three critical growth stages (tillering, flower initiation and milking) under water limited environment enhanced the drought tolerance of wheat cultivars (Lasani-2008, Auqab-2000) and improved the growth and yield components, however, grain filling stage was found more responsive (Aown *et al.* 2012). Lindhauer (1989) reported that potassium imparts a beneficial effect on plants to overcome soil moisture stress. Relative water content was decreased under moisture stress condition in wheat genotypes compared with normal irrigation. Spraying potassium iodide enhanced relative water content especially under moisture stress condition. Premachandra *et al.* (1993) noticed that application of potassium fertilizer under water stress condition reduced the leaf water potential, osmotic potential and increased osmotic adjustment of maize cultivars. This was mainly due to net increase in intercellular solutes as a result of high potassium fertilization. Tyagi *et al.* (2000) reported that application of potassium iodide at different stages of grain development of wheat genotypes (CV 2338) leaf water potential and turgor potential. They proposed that an inbuilt system of water economy enable this drought tolerant wheat genotype to maintain vital physiological function under adverse climatic conditions. Plant height of wheat was reduced under moisture deficit condition as reported by Siddique *et al.* (2000) and Jamal *et al.* (1995, 1996). External application of potassium increased plant height under water stress condition by maintaining stomatal movement, net photosynthesis and the efficiency of CO₂ assimilation (Usherwood 1985).

Information reviewed in this section indicate that under drought stress conditions a physiological approach would be the most attractive way to develop new drought tolerant varieties, as well as yield losses could be minimized by the sufficient supply of K, although its application effect at various plant growth stages is not well understood yet. However, the assessment of physiological mechanisms and genetic controls of the drought tolerant traits at different plant developmental stages, and alleviation of the detrimental effect of drought by increasing K supply in promising wheat genotypes has been relatively scarce in Bangladesh.

Considering the above facts a series of research works were conducted with the following objectives:

1. To identify suitable genotypes for drought prone areas,
2. To find out the influence of water deficit stress on the physiological traits of wheat resulting reduced grain yield,
3. To know the growth phenomena related to yield attributes and yield of wheat genotypes under water deficit condition, and
4. To sustain desirable wheat yield under water deficit condition by increasing K supply.

CHAPTER II

REVIEW OF LITERATURE

Wheat (*Triticum* spp.) is a grass that is cultivated worldwide (Belderok *et al.* 2000). Globally, it is the most important human food grain and ranks second in total production as a cereal crop behind maize; the third being rice (FAOSTAT 2016).

2.1 Botanical description of wheat plant

Wheat (*Triticum aestivum* L. Thell) is an important self-pollinating annual plant, belonging to the family Gramineae or Poaceae (grasses). Wheat is a herbaceous annual plant up to 1.2 m in height. The stems are erect, hollow inside except at the nodes. The ‘mature’ wheat plant is made up of repeating segment called phytomers, which contain a node, a hollow internode, a leaf and tiller bud found in the axis of the leaf (Kirby 2002). In the proximal or basal units, the internode remains short and the nodes are packed closely together. The stem terminates in the ear of wheat plant. A leaf is inserted at each node although at maturity the basal leaves are usually dead and may have disappeared. The leaf structure consists of the sheath and leaf blade. At the junction of leaf blade and leaf sheath, a set of structures like the ligule (membranous structure) and auricle (a pair of small, hairy projection) are formed (Kirby 2002). Leaves are produced on alternative sides of the stem and are numbered so that all even numbered leaves are on one side of the plant (Setter and Carlton 2000). The length of leaves increases from the base until one or two leaves before the flagleaf, in spring wheat varieties (Kirby 2002). The leaf sheath wraps around the stem providing support to the shoot (Setter and Carlton 2000). The shoot is terminated by an ear or spike bearing about 20 spikelets. Tillers, which have the same basic structure as the main shoot, arise from the axils of the basal leaves. At anthesis, only some of the tillers have developed to produce an ear. Others die and may be difficult to find in the mature plant. The mature wheat plant has two distinct types of roots, the seminal (seed) roots develop from the root primordia contained with the grain and are the first root type to emerge (Perry and Belford 2000, Kirby 2002) or roots that

initiate after germination, the nodal (crown or adventitious) roots emerge at the same time that tiller development starts (Kirby 2002). About six root primordia are present in the embryo. At germination, the primary root bursts through the coleorhiza, followed by the emergence of four or five lateral seminal roots. As it approaches anthesis, the ear is completely formed and the pollen grains and carpel are fully developed. The ear of a wheat plant is made up of two rows of spikelets. The spikelets contain the florets and are arranged on opposite sides of a central rachis (Setter and Carlton 2000) in a similar manner to the arrangement of the leaves on the central stem. The florets are enclosed by a lemma and a palea and are composed of the carpel (the ovary and the stigmas) and three stamens and anthers (Setter and Carlton 2000). Each anther consists of four loculi enclosing the pollen grain (Kirby 2002). After anthesis, the florets open, pollen is released and the carpels are pollinated. The stamens and lodicules, their role fulfilled, die and shrivel, and further growth and development takes place in the carpels, the developing grains. At this stage, the ear consists of the main axis or rachis with each internode ovoid in section and curving around the spikelet. A single spikelet is attached at each node, and the rachis terminates in a spikelet set at right angles to the lateral spikelets. Each spikelet comprises an axis, the rachilla, which bears two glumes and a number of florets. Within each spikelet, there are usually from two to four potentially fertile florets. The floret has two sheathing structures, the outer lemma and the inner palea; these envelope two lodicules, three stamens and the carpel. Each stamen is made up of a filament, which is very short at this stage, and a yellow anther. The anther is about 3 mm long and has four chambers or loculi containing numerous pollen grains. The spherical pollen grain has a small circular pore and contains a single nucleus and starch grains (Percival, 1921). After initiating leaves, the apex changes in form and initiates about 20 spikelet primordia, terminating in a terminal spikelet. The caryopsis or grain of the whole plant is made up of the bran coat (caryopsis coat) and the endosperm surrounding the embryo (Setter and Carlton 2000). The bran coat consists of three layers, the pericarp, testa and

aleurone. The endosperm makes up 83% of the wheat grain. It stores the starch and protein important both for the developing plant and flour production. The embryo makes up only a small percentage of the grain but contain the root redicle and the shoot apex surrounded by the coleoptiles. The scutellum separates the endosperm from the embryo (Setter and Carlton 2000).

2.2 Origin and evolution of wheat

Wheat was cultivated at first around 10000 years ago, as part of the ‘Neolithic Revolution’, which saw a transition from hunting and gathering of food to settle agriculture. The earliest cultivated forms were diploid (genome AA) (einkorn) and tetraploid (genome AABB) (emmer). The different ploidy levels and their genetic relationships indicate that they originated from the south-eastern part of Turkey (Heun *et al.* 1997, Nesbitt 1998, Dubcovsky and Dvorak 2007). Wheat cultivation spread out to the Near East by about 9000 years ago when hexaploid bread wheat made its first appearance (Feldman 2001). The earliest cultivated forms of wheat were essentially landraces selected by farmers from wild populations, presumably because of their superior yield and other characteristics, an early and clearly non-scientific form of plant breeding. However, domestication was also associated with the selection of genetic traits that separated them from their wild relatives. The shattering of the spike at maturity occurs at first, which results in seed loss at harvesting. This is clearly an important trait for ensuring seed dispersal in natural populations and the non-shattering trait is determined by mutations at the Br (brittle rachis) locus (Nalam *et al.* 2006). The second important trait is the change from hulled forms, in which the glumes adhere tightly to the grain, to free-threshing naked forms. The free forms arose by a dominant mutant at the Q locus which modified the effects of recessive mutations at the Tg (tenacious glume) locus (Jantasuriyarat *et al.* 2004, Simons *et al.* 2006, Dubcovsky and Dvorak 2007). Cultivated forms of diploid, tetraploid, and hexaploid wheat have a tough rachis apart from the spelt form of bread wheat. Similarly, the early domesticated forms of einkorn, emmer,

and spelt are all hulled, whereas modern forms of tetraploid and hexaploid wheat are free-threshing. Whereas, einkorn and emmer clearly developed from the domestication of natural populations, bread wheat has only existed in cultivation, having arisen by hybridization of cultivated emmer with the unrelated wild grass *Triticum tauschii* (also called *Aegilops tauschii* and *Ae. squarosa*). This hybridization probably occurred several times independently with the novel hexaploid (genome AABBDD) being selected by farmers for its superior properties.

2.3 Cytogenetic origin of wheat

Wheat belongs to the grass family *Graminae* and to the tribe *Hordeae*, forming a true spike. The species of the genus *Triticum* are grouped into i) Diploid ($2n = 2x = 14$), ii) tetraploid ($2n = 4x = 28$), and iii) hexaploid ($2n = 6x = 42$). It is reported that 13 diploid, 12 tetraploid, and five hexaploid species of the genus *Triticum* are found in the globe (Feldman and Sears 1981). Among them, only two species of *Triticum* are commercially important naming i) the hexaploid species, *Triticum aestivum*, which is known as the bread wheat-the principal wheat in commerce, and ii) the tetraploid species, *Triticum turgidum*, which is known as the durum wheat that is used in making pasta. The wild tetraploid species, *Triticum timopheevii*, is the source of cytoplasmic male sterility utilized in breeding hybrid wheat as reported by Miller (1987) (Fig. 2.1).

2.4 Effect of drought stress on wheat

Global climate changes have a major impact on crop production. Drought stress decreases crop yield by adversely affecting germination, phenological, morphological, physiological, and biochemical traits. An attempt has been made in this chapter to present a brief review of research in relation to germination, phenology, physiology, growth and yield of wheat as influenced by drought stress which has been done in Bangladesh and many other countries of the world.

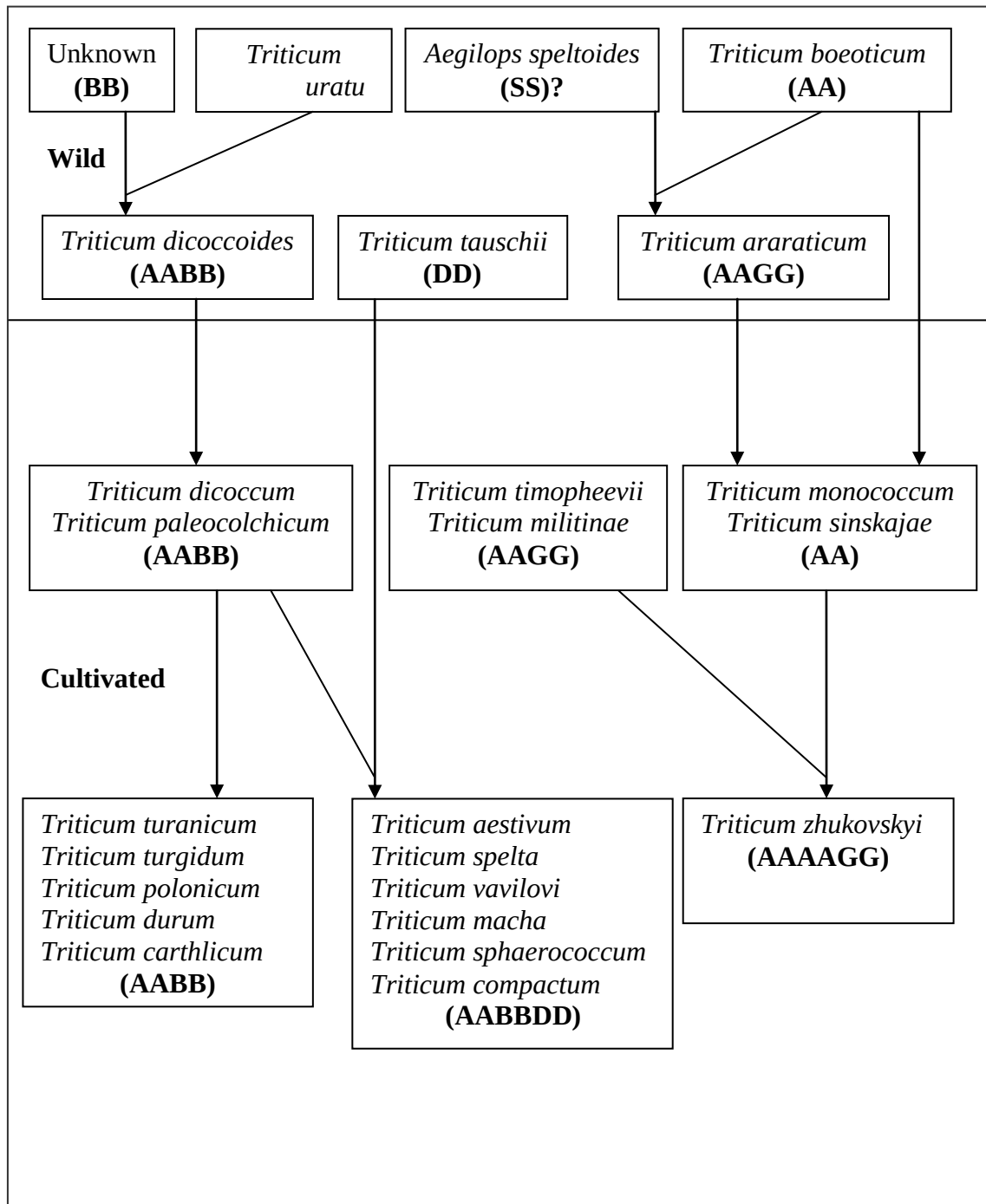


Fig. 2.1. Origin and development of cultivated tetraploid and hexaploid wheat (Miller 1987).

2.4.1 Effect of drought stress (PEG induced) on the germination and seedling growth

Ninety-six diverse wheat genotypes were tested by Dodig *et al.* (2015) in the laboratory for germination and seedling growth in response under osmotic stresses (equivalent to water potentials of -0.2, -0.4 and -0.6 MPa) induced by polyethylene glycol (PEG). Germination percentages, mean germination time, coleoptile length, shoot length and shoot growth rate were reduced with increasing stresses.

In order to assess the relative capability of drought tolerance regarding germination percentages (GP) and seedling growth, Datta *et al.* (2011) tested five wheat varieties viz., K 9107, HD 2954, RAJ 4125, HUW 234, and NW 2036 under artificial drought stress created by preparing solution of PEG-6000 having osmotic potentials of -1.0 bars. The GP, root and shoot length, fresh and dry weights of roots and shoots significantly reduced under drought stress. The variety RAJ 4125 was found to be mostly drought tolerant among the experimental varieties having significant higher GP and seedling growth.

The germination stress tolerance index (GSI) can be used as an effective criterion for genotype screening against various drought stress regimes (Fernandez 1992). High values of GSI indicated the potential for drought tolerance (Zahra and Farshadfar 2011). A great variation in wheat genotypes in relation to germination percentage (GP) has already been observed by Ashraf *et al.* (1996) in response to PEG-induced water stress. The increase in PEG concentrations caused a decrease in the uptake of water by seeds, which caused a decline in GP (Kaydan and Yagmur 2008). Germination rate and final GP correlate with root length and how much biomass is accumulated per unit area (Okçu *et al.* 2005).

Seedling root lengths increase in wheat genotypes under water stress conditions and this extension in root length happened at the cost of reduction in shoot length, thus shifting the relative root:shoot (R:S) equilibrium in favour of the roots which has also been described by various plant scientists (Ashraf and Sarwar 2002, Guoxiong *et al.* 2002). The increase in root

to shoot length ratio under water limitations may be attributed for reduction in supply of water and nutrients to the shoot. The reduction in shoot length under water-limited conditions might be due to decrease in cell expansion, which ultimately reduced the plant height (Okçu *et al.* 2005, Shahbaz *et al.* 2011). Root length and seedling dry weight can be used as major selection criteria for screening genotypes against drought stress (Dhanda *et al.* 2004, Qayyum *et al.* 2012). Deep roots and ability to accumulate dry biomass are considered typical characteristics of drought tolerant genotypes (Zhao *et al.* 2004).

Wheat seeds are usually stored at around 12% moisture content by weight. Seed germinates when the amount of water in grain reaches at least 35-45% of dry weight (Evans *et al.* 1975). Thus, early drought at wheat growing season adversely affects germination and crop establishment.

A field experiment was conducted by Almaghrabi (2012) with eight wheat cultivars including four local cultivars (Madini, Kaseemi, Yamanei and Tabokei) and four introduced cultivars (Sakha 93, Giza 168, Seds 12 and Masr 1) to drought stress induced by polyethylene glycol (PEG) 6000 at different concentrations (0.0, 60, 120, 180, 240 and 300 g/L PEG) during germination and seedling growth stage. The results revealed that germination percentage, mean daily germination, germination index, mean germination time and co-efficient of velocity of germination were significantly influenced by PEG induced water stress, and the values decreased with increasing the stress. Seedling growth traits like shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, seedling length and root number were remarkably affected by stress except root dry weight, and the highest values for most of parameters were recorded for Sakha 93 and Madini cultivars followed by Yamanei, Kaseemi and Tabokei. All the measured germination and seedling growth parameters (except root number) under study can be used as selectable parameters to

discrimination between tolerance and sensitive cultivars under drought stress in breeding programs.

Seeds of six wheat varieties viz. Damani, Hashim-8, Gomali-8, DN-73, Zam-04 and Dera-98 were placed for germination in Petri dishes under 15% polyethylene glycol (PEG) 6000 solution and distilled water (control) conditions. The variety Hashim-8 gave maximum germination percentage (93.33%) whereas maximum coleoptile (1.78cm) and shoot length (5.77cm) was observed in variety DN-73 which was statistically at par with variety Hashim-8. Similarly, the root length (3.63g), fresh shoot (0.15g) and root weight (0.12g) was maximum in variety Dera-98 which was statistically at par with the variety Hashim-8 (Khakwani *et al.* 2011b).

Raza *et al.* (2012) tested eight wheat (*Triticum aestivum* L.) genotypes viz. Pasban-90, Inqilab-91, Auqab-2000, AS-2002, Sahar-2006, Shafaq-2006, Lasani-2008, and FSD-2008) for screening in laboratory under water deficit condition. Three techniques such as (i) seed germination at -0.6 MPa external water potential (PEG-6000), (ii) seedling growth after 14 days at -0.6 MPa (PEG-6000), and (iii) plant water relations of seven-week-old pot-grown plants were used for the screening. Water deficit stress significantly reduced germination and seedling growth properties of all the genotypes, and the highest germination stress tolerance index, root length stress tolerance index and the water content was recorded in the variety Lasani-2008 and the lowest was recorded in Auqab-2000. The highest dry matter percentage was recorded in Pasban-90, while the lowest dry matter percentage was observed in Auqab-2000 significantly. The variety FSD-2008 gained maximum plant height and was recorded minimum in Inqilab-91. Significantly the highest relative saturation deficit was recorded in Auqab-2000 while the lowest was recorded in Lasani- 2008.

Khayantnezhad *et al.* (2010) evaluated 10 wheat genotypes under six levels of drought treatments (0, -3, -6, -9, -12 and -15 bars) induced by PEG and they found significant

decrease in all studied traits under stress levels. The variety Ardabil had the longest root with 72.6 mm and Seimareh had the longest length of plumule. The highest germination percentage (78%) and velocity of germination were recorded in the line 4057, while the lowest germination percentage (49%) and velocity of germination belonged to the genotypes Marahheh and Ahar, respectively. Traits in tolerant cultivars did not show a significant decline up to -3 bars. Considering all the germination indices, the line 4057 was the most tolerant and 11010 was the most sensitive cultivar.

Germinability and seedling growth of five wheat genotypes were evaluated by Homayoun *et al.* (2011) under PEG induced five levels of drought treatments (distilled water, -2, -4, -6 and -8 bars), and they revealed that germination percentage, germination rate, length of radical and plumule, and dry weight of radical and plumule decreased significantly under drought treatments. On the basis of the results, the genotype Seimareh was found to be the most stress resistant cultivar due to having the highest values of all traits under stress conditions.

Jahanbin *et al.* (2012) conducted an experiment consisting of 12 genotypes from synthetic wheat and four levels of poly ethylene glycol density (PEG) with osmotic potentials of 0, -4/0, -8/0, and -2/1 MPa. They reported that germination indices like germination rate (GR), germination index (GI), mean of emergence time (MET), final germination percentage (FGP), and germination rate index (GRI) were significantly affected by the PEG induced stresses and the values of those traits were remarkably decreased with increasing osmotic potentials. They also noted significant differences among the genotypes in different levels of osmotic potentials, and considering the GI, FGP, GRI, length of radicle, length of plumule and stress tolerance index (STI) they declared the genotype S2 as the most resistant type and the genotype S9 as the most sensitive one.

Seven wheat cultivars (Azar, Omid, Dorom, Tabaci, Keraceharv, Arvand and Gv 3-20) were evaluated by Jajarmi (2009) under six levels of drought treatments (distilled water, -3, -6, -9,

-12, -15 bars). The results indicated that drought stress levels significantly decreased the germination and seedling growth parameters and the percentage of germination and the velocity of germination lessened when drought stress exceeded more than -12bars. The highest germination percentage (78%) belonged to the cultivar Gv 3-20, while the lowest (36%) belonged to Arvand. The variety Gv 3-20 showed the highest velocity of germination and coefficient of velocity of germination under all levels of stresses followed by the Tabaci variety. Among the seedling growth traits shoot length showed more sensitivity to drought stress and the variety Azar produced the longest length of plumule under stress conditions. Drought stress reduced the radical length at more than -6 bars and the variety Keraceharv had the longest length of root (63.58 mm), and tolerant cultivars did not show a significant decline up to -3 bars. Considering all germination and seedling growth indices, the cultivar Gv-3-20 was the most tolerant and Arvand was the most susceptible cultivars.

Two durum wheat (*Triticum durum* Desf.) cultivars Omrabia and Omrabia BD290273 were tested by Sayar *et al.* (2010) for salt and drought tolerance at germination, seedling emergence and early seedling growth in NaCl and PEG-8000 solutions of different osmotic potentials (-0.2, -0.4, -0.6 and -0.8 MPa). Results showed that germination and emergence rates in both the cultivars were delayed by the stress treatments, but the cultivar Omrabia showed higher germination and emergence rates than BD290273 in NaCl while BD290273 was less affected by NaCl and PEG solutions at the emergence stage. Sodium chloride had a lesser effect on both the cultivars in terms of germination rate, emergence rate, final germination and emergence percentage than did PEG-8000. This conclusively proves that the adverse effect of PEG-8000 on germination, emergence and early seedling growth was due to the osmotic effect rather than to the specific ion. Seedling growth was reduced by both the stresses. However, NaCl usually caused less damage than PEG to durum wheat seedlings.

Forty wheat genotypes were screened by Ahmad *et al.* (2013) for drought tolerance using 0, 7.5, 15 and 22.5% polyethylene glycol (PEG) 6000 solutions at PMAS Arid Agriculture University, Rawalpindi, Pakistan during 2009-10. The seedling traits showed a decreasing trend in response to increase concentrations of PEG 6000. Wheat genotype Lyalpur-73 was found the best for germination percentage (87.5%) and the genotype C-591 had maximum germination rate index (2.4). Germination percentage and germination rate index showed positive correlation with all other traits. Wheat genotypes Pasban 90 produced the maximum root length (9.9), whereas WC-18 showed the highest seedling vigour (7.4). The genotype Auqab-2000 showed the maximum shoot length (8.3) and Pak-81 along with CB 335 had maximum coleoptile length (1.9). Root length showed positive association with shoot length and coleoptile length, while shoot length had positive correlation with coleoptile length and seedling vigour.

To quantify seed germination of five commonly sown winter wheat cultivars (Moro, Xerpha, Eltan, Buchanan and Finley) were evaluated by Singh *et al.* (2013) under seven water potentials, ranging from 0 to 21.5 MPa. At higher water potentials (0 to 20.5 MPa), all cultivars showed >90% germination and at the higher water potentials (21.0 to 21.25 MPa) showed 74 to 43% germination. However, the cultivar Moro consistently exceeded the speed and extent of germination than other cultivars. It is noted that coleoptile length is an important factor controlling winter wheat seedling emergence from deep sowing depths. They also observed that the variety Moro had excellent emergence ability having a long coleoptile in deep sowing depths in dry soils at lower water potentials than other cultivars.

2.4.2 Effect of drought stress on the phenology

Bazzaz *et al.* (2014) conducted a field experiment with eleven wheat genotypes (BARI Gom 25, BARI Gom 26, Sourav, BAW 1157, BAW 1158, BAW 1159, BAW 1161, BAW 1165, BAW 1167, BAW 1169 and BAW 1170) under two water regimes at the Agronomy research field, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh

during Rabi season (November 2011 to March 2012) to know the phenological changes in wheat and to identify water stress tolerant wheat genotypes. Water deficit condition caused an overall reduction in all studied phenological attributes. The highest decrease in days to heading, days to physiological maturity and grain filling duration was noted in the genotype BAW 1167, and the lowest in BAW 1169, Sourav and BARI Gom 26. The maximum number of days for grain filling was recorded in the genotype BARI Gom 26, Sourav and BAW 1169, while the minimum in BAW 1167. From this experiment, it was concluded that the genotypes BARI Gom 26 and BAW 1169 are water deficit tolerant and BAW 1167 is susceptible. Similar results were also reported by various researchers that drought reduced the number of days to heading (Bayoumi *et al.* 2008, Sial *et al.* 2009, Kiliç and Yağbasanlar 2010, Khakwani *et al.* 2012a), days to maturity (Saleem *et al.* 2007, Kiliç and Yağbasanlar 2010) and grain filling period (Sial *et al.* 2009, Kiliç and Yağbasanlar 2010).

Drought decreases the seed filling duration, leading to smaller seed size (Frederick *et al.* 1991, De Souza *et al.* 1997). The correlation between yield and the mentioned phenological traits showed a marked variation under water stress (Bazzaz *et al.* 2014). A positive and significant correlation was observed between grain yield and grain filling period, while a negative and significant correlation was observed between grain yield and number of days to heading as reported by Kiliç and Yağbasanlar (2010). Likewise, the negative correlation between yield under stress and flowering date has frequently been found (Dodig *et al.* 2010).

The investigation was carried out by Esmail *et al.* (2016) to evaluate some new bread wheat genotypes under normal and water deficit conditions. One check variety (Sakha93) was grown with 25F6 bread wheat genotypes at three different locations in Egypt. Days to heading decreased significantly in almost all genotypes at all locations under stress conditions, and considerable variability among genotypes was opined. Genotypes 10, 11, 12, 13 and 24 were early flowering at all locations under normal and water stress conditions.

Drought reduced the number of days to heading (Kılıç *et al.* 1999, Bayoumi *et al.* 2008, Sial *et al.* 2009, Khakwani *et al.* 2012a), days to maturity (Kiliç and Yağbasanlar 2010, Saleem *et al.* 2007) and grain filling period (Kiliç and Yağbasanlar 2010, Sial *et al.* 2009). Drought decreases the seed filling duration, leading to smaller seed size (Frederick *et al.* 1991, De Souza *et al.* 1997).

A study was carried out by Almeselmani *et al.* (2015) under drought stress to identify drought-tolerant durum wheat lines comparing with one check variety (Douma1, the control) in the Southern part of Syria and to recognize the most important phenological parameters associated with drought tolerance. Data recorded at vegetative and anthesis stages showed that there were significant differences among the lines. Drought stress significantly reduced the vegetative and anthesis stages i.e. crops turn into maturity stage earlier due to stress.

A field experiment was carried out by Bazzaz *et al.* (2015) with 11 wheat genotypes at the research field of Agronomy Department, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh from November 2011 to March 2012 to know the morpho-phenological changes in wheat and to identify water stress tolerant wheat genotypes. They reported that the phenological traits such as days to heading, days to physiological maturity and days to grain filling duration were reduced significantly under water stress condition. The number of days to heading ranged from 66 to 70 and from 59 to 69 under non-stress and water stress conditions, respectively. The correlation between yield and phenological traits showed a marked variation under water stress. A significant positive correlation was found between grain yield under water stress condition and days to heading, days to physiological maturity as well as days to grain filling period. But under non-stress condition, no significant correlation was found between grain yield and above traits. Moreover, among the phenological traits, the days to physiological maturity showed very strong and positive correlation with grain yield which was followed by that in days to grain filling period and days to heading.

An investigation was carried out by Esmail *et al.* (2016) to evaluate some new bread wheat genotypes under normal and water deficit conditions. They found highly significant differences in some phenological traits among the genotypes. They also found that water stress reduced the days to heading and days to flowering than well watered plants at all locations.

2.4.3 Effect of drought stress on the water status of plant

Water use efficiency is considered as an important trait and controlled by several physiological mechanisms that have been associated with drought tolerance of crop plants. Relative water content (RWC) of leaves is an important character, which is directly related to soil water content (Sarker *et al.* 1999, Merah 2001). RWC indicates that the water status of cells has a significant association with yield and stress tolerance (Almeselmani *et al.* 2011a, 2011b, 2012a). Leaf RWC, which is very responsive to drought stress and is correlated with drought tolerance (Colom and Vazzana 2003), has been proposed as a better indicator of water stress than other growth or biochemical parameters (Sinclair and Ludlow 1985). Leaves, when subjected to drought, tend to exhibit large reductions in RWC and water potential, as observed by Bijanzadeh and Emam (2010), who noted that RWC decreased sharply from 92.1% in well-watered conditions to 66.7% (27.5% reduction) under drought stress.

Leaf water potential is also considered to be a reliable parameter for quantifying plant water stress response. Singh *et al.* (1990) observed significant differences in water potential among wheat genotypes under water stress. While Sinclair and Ludlow (1985) proposed that leaf relative water content was a better indicator of water status than water potential. Water stress induced reduction in leaf RWC had been reported by many researchers (Yürekli *et al.* 2001, Jiang and Huang 2002). Generally, leaf water potential decreases with stress intensity (Ashraf *et al.* 1992, Galle *et al.* 2002, Lawlor and Cronic 2002).

Hammad and Ali (2014) reported that water stress levels significantly affected the relative water content (RWC), leaf water deficit (LWD), osmotic pressure (OP) and membrane integrity (MI), and there was a gradual reduction in RWC, and mean while a gradual increase in OP and MI in leaves of wheat plants as compared with control plants. The maximum reduction in RWC reached about 15.15 but LWD, OP and MI were increased under the severe water stress (depletion 80% of available water) compared to control (depletion 50% of available water).

A field experiment was conducted by Mahamed *et al.* (2011) in Ethiopia to know the effects of soil moisture depletion on water use efficiency of bread wheat grown in semi arid conditions, and they reported that drought causes losses in tissue water content which reduce turgor pressure in cell, thereby inhibiting enlargement and division of cell causing of reduce of plant growth and dry mass accumulation. These results are in agreement with those obtained by Delfine *et al.* (2002), Mujtaba *et al.* (2007) and Maria *et al.* (2008) in wheat.

Water deficit stress significantly reduced the water status of plants of wheat varieties (Sourav, BARI Gom 25, BARI Gom 26), and the variety BARI Gom 26 showed the highest xylem exudation rate, leaf water potential, relative water content, water retention capacity followed by the variety Sourav whereas BARI Gom 25 exhibit the lowest values under water deficit condition indicating BARI Gom 26 more drought tolerant than BARI Gom 25 (Tasmina *et al.* 2016).

To determine the response of wheat varieties (Damani, Hashim-8, Gomali-8, DN-73, Zam-04 and Dera-98) under irrigated (100% field capacity) and drought stress (35% field capacity) an experiment was carried out by Khakwani *et al.* (2012a) and they revealed significant effect of water stress on leaf area and relative water content (RWC) per plant. All six wheat varieties behaved independently but significantly for mentioned traits. However, Hashim-8, Zam-04 and Damani showed the best candidates for rainfed regions, recording minimum percent reduction when grown under 35% field capacity (65% drought) in all above-mentioned traits.

The same rainfed varieties also retained higher level of RWC under water stress condition which reflects their adaptability under drought condition.

Drought stress (DS) causes a multitude of biochemical and physiological changes as a consequence of osmotic stress. The imposition of osmotic stress causes a significant decline in chemical activity of water and a loss of turgor in plant cells (Taiz and Zeiger 2002, Zhang *et al.* 2013, Yıldıztuğay *et al.* 2014). These changes, in turn, may impair nitrate assimilation by reducing nitrate reductase activity (NRA) (Zhang *et al.* 2009). Protein degradation also increases under DS due to enhanced protease hydrolysis activity. The net effect of these changes leads to reduced plant growth and/or plant death as well as reduced relative water content (RWC), the latter being an effective indicator of plant water status (Taiz and Zeiger 2002, Zhang *et al.* 2009).

Relative water content (RWC) is an appropriate index of plant water status in terms of the physiological consequences of cellular water deficit and drought stress generally induces a decrease in RWC (Cakmak 2005). Chachar *et al.* (2016) conducted a pot experiment with wheat genotypes for their early seedling and physiological performance under different water stress environments (control i.e. normal four irrigations and terminal drought). They reported that drought stress significantly influenced the osmotic potential (OP) of wheat genotypes. They reported that the genotype MSH-36 and DH-3/48 exhibited the most drought tolerance followed by, Khirman and Chakwal-86 by maintaining their osmotic potential.

Water use efficiency is considered as an important trait and controlled by several physiological mechanisms that have been associated with drought tolerance of crop plants. Bentahar (2015) investigated WUE and its components on ten durum wheat cultivars at different water regimes (95% considered as well watered treatment, 60%, 20% considered as dry treatments). The water use efficiency (WUE), total water consumption (TWC), and relative water content (RWC) significantly decreased under water deficit conditions. Genotypes that have shown high values of WUE, TWC and RWC under dry treatments could

be suggested as drought tolerant genotypes. Based on the correlations between WUE and the studied parameters may suggest some morpho-physiological traits associated with water use efficiency and drought tolerance.

Lawlor and Cornic (2002) depicted that the foliar photosynthetic rate of higher plants is known to decrease concomitant with the decrease in relative water content and leaf water potential under water deficit conditions.

Datta *et al.* (2011) tested five selected wheat varieties (K 9107, HD 2954, RAJ 4125, HUW 234 and NW 2036) under drought stress (created by preparing solution of PEG-6000 having osmotic potentials of -1.0 bars) during winter season of January to April, 2008. In order to assess the relative capability of drought tolerance water traits (water uptake by seeds, relative water content) among various parameters were studied. Drought stress significantly reduced the uptake of water in seeds and relative water content in the seedlings. Among the wheat varieties, RAJ 4125 variety was found to be mostly drought tolerant having significantly higher relative water content.

In order to assess the drought tolerance of wild wheat species a laboratory experiment was conducted Sultan *et al.* (2012) under two water regimes (stress and non-stress treatments) considering the changes in leaf relative water content (RWC) of five wild wheat species including *T. boeoticum* (YS-1L), *T. dicoccum* var. *dicoccoides* (YS-2L), *T. araraticum* (ALLT), and two cultivated varieties of *T. turgidum* ssp. *durum* (MXLK and 87341), with two well-known common wheat cultivars (SH6 and ZY1) possessing strong drought resistance and sensitiveness, respectively during 3-day water stress and 2-day recovery. Stress was induced to hydroponically grown two weeks old wheat seedlings with 20% PEG-6000. They found that stress treatment caused a much smaller decrease in the leaf RWC in YS-1L compared to the other wheat species and depicted the variety YS-1L was the most droughts tolerant among studied species having significantly higher RWC under water stress

conditions. The order of water stress tolerance of these species according to the three parameters is: YS-1L > YS-2L > SH6 > 87341 > ZY1 > MXLK > ALLT. They speculated that the observed drought stress tolerance at a cellular level was associated with the ability to accumulate high water level conservation.

Grover *et al.* (2004) reported that stress exposed plants immediately lower down relative water content in their leaves, resulting decrease in leaf water potential and osmotic potential in plants. Osmotic adjustment i.e. the active lowering of osmotic potential in response to water stress is regarded as the mechanism which significantly contributes to increase water stress resistance of plants (Morgan 1984, Blum and Sullivan 1986, Khan *et al.* 1993).

2.4.4 Effect of drought stress on the photosynthetic pigments/ chlorophyll content

Chlorophyll a and b are the most important pigments active in the photosynthetic process. In photosynthesis, antenna pigments in leaf chloroplasts absorb solar radiation, and through resonance transfer the resulting excitation is channeled to the pigments of reaction centre, which release electrons and as a result the photochemical process set in motion. Leaf chlorophyll content (for example, how it varies both, between and within species) is, therefore, a parameter of significant interest in its own right (Bojovic and Stojanovic 2005).

Chlorophyll maintenance is essential for photosynthesis under drought stress in drought-tolerant wheat genotypes (Sairam *et al.* 1998). This trait has been used successfully for screening and selecting drought-tolerant wheat cultivars (Almeselmani *et al.* 2011a, 2011b, 2012b). According to Izanloo *et al.* (2008), water deficit leads to decrease in chl concentration. Chlorophyll and carotenoid pigments are responsible for harvesting light energy that is used in producing chemical energy such as Adenosine-5'-triphosphate, ATP and Nicotinamide adenine dinucleotide phosphate-oxidase, NADPH (Taiz and Zeiger 2006). There was a marked decrease in chlorophyll and carotenoid content of hexaploid and diploid wheat subjected to drought for 10 days at 50, 60 and 70 days after sowing (Chandrasekar *et*

al. 2000). Drought increases senescence by enhancing chlorophyll degradation, nitrogen loss, and lipid peroxidation (Yang *et al.* 2001). Liu *et al.* (2006) observed marked increase in electrolyte leakage and reduction in chlorophylls a and b in wheat cultivars subjected to water stress.

SPAD value was used to ascertain the onset of senescence and chlorophyll content of leaf over time. According to Manivannan *et al.* (2007) chlorophyll is one of the major components of chloroplasts for photosynthesis which increases biomass production and grain yield (Pandey and Singh 2010).

Saeedipour (2012) reported that the SPAD value progressively increased up to 8-12 days after anthesis (DAA) under control and water deficit conditions then it was decreased in all varieties but well watered plant higher SPAD value than water stressed plant. Water deficits enhanced the senescence by accelerating loss of leaf chlorophyll and soluble proteins and the loss was more in sensitive one than tolerant one. Declined chlorophyll content from 13 to 15% in water-stressed wheat compared with well watered plants was also reported by Nikolaeva *et al.* (2010).

Chlorophyll content in leaves reflects photosynthetic activity and the yield potential of wheat plants. SPAD chlorophyll meter readings and their relationships with the grain yield of spring wheat were studied by Barutcular *et al.* (2016). Sixteen spring wheat genotypes were grown under two temperature (cool and warm) and two moisture (rain-fed and irrigated) regimes during the 2011/2012 growing season in Turkey. There were significant genotypic variations considering the SPAD values under all conditions. The SPAD values were more strongly affected by heat stress than by drought stress. These results showed that SPAD values can be used as an indicator of grain yield in spring wheat, providing that the measurements are taken at appropriate stages at each location.

Tasmina *et al.* (2016) carried out a field experiment at the research field of the Department of Agronomy of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh during November 2014 to March 2015 to assess and evaluate the physiological derivations of wheat varieties under water deficit condition. They revealed that light interception, SPAD value were significantly influenced by water regimes and water stress condition reduced the light interception and SPAD value. The wheat var. BARI Gom 26 showed the highest SPAD value, while BARI Gom 25 exhibited the lowest value. Considering the values of SPAD, BARI Gom 26 could be considered comparatively drought tolerant whereas BARI Gom 25 was susceptible one.

To find out the wheat genotypes having comparatively more drought tolerance, a field experiment was conducted by Akram *et al.* (2012) during 2005-06 and 2006-07 on 497 wheat genotypes, which were subjected to drought conditions in addition to growing under normal soil moisture conditions. Drought stress adversely affected chlorophyll content and the chlorophyll content was reduced under water stress conditions.

A field experiment was conducted by Bentahar *et al.* (2015) on ten durum wheat cultivars at different water regimes (95, 60, 20% FC) and the results revealed that chlorophyll content (CC) significantly decreased under water deficit conditions. Genotypes having higher values of CC indicated drought tolerant genotypes.

Khakwani *et al.* (2012a) conducted a field experiment under irrigated (100% field capacity) and drought stress (35% field capacity) conditions to determine the response of wheat varieties (Damani, Hashim-8, Gomal-8, DN-73, Zam-04 and Dera-98) and informed that drought stress significantly reduced the chlorophyll fluorescence and chlorophyll content. Varieties Hashim-8, Zam-04 and Damani showed the best candidates for rainfed regions, recording minimum percent reduction of chlorophyll fluorescence and chlorophyll content under water stress condition, which reflect their adaptability under drought condition.

2.4.5 Effect of drought stress on the photosynthesis

Photosynthesis, which is the basic process influencing crop productivity, is inhibited by water stress (Chaves and Oliveira 2004). The major effect of water deficiency is the closure of stomata that leads to reduced transpiration rate and a lowered internal concentration of CO₂, which in turn inhibits the *Calvin-cycle* even at moderate water deficits (Horton *et al.* 1996). The reduction in photosynthesis as a result of water stress can be attributed to both stomatal and non-stomatal limitations (Graan and Boyer 1990, Shangguan *et al.* 1999). Stomatal control of water loss has been identified as an early event in plant response to water stress under field conditions leading to limitation of carbon uptake by the leaves (Chaves 1991, Cornic and Massacci 1996). An experiment was conducted by Liu *et al.* (2016) using winter wheat cultivar to assess the effects of different levels of water stress on photosynthetic characteristics of Shijiazhuang 8 (drought resistant) and Yanmai 20 (drought sensitive) cultivars at different growth stages. The effects of four levels of soil water which were selected based on field capacity by controlling the irrigation as follows: 40-45% (severe stress), 55-60% (moderate stress), 65-70% (mild stress) and 75-80% (full irrigation). Under the severe stress treatments, some varieties showed an increase in the concentration of intercellular CO₂ (C_i), indicating an inhibition of photosynthetic activity due to non-stomatal effects. The genotypic differences in the photosynthetic response could be useful for mapping the photosynthetic traits that promote tolerance to drought. They recommend that mild water stress (65-70% water FC) be considered for irrigation scheduling in winter wheat under conditions of water limitation.

Drought decreases photosynthesis by lowering stomatal and mesophyll conductance (Flexas *et al.* 2004), or by oxidative damage of the chloroplast (Zhou *et al.* 2007). Severe drought impairs regeneration of ribulose biphosphate (RuBP) and decreases activity of ribulose 1,5-biphosphate carboxylase/oxygenase (Rubisco) resulting into lower photosynthesis (Bota *et al.* 2004).

Bentahar *et al.* (2015) investigated the effects of water stress (95% considered as well watered treatment, 60%, 20% considered as dry treatments) on 10 durum wheat cultivars and revealed that severe water stress remarkably decreased photosynthesis (Pn) due to reducing leaf area, chlorophyll content, and stomatal conductance (gs). Genotypes that have shown high values of Pn under dry treatments could be suggested as drought tolerant genotypes.

Mamnouie *et al.* (2006) conducted a field experiment with five irrigation levels (0, 25, 50, 75, and 100% crop water requirements) on six barley varieties in Karaj, Iran. They showed the significant effect of irrigation on the photochemical efficiency of photosystem II (Fv/Fm) and the other fluorescence parameters for all varieties. It was concluded that the higher Fv/Fm values under water stress conditions could possibly be the proper criteria for screening the drought tolerant barley genotypes under field or laboratory conditions.

To find out the wheat genotypes having comparatively more drought tolerance, a field experiment was conducted by Akram *et al.* (2012) during 2005-06 and 2006-07 on 497 wheat genotypes, which were subjected to drought conditions in addition to growing under normal soil moisture conditions. Screening of the genotypes was done on the basis of some net physiological parameters like photosynthetic rate, transpiration rate and photoactive radiation. They revealed that drought stress adversely affected all these parameters, which expressed significant decrease in their values. The genotypes under study, on the basis of above physiological attributes were grouped into high yielding drought sensitive, high yielding drought tolerant, low yielding drought tolerant and low yielding drought sensitive groups, employing cluster analysis. Sixteen wheat genotypes were ranked as high yielding drought tolerant out of 497, which can be successfully grown under drought conditions without substantial decrease in grain yield.

Drought stress during the flowering stage disrupts photosynthesis and the transfer of stored substances into grains, which reduces the number and weight of grains of bread wheat (Shamsi and Kobraee 2011).

To determine the response of wheat varieties (Damani, Hashim-8, Gomali-8, DN-73, Zam-04 and Dera-98) under irrigated (100% field capacity) and drought stress (35% field capacity) were studied by Khakwani *et al.* (2012a) and revealed that drought stress significantly reduced the stomatal conductance, stomatal dimension, stomatal density, leaf area and specific leaf area per plant. All varieties behaved independently but significantly for mentioned physiological traits, and Hashim-8, Zam-04 and Damani varieties showed best candidates for rainfed regions, recording minimum percent reduction when grown under 35% field capacity (65% drought) in all above-mentioned traits. The same rainfed varieties also retained higher level of stomatal conductance and RWC under water stress condition and minimum per cent reduction in stomatal dimension and stomatal density, which reflect their adaptability under drought condition.

Bentahar *et al.* (2015) investigated physiological traits of 10 durum wheat cultivars at different water regimes (95, 60 and 20% considered as well watered-control, moderate and severe dry treatments, respectively). They reported that stomatal conductance (gs) significantly decreased while leaf temperature (LT°) increased with the severity of the imposed water regimes.

Cornic (2000) opined that the decrease in RWC has been known to induce stomatal closure and thus a parallel decrease in photosynthetic rate. Thus a high degree of coregulation exists between stomatal opening and photosynthesis (Farquhar *et al.* 2001, Hubbard *et al.* 2001). Galle *et al.* (2002) characterized some drought tolerant wheat cultivars exposing them to low water potential by growth response, stomatal conductance of leaves, by changes in water relations and ion accumulation of tissues and by fluorescence induction parameters. They found two strategies of acclimation to drought stress: plants using the first strategy save tissue water content by a fast decrease of stomatal conductance, maintain pressure potential and photosynthetic activity of leaves. In the second group the closure of stomata occurs later

resulting in an intensive loss of water and a fast decrease of water potential in the leaves and tissues restore their turgor after a relatively long acclimation phase.

2.4.6 Effect of drought stress on canopy temperature depression

Canopy temperature depression (CTD) has been considered a reliable tool to assess drought tolerance in crop plants. It is a difference between air temperature and leaf temperature, and the higher the CTD value more will be the stress tolerance. There was a significant association between CTD and yield of wheat bulks grown under the drought conditions (Reynolds *et al.* 2005). However, in the field, leaf and air temperature should be measured on a clear and sunny day and the best time to measure CTD was proposed as 0900, 1300, and 1800 h (Balota *et al.* 2007).

A field experiment comprised two water regimes (irrigated or control and water stress) with three wheat varieties (BARI Gom 25, BARI Gom 26 and Sourav) at the research field of the Department of Agronomy of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur during November 2014 to March 2015 were carried out by Tasmina *et al.* (2016) to know the action of canopy temperature (CT). They revealed that water stress condition significantly increased the CT in all varieties. The wheat var. BARI Gom 26 showed the lowest CT while BARI Gom 25 showed the highest CT value. BARI Gom 26 could be considered comparatively drought tolerant providing lower CT, whereas BARI Gom 25 was susceptible one increasing higher CT.

Bentahar *et al.* (2015) grown ten durum wheat cultivars under different water regimes (95% considered as well watered treatment, 60%, 20% considered as dry treatments) and revealed that leaf temperature (LT°) was positively influenced by the severity of the water regime imposed. They also noticed that genotypes that have shown high values of LT° under dry treatments could be suggested as drought tolerant genotypes.

Mamnouie *et al.* (2006) grown six barley varieties under five irrigation levels (0, 25, 50, 75, and 100% crop water requirements) in Iran, and they reported that canopy temperature significantly increased with increasing water deficit stresses. They also concluded that the higher canopy temperature (less negative ΔT) under well irrigated conditions and higher Fv/Fm values under water stress conditions could possibly be the proper criteria for screening the drought tolerant barley genotypes under field.

2.4.7 Effect of drought stress on cell membrane stability (CMS)

The cell membrane is one of the first targets of plant stress and the ability of plants to maintain membrane integrity under drought determines a plant's tolerance towards drought (Ahmadizadeh 2013). Electrolyte leakage is also correlated with drought tolerance (Ahmadizadeh *et al.* 2011). Leakage is due to increasing damage to cell membranes (Almeselmani *et al.* 2013), which emphasizes the importance of membrane stability index (MSI) in discriminating drought-tolerant from drought-susceptible lines. Increased electrolyte leakage indicates mechanical strain on membranes under severe drought (Chaves and Oliveira 2004). A plant's drought tolerance strategy may be associated with the integrity of the cell membrane preservation and its rapid reparation while cell and organelle membranes are primary sites for desiccation injury (Gechev *et al.* 2012).

Almeselmani *et al.* (2015) conducted a field experiment with ten Mexican durum wheat (*Triticum durum* Desf.) lines under water stress conditions in Syria, and reported that water stress reduced the cell membrane stability than the control as well as Line 1 (Sora/2*Plata) performed best in terms of the membrane stability index, showing better yield and higher total plant biomass comparing other lines indicating most tolerant lines.

El Basyoni *et al.* (2017) conducted a laboratory experiment on spring wheat genotypes under heat and osmotic pressure (PEG 600) in Egypt to assess stress tolerance by measuring cell membrane stability (CMS). The results indicated highly significant differences among 2111 spring wheat accessions regarding CMS, and the CMS reduced under stress conditions. Moreover, several SNPs were found to be significantly linked with CMS. Thus, the identified

membrane-stable accessions could be used as parental genotypes in breeding programs for heat or drought stress tolerance.

Several physiological sub-traits were used to study the effect of terminal drought and heat stress on wheat production i.e., total biomass, remobilization of stored assimilates, root characteristics, osmotic adjustment, and CMS (Beltrano and Ronco 2008, Tardieu *et al.* 2012, Cobb *et al.* 2013, Iqbal *et al.* 2017). Cell membrane stability (CMS) is one of the sub-traits that have been used to study drought and heat stress and subsequently select tolerant genotypes (Saadalla *et al.* 1990, Öztürk *et al.* 2016).

Several researchers used the effect of PEG on the CMS as an early selection step to select the most promising drought- and stress-tolerant genotypes (Mickky and Aldesuquy 2017). Cell membrane stability was found to be a quantitative trait that was moderately heritable (Hemantaranjan, 2014), with a high genetic correlation with grain yield (Ali *et al.* 2009, Asif and Kamran 2011), and that a small number of genes control a large portion of the variation in the cell membrane permeability (Talukder *et al.* 2014).

The research work was carried out by Bajji *et al.* (2002) to adapt the electrolyte leakage technique to durum wheat and then to evaluate its relevance in the assessment of the cell membrane stability as a mechanism of water stress tolerance based on *in vitro* desiccation of leaf tissues by a solution of polyethylene glycol (PEG) and a subsequent measurement of electrolyte leakage into deionised water. Electrolyte leakage exhibited a characteristic pattern reflecting the condition of cellular membranes (repair and hardening). The extent of the cell membrane damage not only correlated well with the growth responses of wheat seedlings belonging to various cultivars to withholding water but also with the recognized field performances of these cultivars.

Screening for drought stress tolerance under field conditions requires considerable resources and suitable environmental conditions for effective and accurate phenotypic performance that can be used to distinguish tolerant genotypes. Researchers tend to break down stress tolerance

into series of measurable sub-traits to improve tolerance. Several physiological sub-traits were used to study the effect of drought stress on wheat production, and cell membrane stability (CMS) is one of the sub-traits that have been used to study drought stress and subsequently select tolerant genotypes (Öztürk *et al.* 2016).

2.4.8 Impact of drought on wheat growth and development

2.4.8.1 Germination to emergence (E)

Wheat seeds are usually stored at around 12% moisture content by weight. Seed germinates when the amount of water in grain reaches at least 35-45% of dry weight (Evans *et al.* 1975). Thus, early drought at wheat growing season adversely affects germination and crop establishment.

2.4.8.2 Emergence to double ridge (GS1)

Drought during GS1 (growth stage 1) decreases leaf area in wheat (Giunta *et al.* 1995, Royo 2004). Leaf expansion is the most sensitive trait to drought at this stage. When drought occurs, cells lose turgidity, cell walls shrink, which subsequently decreases turgor-dependent activities like leaf expansion and root elongation (Taiz and Zeiger 2006). At this stage, drought also increases phyllochron in wheat (Simane *et al.* 1993). Tillering is another trait affected by drought at this stage (Blum *et al.* 1990). Thus, drought during this stage can decrease relative water content, leaf area and biomass production (Giunta *et al.* 1995, Hafid *et al.* 1998, Dulai *et al.* 2006, Liu *et al.* 2006).

2.4.8.3 Double ridge to anthesis (GS2)

As leaves, stem, and roots keep on growing at growth stage 2, drought adversely affects their growth as explained above. In wheat, up to 20% grain-weight is derived from the reallocation of stem reserves under favorable conditions (Gebbing *et al.* 1999). Stem reserves may account for up to 50% of grain weight under post anthesis drought stress (van Herwaarden *et al.* 1998). Thus, drought at pre-anthesis decreases grain yield by adversely affecting photosynthesis leading to decreased accumulation of stem reserves (water soluble

carbohydrates). Ehdaie *et al.* (2006) showed up to 23% decrease in the main stem weight when wheat was subjected to drought stress. The main sensitive trait to drought stress at this stage is spikelet number spike⁻¹ (Oosterhuis and Cartwright 1983, Moustafa *et al.* 1996, Sangtarash 2010), and the premature death of more distal and basal florets also occurs at this stage under drought (Oosterhuis and Cartwright 1983). As a result, grain number decreases drastically when drought occurs at this stage.

Again, drought stress at early stages of reproductive development (meiosis in pollen mother cells) induces pollen sterility, leading to lower grain numbers (Saini and Aspinall 1981, Ji *et al.* 2010). Lalonde *et al.* (1997) reported water stress induced male sterility in wheat through abnormal vacuolization of tapetal cells, disorientation of reproductive cells, and the lack of starch and intine in pollen grains. It was also observed that desiccation of the sporogenous tissue had not yet occurred at the onset of male sterility, suggesting a decrease in water potential somewhere else in the plant (Saini and Aspinall 1981).

Pollen grains accumulate starch that they use later on for germination and pollen tube growth (Clément *et al.* 1994). The high male sterility leading to a decrease in grain-set may be due to impaired starch accumulation in pollen grains. Sheoran and Saini (1996) reported that reduced starch accumulation in rice pollen grains was due to arrested activities of acid invertase and soluble starch synthase. Dorion (1996) suggested that in addition to reduced acid invertase activities, inability to convert sucrose to hexose might be another reason for reduced starch accumulation in pollen grains. Drought significantly increased reactive oxygen species in rice spikelets of drought susceptible variety as compared to the resistant variety and the resistant variety had enhanced antioxidant (superoxide dismutase, ascorbate, and glutathione) activities and reduced percentage of spikelet sterility (Selote and Khanna-Chopra 2004). Water deficit at meiosis down regulates transcription of vacuolar (*Ivr5*) and cell-wall (*Ivr1*) encoding genes, resulting into reduced activities of vacuolar and cell-wall

invertases of anthers long before the failure of pollen development in wheat, which decreased grain-set substantially (Koonjul *et al.* 2005).

2.4.8.4 Anthesis to maturity (GS3)

Drought during the flowering stage (growth stage 3) decreases grain-set in almost all field crops. It may be due to lower fertilization caused by pollen sterility and/or ovule abortion. Nicolas *et al.* (1985) observed 16% more sterility in the top spikelets of the wheat cultivar ‘Warigal’ when drought was imposed at anthesis. Similarly, Sangtarash (2010) documented higher decline in the grain number when drought occurred at or immediately after anthesis. Fábíán *et al.* (2011) reported seed abortion in winter wheat varieties when drought was applied at 5-9 d after anthesis. Seed abortion was higher in the drought sensitive cultivar ‘Cappelle Desprez’ than in the tolerant cultivar ‘Plainsman V’.

Drought stress during post-anthesis decreases grain yield by decreasing individual grain weight (Ahmadi and Baker 2001, Ji *et al.* 2010). The decrease in individual grain weight may be due to lower grain filling duration (Wardlaw and Willenbrink 2000, Prasad *et al.* 2008b) and a decreased number of endosperm cells and starch granules per cell (Nicolas *et al.* 1985). Wardlaw and Willenbrink (2000) recorded 38% decline in individual grain weight of the wheat cultivar ‘Lyalpur 73’ subjected to drought during anthesis; and Ahmadi and Baker (2001) observed 43% decline in cultivar ‘Cadenza’ subjected to severe drought from 15 d after anthesis. Jatoi *et al.* (2011) depicted that the number of grains, grain yield, biological yield and harvest index of spring wheat genotypes decreased when water stress was imposed at the anthesis stage.

2.4.9 Impact of drought on yield traits and yield

In wheat, grain yield is the function of the number of plants ha^{-1} , the number of fertile tillers plant^{-1} , the number of grains spike^{-1} , and individual grain weight. Factors that affect one of these components directly or indirectly will affect the grain yield. Drought adversely affects

these components as described above resulting into a marked decline in grain yield. Drought decreased grain yield spike⁻¹ by about 70% when stress was applied during early seed development in spring wheat cultivars ‘Cappelle Desprez’ and ‘Plainsman V’ (Fábián *et al.* 2011). There was about 40% decline in average grain yield ha⁻¹, when drought stress was imposed on 30 wheat cultivars and 21 landraces from tillering to maturity by installing mobile roofs (Denčić *et al.* 2000). Fischer and Maurer (1978) reported a decrease in average grain yield by 37 to 86%, when durum wheats, triticales, barley and bread wheat were subjected to drought by withholding irrigation at various stages before the anthesis. The effect of drought on Chinese’s wheat, as alerted by FAO in February 2011 and mentioned above was on plant stand and number of fertile tillers plant⁻¹, because Chinese’s wheat growing areas were facing severe early season drought. In Kansas of the USA, drought at GS2 and GS3 stages is the frequent phenomenon resulting in wheat yield loss.

Tasmina *et al.* (2016) carried out a field experiment comprising two water regimes (irrigated or control and water stress) with three wheat varieties (BARI Gom 25, BARI Gom 26 and Sourav) at the research field of the Department of Agronomy of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur during November 2014 to March 2015 to assess and evaluate the agronomical derivations. They revealed that yield and yield traits were reduced under water deficit conditions in all the varieties and the performance can be ranked as BARI Gom 26 > Sourav > BARI Gom 25.

The investigation was done by Mirzaei *et al.* (2011) in order to study the response of grain yield and yield components of bread wheat cultivars to drought stress in western Iran in 2008-2009. Four levels of drought stress (full irrigation, stress at early stem elongation, flowering and grain filling stages) were applied on three wheat cultivars (Chamran, Dez, and Verinak). The results indicated that drought stress at all growth stages reduced grain yield and yield components. Drought stress at stages of stem elongation, flowering and grain filling

stages induced 32, 32 and 35% reduction in grain yield, respectively. Stress at stem elongation stage had the highest sensitivity than other growth stages. They recommended the cultivar *Verinakas* the most drought tolerant cultivar for western Iran.

Khakwani *et al.* (2012a) grown wheat varieties (Damani, Hashim-8, Gomali-8, DN-73, Zam-04 and Dera-98) under irrigated (100% field capacity) and drought stress (35% field capacity) and reported that drought stress significantly reduced the yield and yield traits of all varieties. However, Hashim-8, Zam-04 and Damani showed best candidates for rainfed regions, recording minimum percent reduction of yield when grown under 35% field capacity (65% drought).

Mahamed *et al.* (2011) conducted a field experiment in Ethiopia to know the effects of soil moisture depletion at different growth stages on the yield of bread wheat grown in semi arid conditions and reported that drought causes losses in tissue water content which reduce turgor pressure in cell, thereby inhibiting enlargement and division of cell causing of reduce of plant growth and dry mass accumulation and finally reduced grain yield. These results are in agreement with those obtained by Delfine *et al.* (2002), Mujtaba *et al.* (2007) and Maria *et al.* (2008) in wheat.

Mirbahar *et al.* (2009) carried out field experiments to study the effect of different water stresses applied at different crop development stages on the yield and yield components of 25 wheat varieties. They used five water stress treatments i.e. T₁ (control), T₂ (post-flowering drought), T₃ (Pre-flowering drought), T₄ (Tillering stage drought) and T₅ (terminal drought). Water stress significantly reduced the plant height, spike length, spikelets per spike, grains per spike and 1000-grain weight of all 25 wheat varieties. The highest reduction in all parameters was found in T₅, while T₂ and T₃ affected the 1000-grain weight significantly. The varieties Sarsabz and Kiran-95 showed significantly good performance than other wheat varieties in control as well as at terminal drought stress.

Nohong and Nompo (2015) conducted a greenhouse experiment at Hasanuddin University, Makassar, Indonesia to investigate the effect of water stress treatments (W_0 = Field capacity (FC), no water stress), W_1 (50% FC, for 1 week), W_2 (50% FC, for 2 weeks), and W_3 (50% FC, for 3 weeks) on growth and yield of two grass species (Signal grass and Napier grass). They showed that increasing water stress duration induced reduction in plant height, number of tillers, and dry matter yield. Signal grass species had the highest number of tiller compare to Napier grass species, while Napier grass species was higher in plant height and yield. This indicates variation between the two species grass in growth, yield, and could be altered by duration of water stress.

The experiment was conducted by Bazzaz *et al.* (2014) with eleven wheat genotypes at the research field of the Department of Agronomy of the Bangabandhu Sheikh Mujibur Rahman Agricultural University from November 2011 to March 2012 to find out the drought tolerant wheat genotypes under water deficit condition. From this experiment, it was found that water deficit condition severely reduced the plant height, number of effective tillers m^{-2} , spike length, number of spikelets $spike^{-1}$, number of grains $spike^{-1}$, thousand grains weight and grain yield. Based on the percentage of yield reduction, the genotypes BARI Gom 26, Sourav, BAW 1169 and BAW 1158 were categorized in tolerant group exhibited low yield reduction (<30%) and the genotypes Seri, Pavon, BAW 1166, BAW 1167, BAW 1171 and BAW 1173 were ranked in susceptible group due to very low yielding ability with high yield reduction which ranged from 50.01% to 59.17% in water deficit condition.

The experiment was conducted by Bazzaz *et al.* (2015) with thirty-five wheat genotypes at the research field of the Department of Agronomy of the Bangabandhu Sheikh Mujibur Rahman Agricultural University from November 2011 to March 2012 to find out the drought tolerant wheat genotypes under water deficit condition. The highest mean productivity, geometric mean productivity and stress tolerance index values were recorded in the

genotypes BARI Gom 26, BAW 1158, Sourav, BAW 1169 and BAW 1170. They also revealed that BARI Gom 26, BAW 1158, Sourav, BAW 1169 and BAW 1170 were more capable to tolerate water deficit condition.

To find out the wheat genotypes having comparatively more drought tolerance, a field experiment was conducted by Akram *et al.* (2012) on 497 wheat genotypes, which were subjected to drought conditions in addition to grow under normal soil moisture conditions. Drought stress adversely affected plant height, productive tillers, grains per spike, 1000-grain weight, biological yield, grain yield per plant and harvest index, which expressed significant decrease in their values. The genotypes under study, on the basis of yield attributes and yield were grouped into high yielding drought sensitive, high yielding drought tolerant, low yielding drought tolerant and low yielding drought sensitive groups, employing cluster analysis.

The investigation was carried out by Esmail *et al.* (2016) to evaluate some new bread wheat genotypes under normal and water deficit conditions. Bread wheat of 25F6 genotypes and one check variety (Sakha93) were grown at three different locations (Menofiya, Kalubia and Beheira) in Egypt. They studied many agronomic traits such as flag leaf area (cm²), plant height (cm), number of spikes/plant, spike length (cm), 100 kernel weight (gm), grain yield/plant (gm), harvest index and biological yield / plant and reported that water deficit condition reduced remarkably of the mentioned traits and yield. The results revealed highly significant differences among the genotypes for all characters indicating the presence of considerable variability among them. Genotypes 10,11,12,13 and 24 were early flowering at all locations under normal and water stress conditions. Genotypes 7, 2, 1, 9 and 3 gave the highest performance for no. of spikes/plant. The best selected genotypes for grain yield were 5, 12, 18, 20, 21 and 22 which exhibited high grain yield under spray irrigation at Nubaria.

Duggan and Fowler (2006) conducted a field experiment under water deficit conditions and observed large differences in kernels/spikelet and kernel weight which indicated that these two variables were responsible for yield adjustments to stress during spikelet and kernel development phase. Baser *et al.* (2004) studied the effect of water stress on the yield and yield components of winter wheat and found a decrease of about 40% in yield under water stressed conditions as compared to control. Weight of grains/spike was reported by many researchers as the most closely linked variable related to grain yield per unit area and was often used in selecting high yielding wheat strains (Kumbhar *et al.* 1983). The 1000-grain weight had also been shown as the main yield component accounting for 20% of variation in wheat grain yield (Collaku 1989). Less decrease in wheat yield under water stress is usually observed in water stress tolerant cultivars as compared to sensitive ones (Gáspár *et al.* 2005, Khakwani *et al.* 2011a).

2.4.10 Impact of drought stress on the compatible solutes

Six wheat genotypes (Khirman, Chakwal-86, MSH-36, DH-3/48, NIA Amber and NIA-10 10/8) were tested by Chachar *et al.* (2016) in pot experiment for their early seedling and physiological performance under different water stress environments (control and terminal drought). Drought stress significantly influenced the physiological indices, including proline content, glycine-betaine, total sugars, total chlorophyll, nitrate reductase activity (NRA), potassium (K^+) content, and osmotic potential (OP) of wheat genotypes. They reported that the genotype MSH-36 and DH-3/48 exhibited the tolerance followed by, Khirman and Chakwal-86 by maintaining their osmotic potential and accumulation of higher proline and glycine-betaine content that helpful for plant to enhancing their tolerance under water stress and to maintain their growth and development, whereas NIA Amber and NIA-10 10/8 are the drought sensitive genotypes as they could not maintain their osmotic potential under drought stress environment.

The effect of water stress treatments (W_0 = Field capacity (FC), no water stress), W_1 (50% FC, for 1 week), W_2 (50% FC, for 2 weeks), and W_3 (50% FC, for 3 weeks) on proline, and total soluble sugars contents of two grass species (Signal grass and Napier grass) were studied by Nohong and Nompo (2015) through a greenhouse experiment at Hasan uddin University, Makassar, Indonesia. They showed that prolonged water stress led to increase in the proline and soluble sugars both grass species. Signal grass species had the higher proline content than Napier grass, while Napier grass species produced higher soluble sugar contents.

To evaluate the response of proline and soluble sugars content, catalase (CAT) and ascorbate peroxidase (APX) activity in wheat leaves to different irrigation regimes at two growth stages, a greenhouse factorial experiment was conducted by Nazarli and Faraji (2011). The factors consisted of four different irrigation regimes as 100% (I_0), 75% (I_1), 50% (I_2) and 25% (I_3) of field capacity and growth stages: 50% emergence to booting stage (GS_1) and booting stage to physiological maturity (GS_2). According to the results they showed that irrigation regimes had significant effect on proline content, soluble sugars and APX activity, but no significant differences were detected among irrigation regimes for catalase (CAT) activity. Limited irrigation increased proline concentration and total soluble sugars in leaves. None of studied traits were affected by growth stages. Interaction between irrigation regimes and growth stages was not significant for all studied traits. Results indicated that the highest proline content, total soluble sugars and APX activity were related to irrigation at 25% of field capacity (I_3). They also concluded that proline and soluble sugar levels were increased in wheat leaves under deficit irrigation regimes.

The effect of water deficit on carbohydrate status and enzymes of carbohydrate metabolism (α and β amylases, sucrose phosphate synthase, sucrose synthase, acid and alkaline invertases) in wheat was investigated by Kaur *et al.* (2007) in the seedlings of drought-sensitive (PBW 343) and drought-tolerant (C 306) cultivars. The water deficit was induced by

adding 6% mannitol (water potential -0.815 Mpa) in the growth medium. The water deficit reduced starch content in the shoots of tolerant seedlings as compared to the sensitive ones, but increased sucrose content in the shoots and roots of tolerant seedlings, indicating their protective role during stress conditions. It also decreased the α -amylase activity in the endosperm of seedlings of both the cultivars, but increased α and β amylase activities in the shoots of tolerant ones. Sucrose phosphate synthase (SPS) activity showed a significant increase at 6 days of seedling growth (DSG) in the shoots of stressed seedlings of tolerant cultivar. However, SPS activity in the roots of stressed seedlings of sensitive cultivar was very low at 4 DSG and appeared significantly only at day 6. Sucrose synthase (SS) activity was lower in the shoots and roots of stressed seedlings of tolerant cultivar than sensitive ones at early stage of seedling growth. Higher acid invertase activity in the shoots of seedlings of tolerant cultivar appeared to be a unique characteristic of this cultivar for stress tolerance. Alkaline invertase activity, although affected under water deficit conditions, but was too low as compared to acid invertase activity to cause any significant affect on sucrose hydrolysis. In conclusion, higher sucrose content with high SPS and low acid invertase and SS activities in the roots under water deficit conditions could be responsible for drought tolerance of C 306.

Sultan *et al.* (2012) carried out a laboratory experiment of five wild wheat species including *T. boeoticum* (YS-1L), *T. dicoccum* var. *dicoccoides* (YS-2L), *T. araraticum* (ALLT), and two cultivated varieties of *T. turgidum* ssp. *durum* (MXLK and 87341), with two well-known common wheat cultivars (SH6 and ZY1) under two water regimes (stress and non-stress treatments) during 3-day water stress and 2-day recovery in order to assess the drought tolerance (drought resistance and sensitiveness) of these wild wheat species taking into account the changes in freeproline content, and malondialdehyde (MDA) accumulation. Stress was induced to hydroponically grown two weeks old wheat seedlings with 20% PEG-6000 and the stress treatment caused a rise in MDA content in YS-1L compared to the other wheat species. They also reported that YS-1L was the most drought tolerant among studied

species having significantly higher proline while lower MDA content under water stress conditions. The order of water stress tolerance of these species according to the three parameters is: YS-1L > YS-2L > SH6 > 87341 > ZY1 > MXLK > ALLT. They speculated that the observed drought stress tolerance at a cellular level was associated with the ability to accumulate proline and high water level conservation.

Osmoregulation is one of the mechanisms that plants use to combat the detrimental effects of water loss by synthesizing compatible solutes, typically certain polyols, sugars, amino acids, betaines and related compounds (Bohnert *et al.* 1996, Ramanjulu and Bartels 2002). Accumulation of proline under stress in many plant species has been correlated with stress tolerance, and its concentration has been known to be usually higher in stress tolerant than in stress-sensitive plants (Ashraf and Foolad 2007). Proline not only acts as an osmolyte but it also contributes in stabilizing subcellular structures (e.g. membranes and proteins), scavenging free radicals, and buffering cellular redox potential under stress conditions. It may also functions as a protein compatible hydrotrope (Srinivas and Balasubramanian 1995), alleviating cytoplasmic acidosis, and maintaining appropriate $\text{NADP}^+/\text{NADPH}$ ratios compatible with metabolism (Hare and Cress 1997). Moreover, upon relief from stress rapid catabolism of proline may provide sufficient reducing agents that support mitochondrial oxidative phosphorylation and generation of ATP for recovery from stress and repairing of stress induced damages (Hare and Cress 1997, Hare *et al.* 1998).

The naturally occurring quaternary ammonium compound, glycine betaine (GB), has received attention as a compatible solute that may aid in water stress tolerance by allowing maintenance of turgor pressure (Makela *et al.* 1999). The GB not only acts as an osmoregulator, but also stabilizes the structures and activities of enzymes and protein complexes, and maintains the integrity of membranes against the damaging effects of different abiotic stresses (Sakamoto and Murata 2002). The GB also protects physiological

processes such as photosynthesis and protein synthesis from the results of water deficit and other stresses (Gibson *et al.* 1984, Larher *et al.* 1996). The GB is known to accumulate in response to stresses in many crop plants, including sugar beet (*Beta vulgaris*), spinach (*Spinacia oleracea*), barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), and sorghum (*Sorghum bicolor*) (McCue and Hanson 1990, Rhodes and Hanson 1993, Yang *et al.* 2003). In these species, tolerant genotypes generally accumulate more GB than sensitive genotypes in response to stress.

2.5 Alleviation of drought stress through K

It is reported in several studies that K plays a vital role in improving the plant resistance in many ways such as K regularizes physiological processes like photosynthesis, translocation of cations into sink organs, regulation of turgor pressure and enzymes activation (Mengel and Kirkby 2001), plant suffering from drought stress required more internal K (Cakmak 2005), low grain yield resulting from water deficit could be overcome by increasing K supply (Damon and Rengel 2007). During stress condition, ROS (reactive oxygen species) formation was induced and oxidative damage to cells occurred and requirement for K was increased (Foyer *et al.* 2002). This enhanced need for K by plants suffering from drought stress showed that K is required for photosynthetic and CO₂ fixation, because water deficit caused stomatal closure and decreased the CO₂ fixation. By the studies of Jiang and Zhang (2002) it is documented that the impairment in photosynthesis increased the ROS production and carbohydrate metabolism was also disturbed. Mengel and Kirkby (2001) observed that due to low K concentration, ROS production was induced during water deficit which caused disturbance in stomatal opening. In legumes damaging effects of drought can be diminished by ample K supply (Sangakkara *et al.* 2000).

Aown *et al.* (2012) carried out experiment during 2008-09 in pots (wire house) at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan to find out the response of

wheat (*Triticum aestivum* L.) cultivars (Lasani-2008, Auqab-2000) to foliar application of 1% potassium at different growth stages (tillering, flower initiation and milking) under water limited environment. They found that foliar application of K at all three critical growth stages improved the drought tolerance of plants and improved the growth and yield components, however, grain filling stage was found more responsive.

A study was conducted by Imanparast *et al.* (2013) to evaluate potassium humate effects on the primary growth of three varieties of wheat (Azar2, Gascogen and Sardari) under four water conditions (Normal, normal with potassium humate, stress and stress with potassium humate) in the Villkage greenhouse during 2012 in Ardabil, Iran. Results showed that (except seedling weight,) growth traits like seedling length, leaf sum lengths, leaf width, leaf area index, seedling dry weight and root dry weight significantly reduced under water stress condition. Application potassium remarkably increased the values of those mentioned traits.

It is reported that drought stress significantly reduces the cell membrane stability. The maintenance of membrane integrity and stability under drought stress is also essential for plant drought tolerance (Bajji *et al.* 2002). In a study by Premachandra *et al.* (1991), maize plants with higher K applications showed greater adaptation to water stress. This improvement was mainly attributed to the role of K in improving cell membrane stability and osmotic adjustment ability. An adequate K supply is essential for enhancing drought resistance by increasing root elongation and maintaining cell membrane stability.

Drought is a common stress limiting crops growth and it may increase cellular membrane permeability, resulting in K outflow. Internal K starvation may disorder plant metabolism and limit plant growth. Regarding this issue a hydroponic experiment was carried out in a non-controlled greenhouse at Beijing, PR China by Wei *et al.* (2013). Seedlings of SN16 and JM22 were simultaneously treated by five levels of K₂CO₃ (0, 2.5, 5, 7.5, 10 mM) and two levels of PEG 6000 (0, 20%) for 7 days. External K₂CO₃ significantly increased shoot K⁺

content, water potential, chlorophyll content as well as gas exchange, but decreased electrolyte leakage and MDA content in both cultivars under PEG 6000 stress. Antioxidant enzymes activities were up-regulated by PEG 6000 while external K_2CO_3 reduced those changes. Shoot and root biomass were also increased by K_2CO_3 supply under drought stress and the variety SN16 was better than JM22 due to its high drought tolerance. Adequate external K may effectively protect winter wheat from drought injuries and adequate external K supply may be a promising strategy for better growth in arid and semi-arid regions.

Fayez and Bazaid (2013) conducted a pot experiment at greenhouse condition, Taif University, KSA for evaluation of growth and physiological activities of barley (*Hordeum vulgare* L. cv. Gustoe) to recognize the ameliorative role of KNO_3 against the negative effects of water deficit stresses. They concluded that the addition of KNO_3 can ameliorate the oxidative stress in barley stressed plants. This ameliorative effect might be maintained through low MDA (malondialdehyde) contents and decreased Na^+/K^+ ratio in leaves. This study also provided evidence for the ability of barley cultivation in water deficit soils due to its capacity for osmotic adjustment.

Shabbir *et al.* (2015) conducted a field experiment to investigate the effects of supplemental foliar nitrogen (N), phosphorous (P) and potassium (K) spray, alone or in various combinations, on physiological processes and nutrients uptake in wheat under water deficit conditions. The results revealed that limited water supply significantly reduced germination, growth and uptake of N, P and K. Supplemental foliar fertilization of these macronutrients alone or in different combinations significantly improved the water relations, gas exchange characteristics and nutrient contents in both the genotypes. Bhakkar-2002 maintained higher turgor, net CO_2 assimilation rate (P_n), transpiration rate (E), stomatal conductance (g_s) and accumulated more N, P and K in shoot than Shafaq-2006. The foliar spray of NPK in combination was effective in improving wheat growth under both well-watered and water-deficit conditions.

The role of potassium (K) in mitigating the adverse effects of drought stress (DS) on the two maize (*Zea mays* L.) cultivars, ‘Shaandan 9’ (drought-tolerant) and ‘Shaandan 911’ (drought-sensitive), was assessed by Zhang *et al.* (2014). K application increased dry matter (DM) across all growth stages and grain yield (GY) in both cultivars under DS, but not under control conditions. Drought tolerant cultivar Shaandan 9 was superior to drought-sensitive cultivar Shaandan 911 under DS in terms of DM and GY regardless of K addition. Additionally, K application increased relative water content, nitrate reductase activity, and concentrations of potassium ion, free proline, soluble protein, and endogenous glycine betaine in both the cultivars. In contrast, the differences in the above parameters between K-treated plants and plants under control conditions were either non-significant or marginal. This study provides direct evidence of the beneficial physiological function of K fertilization in mitigating the adverse effects of DS by increased nitrate assimilation and osmotic regulation, but not due to its nutritive role.

The physiological and nutrient uptake performance of wheat cultivars (Lasani-2008 and Auqab-2000) to foliar application of 1% potassium (K) at three different growth stages (tillering, flower initiation and grain filling) was investigated by Raza *et al.* (2013) under water limited environment in a wire house experiment at the Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan. They reported that the drought stress at all three critical growth stages of wheat adversely affected plant’s nutrient uptake, water potential, osmotic potential and turgor potential of wheat plants. The exogenous application of K under drought stress at all three critical growth stages enhanced tolerance of wheat by reducing toxic nutrient’s uptake and improving the physiological efficiency. In this regards, maximum improvement in all the recorded nutrients uptake and physiological parameters was achieved when K was applied at grain filling stage of both the cultivars.

K is the most abundant cation in plants and Pettigrew (2008) has been shown a strong positive relationship between K fertilizer and grain yield of wheat, maize and soybean. Under

drought stress condition, K plays essential roles in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance and resists drought stress (Marschner 2012).

Water deficit has strong damaging effect on the plants and it reduced the uptake of P and Ca by plants. More reduced P and Ca uptake was recorded (62 and 34%, respectively) in the plants where drought was created at flower initiation and at tillering stage, respectively. Water stress has the adverse effect on P uptake; P uptake decreased with decreasing soil moisture in wheat genotypes (Ashraf *et al.* 1998) and same response was reported by Turner (1985) in pepper. Foliar application of K ameliorated the adverse effect of drought on plants and improved the uptake of P by 36% and Ca by 18% in plants under water deficit at grain filling stage.

Aslam *et al.* (2013) reported that drought stress have deleterious effects on the seedling establishment, vegetative growth, photosynthesis, root growth, anthesis, anthesis-silking interval, pollination and grain formation in maize crop and these deleterious effects can be mediated by the application of nutrients such as potassium in maize plant under drought stress.

An experiment was conducted by Malek-Mohammadi *et al.* (2013) in the fall of 2011 in Dehloran region, Iran to study the effect of potassium sulfate and zinc fertilizers on wheat drought resistance under water stress conditions. Potassium fertilizer concentrations of zero, 60, 120 and 180 kg ha⁻¹ as potassium sulfate source and zinc concentrations of zero and 25 kg ha⁻¹ as zinc sulfate source were applied under normal irrigation and water stressed plots of wheat crop. The results showed that potash fertilizer had a positive effect on most traits.

Baque *et al.* (2006) conducted an experiment to find out the effects of three levels of potassium (low, medium and high) and three levels of soil moisture (control, mild and severe water stress) on wheat. They found that water stress affected dry matter production in leaf,

stem, spike and root significantly. The uptake of N, P and K was lowered by the water stress. Consequently, most of the yield contributing characters as well as grain yield was reduced substantially. High level of K improved the dry matter production in different plant parts. Yield and yield contributing characters of wheat were also improved due to high level of K application. Uptake of N, P and K was also enhanced with the increasing levels of K especially under water stress conditions. Lindhauer (1989) reported that potassium imparts a beneficial effect on plants to overcome soil moisture stress. Relative water content was decreased under moisture stress condition in wheat genotypes compared with normal irrigation. Spraying potassium iodide enhanced relative water content especially under moisture stress condition.

Premachandra *et al.* (1993) noticed that application of potassium fertilizer under water stress condition increased osmotic adjustment of maize cultivars. This was mainly due to net increase in intercellular solutes as a result of high potassium fertilization.

Plant height of wheat was reduced under moisture deficit condition as reported by Siddique *et al.* (1999) and Jamal *et al.* (1996). External application of potassium increased plant height under water stress condition by maintaining stomatal movement, net photosynthesis and the efficiency of CO₂ assimilation (Usherwood 1985).

Mohammadi *et al.* (2013) conducted a field experiment on wheat with and without K, Zn and irrigation treatments and reported that K as potassium sulfate significantly increased the grain yield of wheat.

CHAPTER III

Experiment I: EVALUATION OF WHEAT GENOTYPES UNDER POLYETHYLENE GLYCOL (PEG) INDUCED WATER DEFICIT STRESS DURING GERMINATION AND EARLY SEEDLING GROWTH

INTRODUCTION

The most threatening problem in wheat production is the shortage of water at the seedling stage, mid season water stress, terminal stress or a combination of any two or three. Various factors affect the yield of a crop like seed germination, seedling vigour, growth rate, and mean emergence time and desiccation tolerance (Noorka *et al.* 2007).

Evaluation of crop tolerance to environmental stresses during seed germination and seedling emergence is a main measure to choose them for cropping in different circumstances. Since, common investigations in field conditions are time consuming and influenced by many companion variables of soil, climate and agricultural practices, so fast and precise evaluation of crop response to stress would be achieved using an experiment in controlled environment conditions (Khalesro and Aghaalikhani 2006). The relative yield performance of genotypes in drought stressed and more favorable environments seems to be a common starting point in the identification of traits related to drought tolerance and the selection of genotypes for use in breeding for dry environments (Clarke *et al.* 1992).

Selection for drought tolerance at early stage of seedlings is most frequently practiced using poly-ethylene glycol (PEG 6000) in the medium (Rauf *et al.* 2007). Poly-ethylene glycol (PEG) is used for artificial induction of osmotic stress (Rauf *et al.* 2007, Khakwani *et al.* 2011a). The PEG 6000 molecules are inert, non-ionic and virtually impermeable chains, and have frequently been used to induce water stress without causing any significant potential of nutrient solution culture and can induce plant water deficit in a relatively controlled manner, appropriate to experimental protocols (Lagerwerff *et al.* 1961).

Earlier studies focusing on identification of the drought tolerant wheat genotypes using different concentrations of PEG 6000 have showed significant differences for different seedling traits (Rauf *et al.* 2007, Singh *et al.* 2008). The seedling traits when pooled together could discriminate between drought tolerant and susceptible genotypes (Noorka and Khaliq 2007).

Identification of wheat genotypes that can tolerate limited water condition is vital to boost the wheat production which can be achieved only by exploring the maximum genetic potential from available germplasm of wheat. Knowledge of characteristic association for seedling traits under water deficit conditions is also important for understanding yield limiting factors. The endeavor of present research was to assess the tolerance capacity of thirty wheat genotypes against PEG induced water deficit stress stress based on germination and seedling traits.

MATERIALS AND METHODS

The materials used in the present experiment and the details methodology followed during the research period are presented in this chapter.

3.1.1 Location and duration

The experiment was conducted at the Laboratory of the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh during September 2014.

3.1.2 Experimental treatments and design

The experiment consisted of two factors namely Factor A: Three levels of water potential viz. i) Control (Tap water), ii) Moderate stress (-2 bars) induced by PEG (Polyethylene Glycol 6000), and iii) Higher stress (-4 bars) induced by PEG; and Factor B: Thirty wheat genotypes including existing popular varieties, advanced lines and entries. The experiment was laid out in completely randomized design (CRD) with five replications. Wuest and Lutcher (2012) recorded the normal germination of wheat seed up to -1.1 Mpa soil water potential, but the value is slower from -1.3 to 1.6 Mpa and hampered greatly with below -1.6 Mpa.

3.1.3 Collection of seed

Thirty wheat genotypes including six existing varieties and 24 advanced lines collected from Wheat Research Centre (WRC) of BARI, Dinajpur were used for the present study (Table 3.1.1).

3.1.4 Placement of seed for germination

The seeds were surface sterilized by dipping the seeds in 1% mercuric chloride solution for 2 minutes, and rinsed thoroughly with sterilized water. Three levels of water potential according to treatments (Tap water, -2 bars and -4 bars) were developed dissolving calculating amount of PEG in tap water as described by Michel (1983). 119.5 g and 178.4 g PEG were dissolved in 1 kg of water for preparing -2 and -4 bars water potential, respectively. Twenty five seeds of each

Table 3.1.1. List of wheat genotypes used for the present study

SN	Genotypes	Pedigree/Selection history
1.	Sourav (BAW 897)	Variety, NAC/VEE CM 64224-5Y-1M-1Y-2M-0Y
2.	Shatabdi (BAW 936)	Variety, MRNG/BVC//BLO/PVN/3/PJB-81 CM98472-1JO-0JO-0O-1JO-0JO-0R2DI
3.	BARI Gom 25 (BAW 1059)	Variety, ZSH 12/HLB 19//2*NL 297
4.	BARI Gom 26 (BAW1064)	Variety, ICTAL123/3/RAWAL87//VEE/HD2285 BD(JOY) 86-0JO-3JE-010JE-010JE-HRDI-RC5DI
5.	BARI Gom 27 (BAW 1120)	Variety, (FRANCOLIN#1)WAXWING*2/VIVITSI CGSS01B00056T-099Y-099M-099M-099Y-099M-14Y-0B
6.	BARI Gom 28 (BAW 1141)	Variety, CHIL/2*STAR/4/BOW/CROW//BUC/PVN/3/2*VEE#10 CMSS95Y00624S-0100Y-0200M-17Y-010M-5Y-0M
7.	E 2	BOW/VEE/5/ND/VG9144//KAL/BB/3/YACO/4/CHIL/6/CASKOR/3 /CROC_1AESQUARROSA(244)//OPATA/7/PASTOR//MILAN/KAU Z/3/BAV92 CMSA04M01201T-050Y-040ZTP0M-040ZTY-040ZTM-040SY-6ZTM-01Y-0B
8.	E 3	BOW/VEE/5/ND/VG9144//KAL/BB/3/YACO/4/CHIL/6/CASKOR/3 /CROC_1AESQUARROSA(244)//OPATA/7/PASTOR//MILAN/KAU Z/3/BAV92 CMSA04M01201T-050Y-050ZTP0M-040ZTY-040ZTM-040SY-6ZTM-03Y-0B
9.	E 18	PBW343*2/KUKUNA//WBLL1*2/KUKUNA 5M00118S-0100ZTM-029(LR34HOM+HET)ZTY-040ZTM-040SY-2ZTM-0Y-0B
10.	E 23	KS85W663.42/MONARCAF2007//WBLL1*2/TUKURU CMSA06Y00889T-040ZTM-040ZTPOY-040ZTM-040SY-8ZTM-0Y-0B
11.	E 24	FRTL//ATTILA/3*BCN , PTSS02Y00011S-099B-099Y-099B-0Y-0B-17Y-0ZTB-0SY-0B-0Y
12.	E 28	PUB94.15.1.12/WBLL1 PTSS02Y00027S-011Y-0B-0Y-0B-7Y-0M-0SY-0Y-0Y
13.	E 29	CROC_1/AE.SQUARROSA (205)//KAUZ/3/SASIA CMSS93Y01001S-12Y-1KBY-010M-010Y-1M-0KBY-0M-2KBY-0Y-0HTY-0Y-0Y
14.	E 30	PBW343*2/KUKUNA//WBLL1*2/KUKUNA CMSA05M00118S-0100ZTM-029(LR34HOM+HET)ZTY-040ZTM-040SY-45ZTM-0Y-0B
15.	E 34	MEX94.2.19 -0Y-0Y-0Y
16.	E 38	SOKOLL//W15.92/WBLL1, PTSS02B00088T-0TOPY-0B-0Y-0B-5Y-0M-0SY-0B-0Y
17.	E 42	SOKOLL/WBLL1 PTSS02Y00021S-099B-099Y-030ZTM-040SY-040M-31Y-0M-0SY-0B-0Y
18.	BAW 1118	BAW969/SHATABDI BD(DI)1319S-0DI-6DI-1DI-DIRC7
19.	BAW 1130	GOURAB/PAVON76 NCD99-04-0DI-1DI-0DI-0DI-0DI-0DI-22DI-DIRC4
20.	BAW 1135	BAW969/SHATABDI BD(DI)1319S-0DI-6DI-1DI-DIRC6
21.	BAW 1138	CHEN/AE.SQ(TAUS)//BCN/3/2*PASTOR CMSS98Y00844S-040Y-0B-0MXI-3DI-010DI-010DI-1DI-DIRC6

List of wheat genotypes (Contd.)

22.	BAW 1140	SOURAV/GOURAB BD(JE)959S-0DI-5DI-010DI-010DI-010DI-1DI-DIRC8
23.	BAW 1143	BAW923/BAW1004 BD(DI)1207S-0DI-4DI-010DI-010DI-0DI-DIRC7
24.	BARIGom 29 (BAW 1151)	SOURAV/KLAT/SOREN//PSN/3/BOW/4/VEE#5.10/5/CNO 67/MFD//MON/3/ SERI/6/NL297 BD(DI)112S-0DI-030DI-030DI-030DI-9DI
25.	BAW 1157	BAW923/BAW1004 BD(DI)1207S-0DI-4DI-010DI-010DI-0DI-DIRC6
26.	BARI Gom 30 (BAW 1161)	BAW677/BIJOY BD(JA)1365S-0DI-15DI-3DI-HR12R3DI
27.	BAW 1163	SHATABDI/BAW824 BD(JE)1176S-0DI-11DI-010DI-010DI-8DI-HR27R8DI
28.	BAW 1168	BAW923/BIJOY BD(DI) 1327S-0DI-3DI-1DI-DIRC4
29.	BAW 1170	CHIR7/CBRD//GOURAB BD(DI) 1327S-0DI-3DI-1DI-DIRC4
30.	BAW 1171	CHIR7/CBRD//GOURAB BD(DI) 1335S- 16DI-010DI-010DI-010DI-1DI-DIRC4

genotype were placed in each petri-dish (11cm diameter) for germination on sand bed and irrigated in accordance with the respective treatment. The petri-dishes were irrigated daily with required amount of respective solution. Each treatment was replicated five times. Seedlings were allowed to grow up to 7 days after placement of seeds for germination.

3.1.5 Data recorded on germination characters

The number of germinated seed was counted at 24-hour interval, and continued up to 7th day (168 hrs). A seed was considered germinated as plumule and radicle came out and were >2 mm long.

The rate of germination was calculated following Krishnasamy and Seshu (1990).

$$\text{Rate of germination (\%)} = \frac{\text{No. of seeds germinated at 48 h}}{\text{No. of seeds germinated at 168 h}} \times 100$$

Co-efficient of germination and vigour index were calculated using the following formulae (Copeland 1976).

$$\text{Co-efficient of germination} = \frac{100 (A_1 + A_2 + \dots + A_n)}{A_1T_1 + A_2T_2 + \dots + A_nT_n}$$

$$\text{Vigour index} = \frac{A_1}{T_1} + \frac{A_2}{T_2} + \dots + \frac{A_n}{T_n}$$

Where, A = Number of seeds germinated
 T = Time (days) corresponding to A
 n = No. of days to final count

3.1.6 Data recorded on shoot length, root length and seedling dry weight

At 7th day after placement for germination, all other seedlings were removed from each petri-dish keeping 10 healthy seedlings and allowed to grow upto 10 days by adding required amount of respective solution daily. At 10 days after placement of seeds for germination, five seedlings from each petridish were sampled. Shoot and root length of individual seedling were recorded manually with scale. Then the seedlings were separated in root and shoot and were dried at 70°C for 72 h in an electric oven (Model- E28# 03-54639, Binder, Germany), and weight were recorded with an electrical balance (Model- AND EK- 300 i). The mean length (cm) and mean dry weight (mg) were calculated for each treatment combination.

3.1.7 Stress tolerance index (STI)

Stress tolerance index was calculated as Goudarzi and Pakniyat (2008) using the following formula-

$$\text{Stress tolerance index} = \frac{\text{Variable measured under stress condition}}{\text{Variable measured under normal condition}}$$

3.1.8 Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer using MSTAT program. The treatment means were compared using Duncan's Multiple Range Test. Cluster analysis was done for grouping the wheat genotypes based on stress tolerance index to classify the 30 wheat genotypes subjected to water stress tolerance index of each character was subjected to multivariate analysis viz. Cluster Analysis and Principal Component Analysis (PCA) using GENSTAT 513 (Mahalanobis 1936, Digby *et al.* 1989).

RESULTS AND DISCUSSION

The seed germination characteristics and seedling traits of thirty wheat genotypes as influenced by water deficit conditions induced by poly-ethylene glycol (PEG 6000) in the medium are presented and discussed in this section.

3.1.9 Germination characters

Rate of germination (%)

The analysis of variance showed that the rate of germination which indicated the speed of germination was influenced significantly by wheat genotypes and different levels of water stress induced by PEG. The rate of germination was also influenced significantly by the interaction effect of water stress levels and wheat genotypes during seed germination (Table 3.1.2).

The results of Table 3.1.3 showed that the rate of germination was reduced with the increment of water deficit stress. Under well water condition the rate of germination varied from 82.43 to 98.67 with a mean of 94.34. Under moderate stress condition it was varied from 75.45 to 94.84 with a mean of 87.75 and under severe stress condition it was varied from 61.19 to 92.33 with a mean of 80.47.

Dodig *et al.* (2015) reported that polyethylene glycol (PEG) induced osmotic stress significantly decreased the germination percentages and mean germination time of 96 diverse wheat genotypes. Almaghrabi (2012) depicted that PEG 6000 at different concentrations remarkably inhibited the germination percentage, mean daily germination, germination index, mean germination time of eight wheat genotypes. The results in this study are also in agreement with the findings of Ashraf *et al.* (1996), Kaydan and Yagmur (2008), Khayantnezhad *et al.* (2010), Raza *et al.* (2012), and Jahanbin *et al.* (2012) who reported that the increase in PEG concentrations caused a decrease in the uptake of water by seeds, which caused a decline in germination percentage (GP). Fig. 3.1.1 presented the stress tolerance index (STI) of 30 wheat genotypes based on rate of germination at moderate water deficit stress.

Table 3.1.2. Mean square and co-efficient of variation of different quantitative characters as influenced by water stress level and wheat genotypes

Plant Characters	Mean square			CV (%)
	Stress level (A)	Wheat genotypes (B)	Interaction (A× B)	
Rate of germination (%)	4331.072**	302.459**	52.806 **	4.24
Co-efficient of germination	5.936 **	0.718**	0.090 NS	1.82
Vigour index	680.046**	35.909**	11.231 **	5.39
Shoot length (cm)	2667.724 **	12.301**	2.748 **	5.66
Root length (cm)	103.931 **	7.341 **	0.941 **	6.04
Shoot dry weight (mg)	742.559**	11.896 **	4.627**	7.86
Root dry weight (mg)	97.971 **	32.097**	1.922**	7.63
Seedling dry weight (mg)	1358.584 **	40.229**	9.091*	5.37

Table 3.1.3. Range and mean of quantitative characters of 30 wheat genotypes under well water, moderate water stress (-2 bars) and higher water stress (-4 bars) conditions

Plant Characters	Well water		Moderate stress (-2 bars)		Higher stress (-4 bars)	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
Rate of germination (%)	82.43-98.67	94.34 ± 4.12	75.45-94.84	87.75 ± 5.93	61.19-92.33	80.47 ± 9.16
Co-efficient of germination	21.61-22.99	22.12 ± 0.30	20.73-22.21	21.86 ± 0.30	20.55-22.07	21.61 ± 0.34
Vigour index	34.04-43.32	38.42 ± 2.54	33.21-38.79	35.93 ± 1.71	27.33-38.22	32.93 ± 3.18
Shoot length (cm)	17.63-23.89	21.39 ± 1.33	13.78-18.88	16.06 ± 1.18	6.93-13.39	10.50 ± 1.66
Root length (cm)	9.99-13.67	11.69 ± 0.83	9.19-12.55	10.72 ± .95	7.41-11.97	9.55 ± 1.21
Shoot weight (mg)	11.12-19.40	14.39 ± 1.84	8.80-14.97	11.17± 1.25	6.87-13.25	8.66 ± 1.45
Root weight (mg)	5.74-17.90	9.37 ± 2.53	5.33-13.63	8.34 ± 1.84	3.87-10.20	7.29 ± 1.47
Seedling weight (mg)	17.18-35.10	23.76 ± 3.35	14.67-22.90	19.51 ± 2.03	12.07-20.07	15.95 ± 2.00

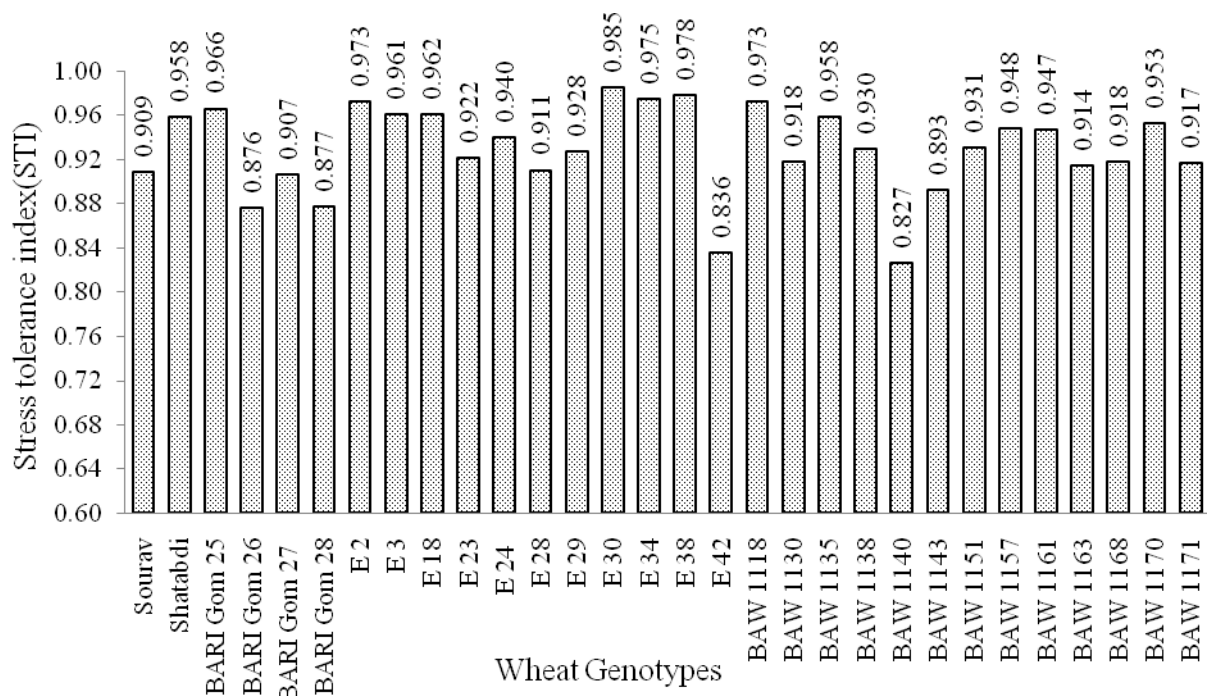


Fig. 3.1.1. Stress tolerance index of 30 wheat genotypes based on rate of germination (%) under moderate water stress (-2 bars)

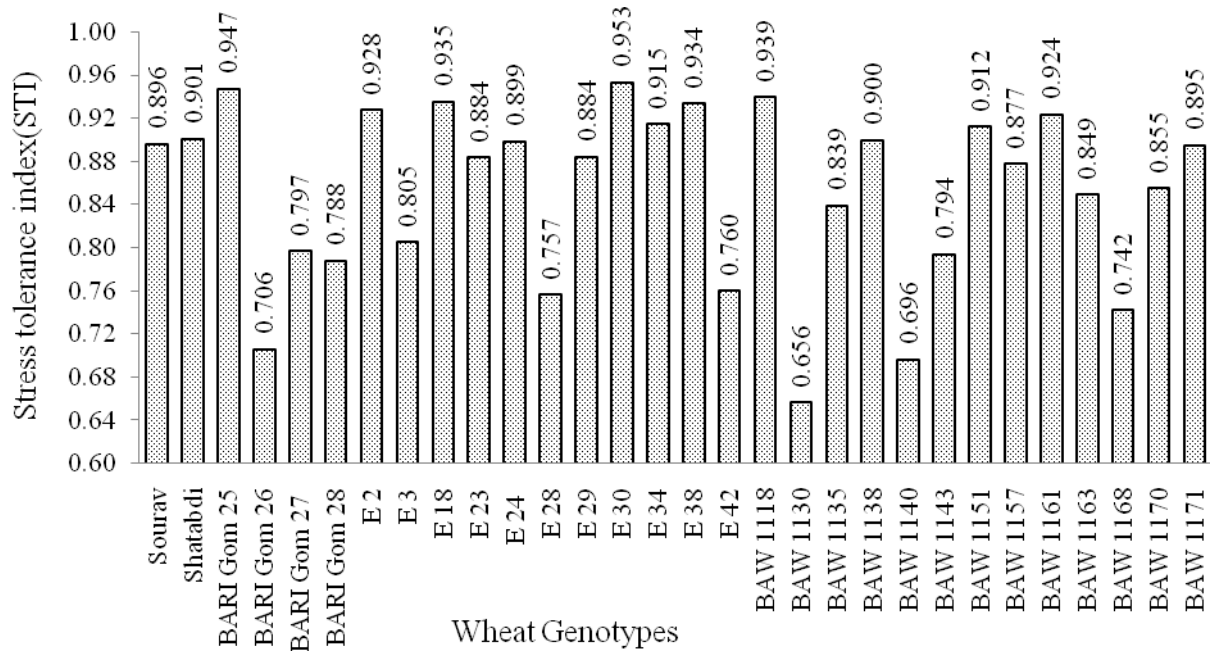


Fig. 3.1.2. Stress tolerance index of 30 wheat genotypes based on rate of germination (%) under higher water stress (-4 bars)

These STI values indicated an extensive difference in water deficit stress tolerance among the wheat genotypes.

Wheat genotypes- BARI Gom 25, E 2, E 3, E 18, E 30, E 34, E 38 and BAW 1118 showed more than 0.96 STI, while the wheat genotypes- BARI Gom 26, BARI Gom 28, E 42 and BAW 1140 provided less than 0.88 STI. The other wheat genotypes showed STI in between 0.88 and 0.96. The STI of thirty wheat genotypes based on rate of germination (%) at higher water deficit stress is presented in Fig. 3.1.2. These STI values also indicated a wide difference in water deficit stress tolerance among the wheat genotypes. Shatabdi, BARI Gom 25, E 2, E 18, E 30, E 34, E 38, BAW 1118, BAW 1151 and BAW 1161 showed larger than 0.90 STI while wheat genotypes- BARI Gom 26, BARI Gom 27, BARI Gom 28, E 28, E 42, BAW 1130, BAW 1140, BAW 1143 and BAW 1168 showed less than 0.80 STI and the other wheat genotypes sprayed STI in between 0.80 and 0.90.

Co-efficient of germination

Co-efficient of germination (COG) which indicates the speed of germination also, was significantly varied by water stress levels and wheat genotypes during germination but COG was not significantly influenced by the interaction effect of water stress levels and wheat genotypes during germination (Table 3.1.2).

The results also revealed that the COG values decreased with decreasing water potential levels from 0 to -4 bars. The COG was found lower (ranging from 20.55 to 22.07 with a mean of 21.61), moderate (ranging from 20.73 to 22.21 with a mean of 21.86), and higher (ranging from 21.61 to 22.99 with a mean of 22.12) at higher water deficit stress, moderate water deficit stress and well watered conditions, respectively (Table 3.1.3).

Jajarmi (2009) and Jahanbin *et al.* (2012) reported that PEG induced water stress reduced the coefficient of germination and the reduction depends on the nature of wheat genotypes.

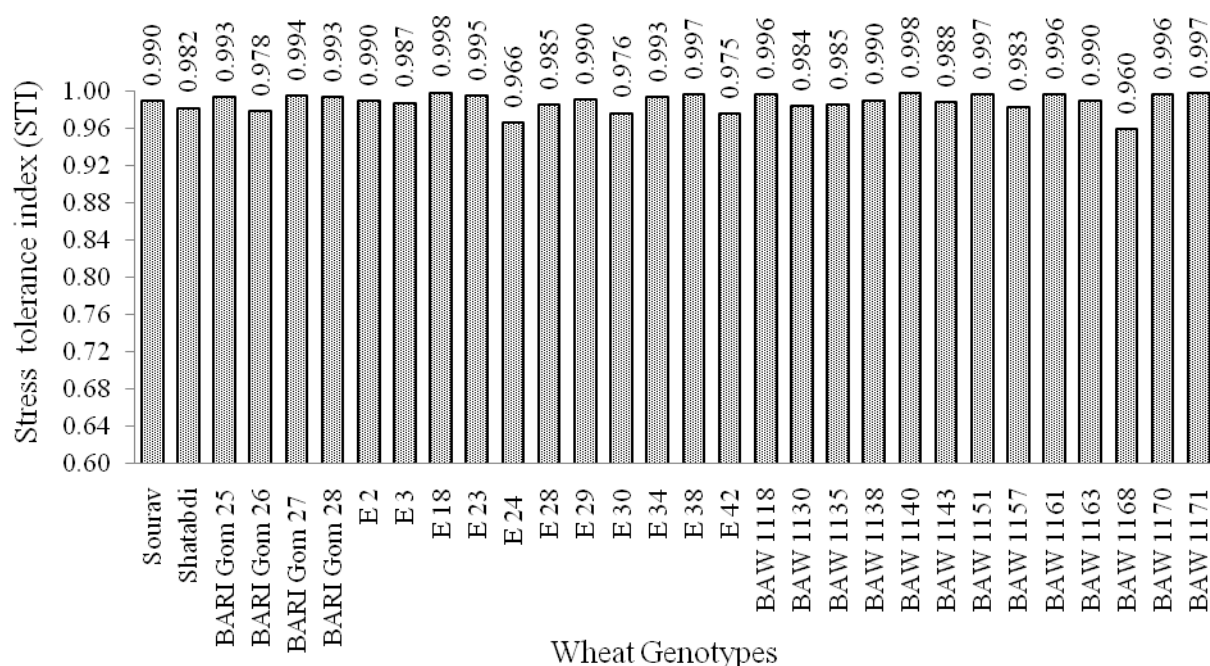


Fig.3.1.3. Stress tolerance index of 30 wheat genotypes based on co-efficient of germination under moderate water stress (-2 bars)

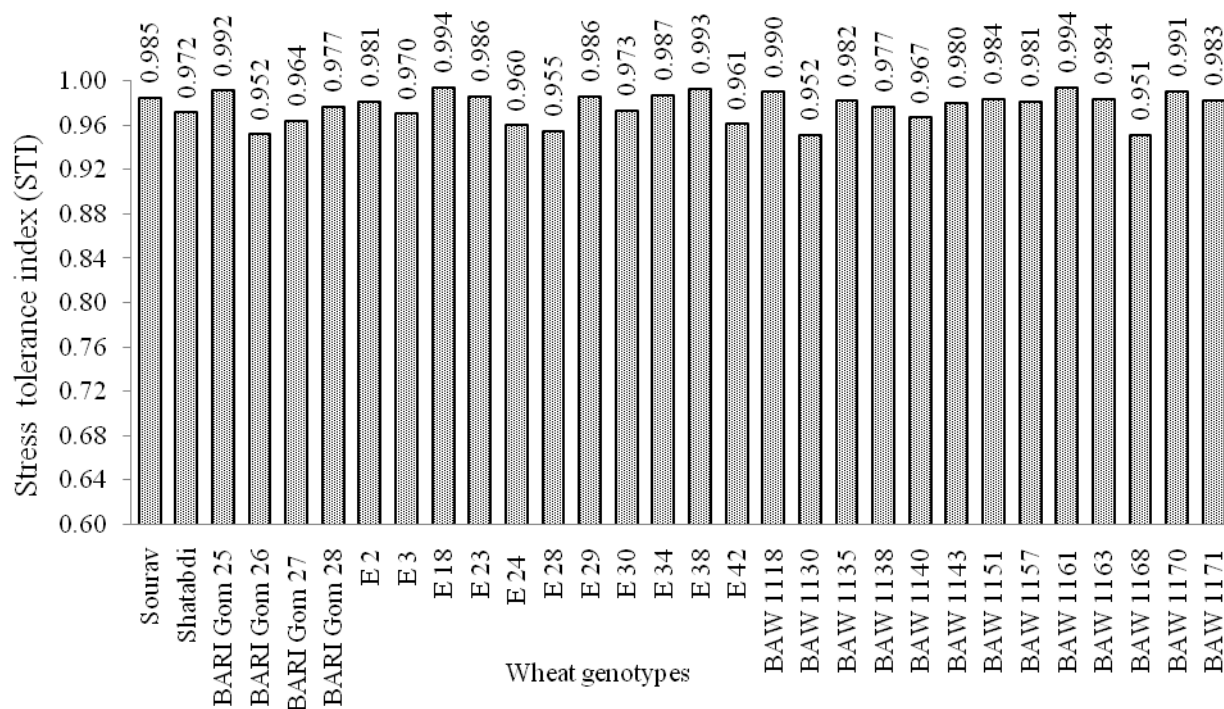


Fig. 3.1.4. Stress tolerance index of 30 wheat genotypes based on co-efficient of germination under higher water stress (-4 bars)

Almaghrabi (2012) concluded that the coefficient of velocity of germination of eight wheat cultivars was significantly influenced by polyethylene glycol (PEG) 6000 induced to drought stress at different concentrations (0.0, 60, 120, 180, 240 and 300 g/L PEG) during germination. The STI based on co-efficient of germination at moderate water deficit stress (-2 bar) is presented in Fig. 3.1.3. The STI values were greater than 0.990 in the BARI Gom 25, BARI Gom 27, BARI Gom 28, E 18, E 23, E 34, E 38, BAW 1118, BAW 1140, BAW 1151, BAW 1161, BAW 1170, and BAW 1171 genotypes, whereas the values were lower than 0.980 in BARI Gom 26, E 24, E 30, E 42 and BAW 1168 and the values ranges in between 0.980 and 0.990, were recorded in the other wheat genotypes.

Fig. 3.1.4 showed the STI of 30 wheat genotypes based on co-efficient of germination at higher water deficit stress (-4 bars). Wheat genotypes Sourav, BARI Gom 25, E 2, E 18, E 23, E 29, E 34, E 38, BAW 1118, BAW 1135, BAW 1151, BAW 1157, BAW 1161, BAW 1163, BAW 1170 and BAW 1171 provided higher STI values larger than 0.980, contrary, wheat genotypes BARI Gom 26, BARI Gom 27, E 24, E 28, E 42, BAW 1130, BAW 1140 and BAW 1168 produced lower STI values less than 0.970 but intermediate STI values (between 0.980 and 0.970) were recorded in the rest wheat genotypes .

The STI values in two conditions (-2, and -4 bars) revealed that the genotypes producing higher values can be treated as higher water stress tolerant, while lower STI value generating the genotypes can be designated as water stress susceptible and the genotypes those intermediate STI value indicating moderate level water stress tolerant genotypes (Figs. 3.1.3 and 3.1.4). Ahmad *et al.* (2013) reported that germination rate index exhibited a positive association with all other parameters including seedling vigour.

Germination vigour index

Germination vigour index (GVI) which also expresses the speed of germination. Results of the analysis of variance for GVI showed highly significant difference among water stress levels, and wheat genotypes and GVI was also influenced significantly by the interaction of

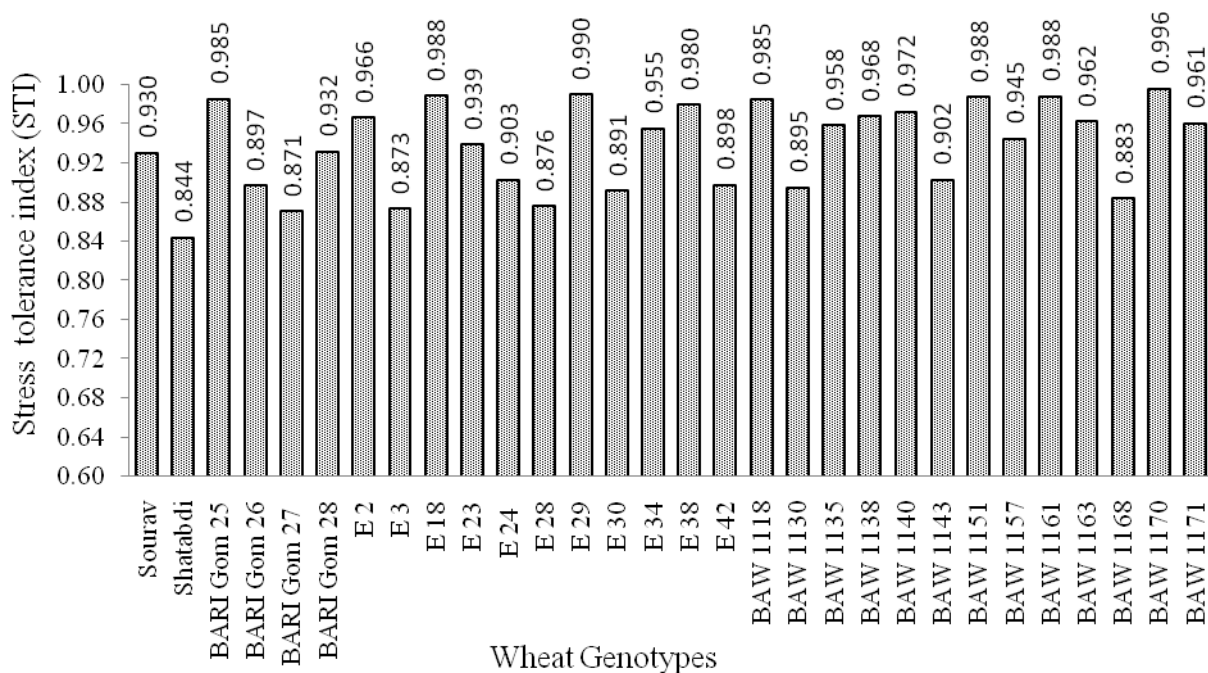


Fig. 3.1.5. Stress tolerance index of 30 wheat genotypes based on vigour index under moderate water stress (-2 bars)

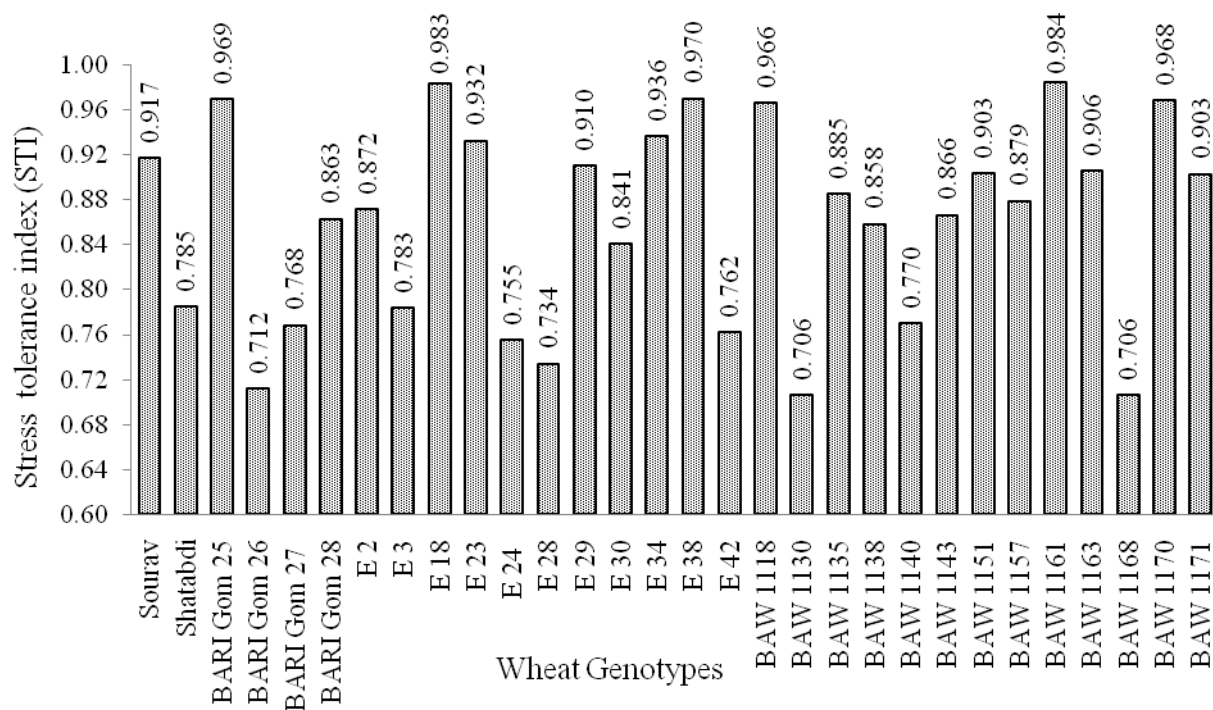


Fig. 3.1.6. Stress tolerance index of 30 wheat genotypes based on the vigour index under higher water stress (-4 bars)

water stress levels and genotypes (Table 3.1.2). The range GVI among the wheat genotypes was 34.04 to 43.32 with a mean of 38.42 at well water condition, 33.21 to 38.79 with a mean of 35.93 at moderate water stress level and 27.33 to 38.22 with a mean of 32.93 at higher water stress level (Table 3.1.3). The results on GVI showed that the speed of germination was reduced with the increment of water deficit stress.

STI value indicates tolerance capability of genotypes against water deficit stress. At moderate water stress (-2 bars), the STI values of thirty wheat genotypes based on GVI are presented in Fig. 3.1.5. The genotypes BARI Gom 25, E 2, E 18, E 29, E 38, BAW 1118, BAW 1138, BAW 1140, BAW 1151, BAW 1161, BAW 1163, BAW 1170 and BAW 1171 showed STI values more than 0.960, while the genotypes Shatabdi, BARI Gom 27, E 3 and E 28 showed STI values less than 0.880. In the middle level of STI values ranging from 0.96 to 0.880 were observed in the other wheat genotypes. The STI of thirty wheat genotypes based on GVI at higher water deficit stress (-4 bars) was also measured, and presented in the Fig. 3.1.6. Nonetheless, higher STI values (>0.920) were observed in BARI Gom 25, E 18, E 23, E 34, E 38, BAW 1118, BAW 1161 and, BAW 1170 whereas moderate STI ranged from 0.920 to 0.800 were recorded in Sourav, BARI Gom 28, E 2, E 29, E30, BAW 1135, BAW 1138, BAW 1143, BAW 1151, BAW 1157, BAW 1163 and BAW 1171, and very lower STI values less than 0.800 were obtained in the other (Shatabdi, BARI Gom 26, BARI Gom 27, E 3, E 24, E 28, E 42, BAW 1130, BAW 1140 and BAW 1168) wheat genotypes. The maximum, minimum and in-between STI value providing genotypes indicating their higher tolerant, susceptible and moderate tolerant to water deficit stresses, respectively (Figs. 3.1.5 & 3.1.6). Greater and early seeding vigour of wheat cultivars can increase the water use efficiency by as much as 25% (Siddique *et al.* 1990), and it is recognized as a trait to select for improving yield of wheat under water stress (Botwright *et al.* 2002, Richards *et al.* 2002). Ahmad *et al.* (2013) showed that an increase in germination rate index will cause an increase in root length, shoot length, coleoptile length and seedling vigour. The results are in line with

findings of Jahanbin *et al.* (2012) who reported that germination indices like germination index (GI), and germination rate index (GRI) of 12 wheat cultivars were remarkably decreased with increasing PEG induced osmotic potentials (0, -4/0, -8/0 and -2/1 mp), and noted significant differences among the genotypes considering the stress tolerance index (STI), and also they declared the genotype S2 as the most resistant type and the genotype S9 as the most sensitive one.

3.1.10 Early seedling growth

Shoot length (cm)

The analysis of variance showed that there were highly significant differences among water deficit stress levels, wheat genotypes, and also their interaction effect for the shoot length of 10 days old seedling (Table 3.1.2). The maximum and minimum shoot lengths of 23.89 and 17.63 cm, respectively with a mean of 21.39 in well water condition, 18.88 and 13.78 cm, respectively with a mean of 16.06 cm in moderate water deficit stress and 13.39 and 6.93 cm, respectively with a mean of 10.50 cm in higher water deficit stress were recorded (Table 3.1.3). The results revealed that the shoot length was decreased with the decreased of water potentials. Stress tolerance index based on shoot length of thirty wheat genotypes were measured under moderate water stress (-2 bars). The higher STI value (>0.80) providing genotypes were E 18, BAW 1135, BAW 1138, and BAW 1171 and as the same time as lower STI (< 0.75) producing genotypes were Sourav, BARI Gom 26, E3, E 28, E 34, BAW 1140, BAW 1143, BAW 1151, BAW 1157, BAW 1163, BAW 1168, and BAW 1170 and the other genotypes were laid between 0.80 and 0.75 STI (Fig. 3.1.7). On the contrary, under higher water deficit stress the higher STI (>0.55) generating genotypes were Shatabdi, BARI Gom 25, E 18, E 38 and BAW 1118, BARI Gom 27, E 24, E 34, BAW 1143, BAW 1170, and lower STI (< 0.450) producing genotypes were Sourav, BARI Gom 26, BARI Gom 28, E 2, E 3, E 28, E 29, BAW 1130, BAW 1151, and BAW 1168 and the other genotypes provide moderate STI (0.55 to 0.450) (Fig. 3.1.8). Higher STI value indicates higher tolerant to water stress deficit, moderate STI value shows moderate tolerant to water deficit stress and lower STI value designates susceptible to water deficit stress. Dodig *et al.* (2015) tested 96 wheat

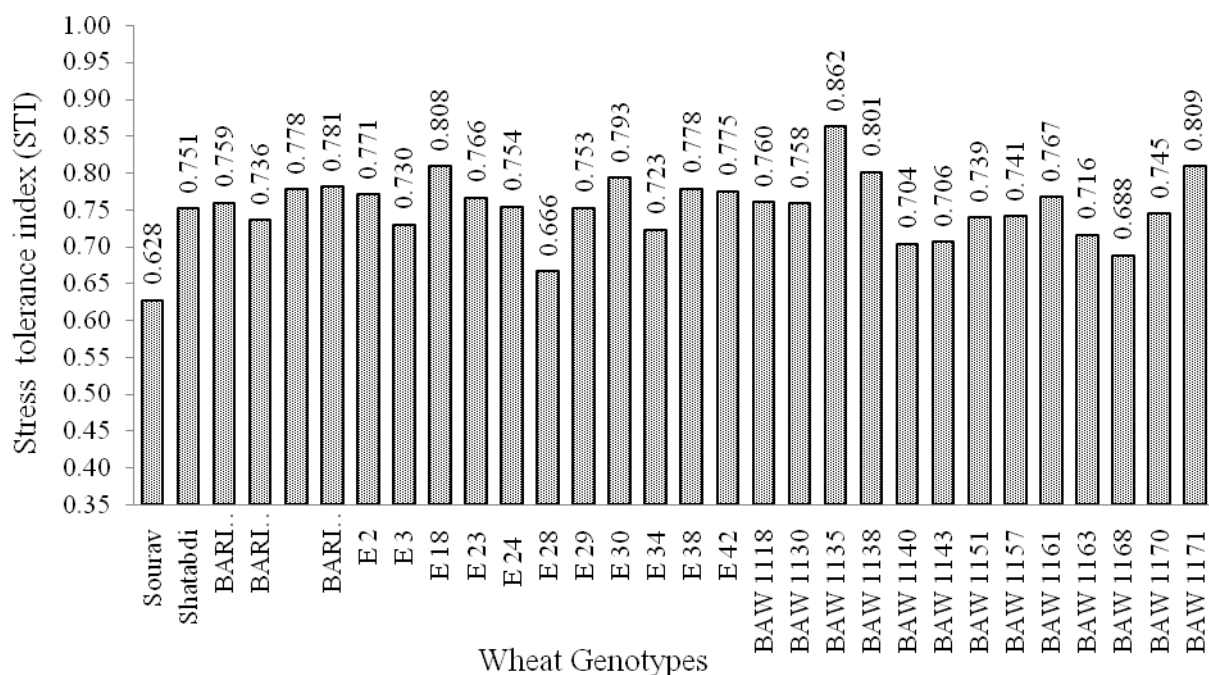


Fig. 3.1.7. Stress tolerance index of 30 wheat genotypes based on shoot length (cm) under moderate water stress (-2 bars)

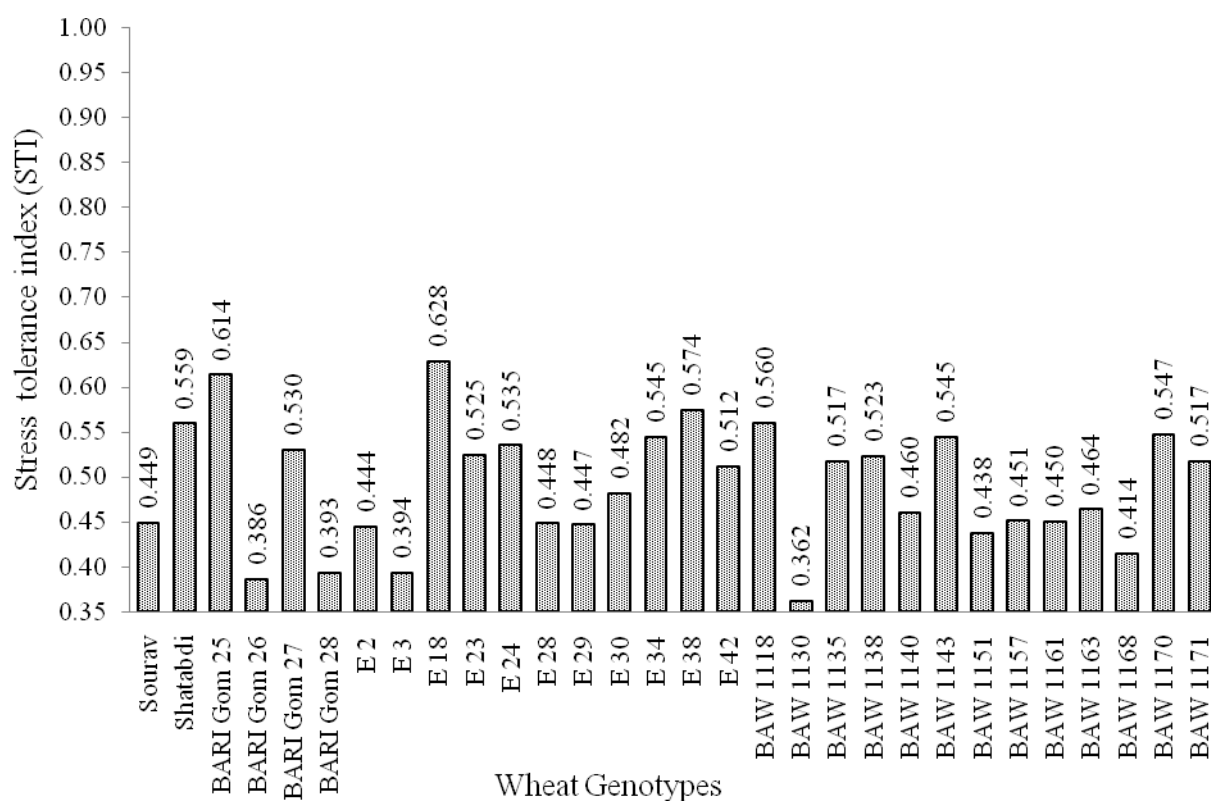


Fig. 3.1.8. Stress tolerance index of 30 wheat genotypes based on the shoot length (cm) under higher water stress (-4 bars)

genotypes at germination and seedling growth stages under PEG induced osmotic stresses (-0.2, -0.4 and -0.6 MPa) and the shoot length was reduced with increasing stresses. Polyethylene glycol (PEG) 6000 induced drought stress reduced the shoot length of eight wheat genotypes (Almaghrabi 2012) and plumule length of 12 wheat genotypes (Jahanbin *et al.* 2012).

Root length (cm)

The root length of 10 days old seedling was significantly influenced by wheat genotypes and water potential levels induced by PEG and the interaction effect also influenced significantly by water potential levels and wheat genotypes (Table 3.1.2). A wide range of variability was observed among genotypes against water deficit conditions.

The results showed that the root lengths range with a mean at well watered, moderate water potential level and higher water potentials level were 9.99 to 13.67 cm with a mean of 11.69 cm; 9.19 to 12.55 cm with a mean of 10.72 cm; 7.41 to 11.97 cm with a mean of 9.55 cm, respectively (Table 3.1.3). The root length was found to be reduced with the increment of water deficit stress from 0 to -4 bars. However, the highest root length was recorded at control condition while the lowest at -4 bars water stress (Table 3.1.3).

The STI values based on the root length were measured against water deficit stress (Fig. 3.1.9 & 3.1.10). Figure 3.1.9 showed stress tolerance index based on root length of thirty wheat genotypes under moderate water stress (- 2 bars). Nevertheless, the genotypes of BARI Gom 25, BARI Gom 28, E 3, E 18, E 23, E 29, E 34, E 38, BAW 1118, BAW 1135, BAW 1138, and BAW 1161 showed more than 0.94 STI values, while the genotypes BARI Gom 26, E 28, E 42, BAW 1130, BAW 1157, BAW 1168 and BAW 1170 showed less than 0.88 STI values, and the other genotypes showed intermediate STI values in-between 0.940 and 0.88 (Fig. 3.1.9). The STI considering the root length at higher water deficit stress also measured (Fig. 3.1.10). However, the STI values ranged from 0.97 to 0.87 in the genotypes of BARI Gom 25, E 18, E 23, E 24, E 29, E 34, E 38, BAW 1118, BAW 1135 and BAW 1161,

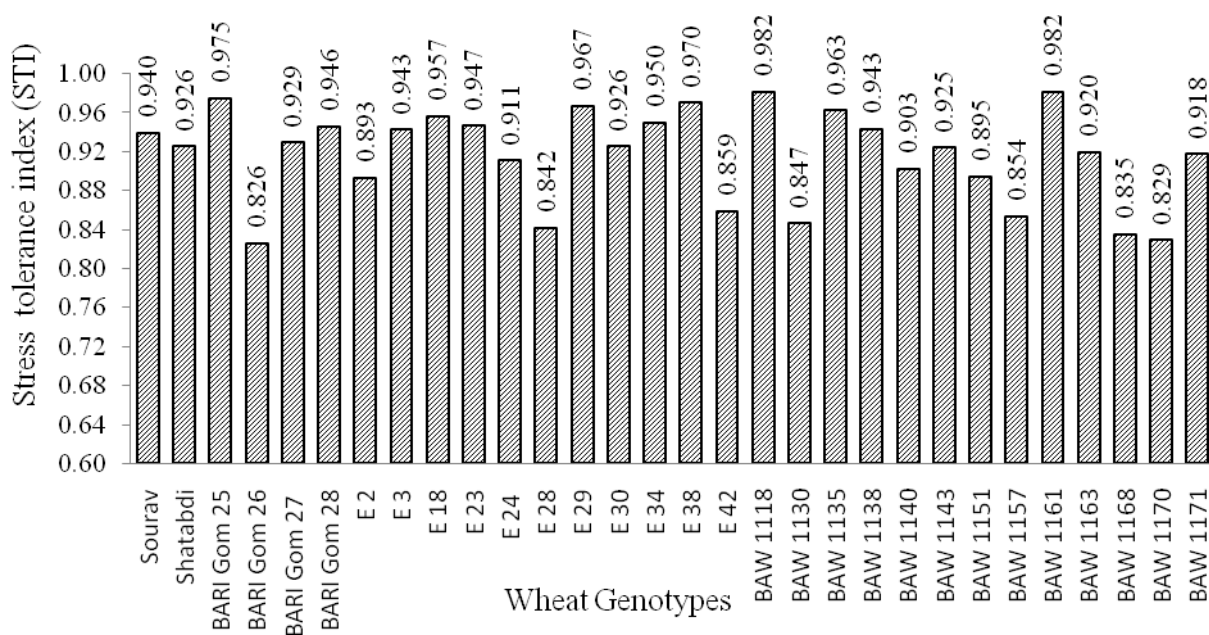


Fig. 3.1.9. Stress tolerance index of 30 wheat genotypes based on root length (cm) under moderate water stress (-2 bar)

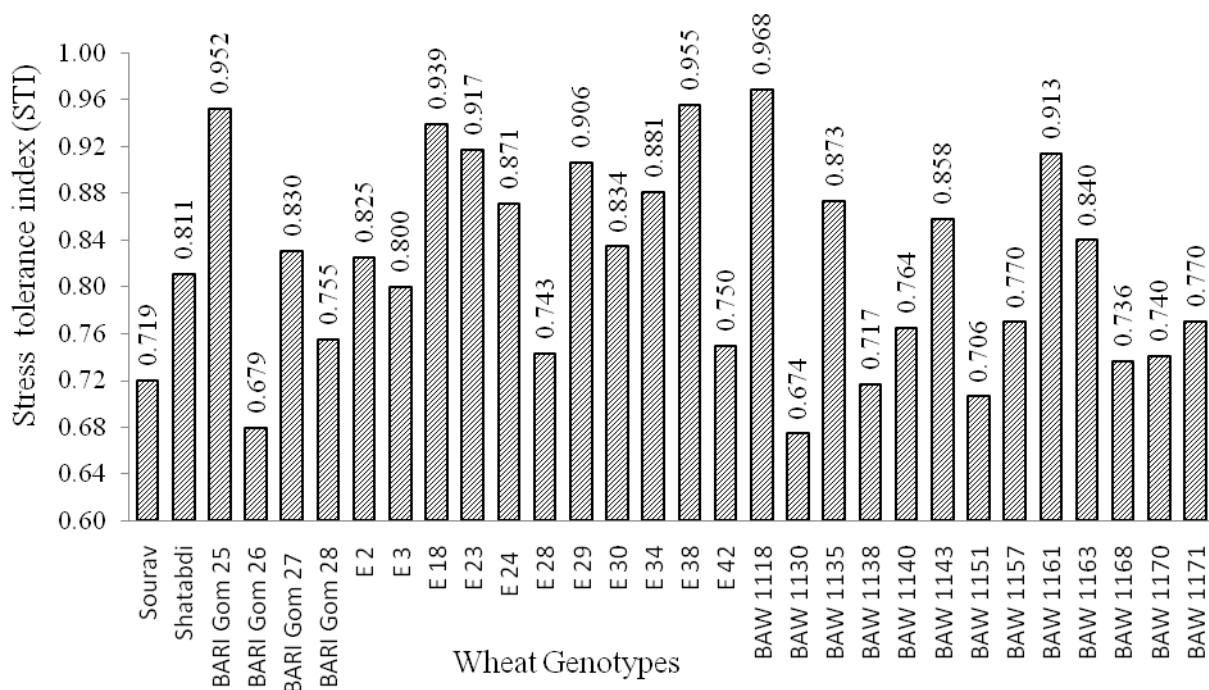


Fig. 3.1.10. Stress tolerance index of 30 wheat genotypes based on root length (cm) under higher water stress (-4 bar)

indicating water deficit stress tolerant genotypes, while the moderate STI values ranged from 0.86 to 0.76 in the genotypes of BARI Gom 27, E 2, E 3, E 30, BAW 1140, BAW 1143, BAW 1157, BAW 1163 and BAW 1171, and rest of the genotypes used in this experiment contained lower STI values less than from 0.76. From the results it is indicated that the higher STI value containing genotypes under water deficit stress can be treated as higher tolerant genotypes to water stress deficit, and lower STI value containing genotypes signifying as susceptible to water deficit stress. Root length and seedling dry weight can be used as major selection criteria for screening genotypes against drought stress (Dhanda *et al.* 2004, Qayyum *et al.* 2012). Deep roots and ability to accumulate dry biomass are considered typical characteristics of drought tolerant genotypes (Zhao *et al.* 2004). Root length/radical length of wheat genotypes significantly reduced with increment of PEG induced water stress as reported by Shahbaz *et al.* (2011), Almaghrabi (2012), Jahanbin *et al.* (2012), Raza *et al.* (2012) and Doding *et al.* (2015).

Stress tolerance index (STI) based on seedling growth traits is a good selection criterion of wheat genotypes under drought stress, and higher values of STI indicates higher drought stress tolerance (Dadbakhsh *et al.* 2011, Jahanbin *et al.* 2012, Fard and Sedaghat 2013). Raza *et al.* (2012) tested eight wheat (*Triticum aestivum* L.) genotypes (viz. Pasban-90, Inqalab-91, Auqab-2000, AS-2002, Sahar-2006, Shafaq-2006, Lasani-2008, and FSD-2008) and reported that water deficit stress significantly reduced seedling growth properties of all the genotypes and the highest root length stress tolerance index and the water content was recorded in the variety Lasani-2008 and the lowest was recorded in Auqab-2000, indicating drought tolerant and susceptible genotypes, respectively.

Shoot dry weight (mg)

The analysis of variance showed that a highly significant differences among the different levels of water stress induced by PEG, among wheat genotypes, and the interaction effect of water stress $\times$ wheat genotype for producing the shoot dry weight (mg) was observed (Table

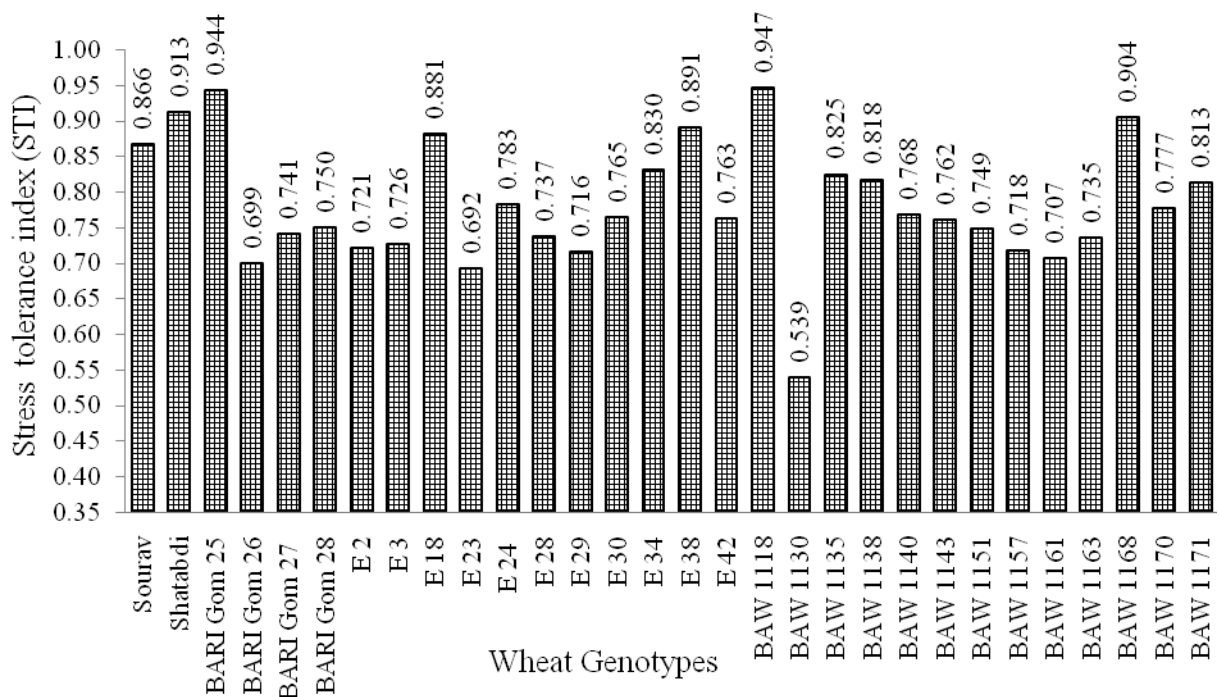
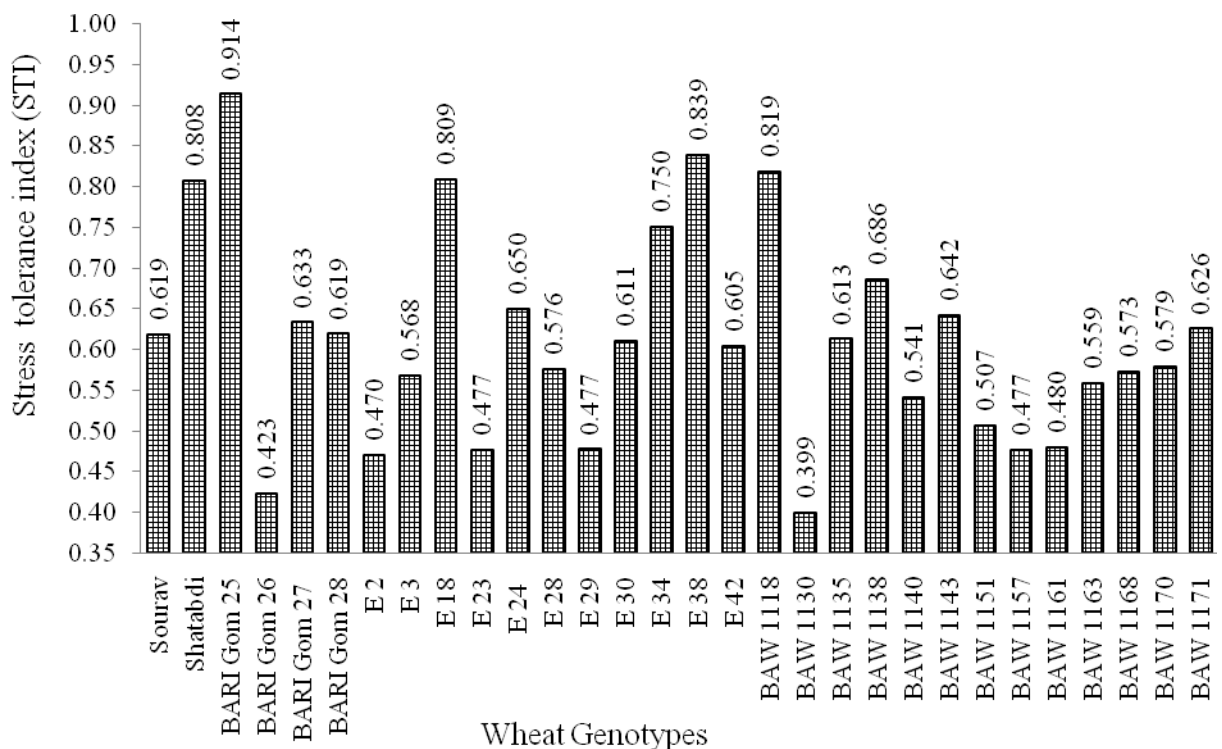


Fig. 3.1.11. Stress tolerance index of 30 wheat genotypes based on individual shoot weight (mg) under moderate water stress (-2 bars)



ig. 3.1.12. Stress tolerance index of 30 wheat genotypes based on individual shoot dry weight (mg) under higher water stress (-4 bars)

3.1.2). This result revealed that there was remarkable difference among the genotypes on producing shoot dry weight. However, the highest and lowest shoot weight (mg) was 13.25 and 6.87 mg with a mean of 8.66 in higher water stress, and from 14.97 to 8.80 with a mean of 11.17 in moderate water stress levels and from 19.40 to 11.12 with a mean of 14.39 in well watered condition (Table 3.1.3). From Table 3.1.3 also it was observed that the shoot dry weight (mg) was reduced with the increment of water deficit stress. Fig. 3.1.11 presented the STI of thirty wheat genotypes based on the shoot dry weight (mg) at moderate water deficit stress. STI was calculated shoot dry weight (mg) of stressed plants to that of non-stressed plants. These STI values indicated a broad difference in water deficit stress tolerance among the wheat genotypes. Wheat genotypes Sourav, Shatabdi, BARI Gom 25, E 18, E 38, BAW 1118 and BAW 1168 showed more than 0.85 STI, the wheat genotypes BARI Gom 26, E 23, E 29, BAW 1130, BAW 1157 and BAW 1161 provided less than 0.72 STI, and the other wheat genotypes (BARI Gom 27, BARI Gom 28, E 2, E 3, E 24, E 28, E 30, E 34, E 42, BAW 1135, BAW 1138, BAW 1140, BAW 1143, BAW 1163, BAW 1170 and BAW 1171) showed STI in-between 0.85 and 0.72. Fig. 3.1.12 shows the STI of thirty wheat genotypes based on shoot weight at higher water deficit stress. These STI values indicated a spacious difference in water deficit wheat genotypes based on shoot weight at higher water deficit stress. These STI values indicated a spacious difference in water deficit stress tolerance among the wheat genotypes. The wheat genotypes Shatabdi, BARI Gom 25, E 18, E 34, E 38 and BAW 1118, provided larger than 0.700 STI, wheat genotypes BARI Gom 26, E 2, E 23, E 29, BAW 1130, BAW 1140, BAW 1151, BAW 1157 and BAW 1161 showed STI less than 0.550 and the other wheat genotypes sprayed STI in between 0.700 to 0.550. It was observed that, the genotypes controlled higher STI values were the most water stress tolerant, the genotypes controlled lower STI value, were water stress susceptible, and the genotypes those controlled moderate STI value were moderate level water stress tolerant genotypes. Doding *et al.* (2015) reported that shoot growth rate was reduced with increasing PEG induced osmotic stresses (-0.2, -0.4 and -0.6 MPa) at germination and seedling growth stages of 96 diverse wheat genotypes. The results in this study are also consisted with the findings

of Almaghrabi (2012) who reported that seedling growth traits like shoot length, shoot fresh weight and shoot dry weight were reduced with the imposition of drought stresses (0.0, 60, 120, 180, 240 and 300 g/L PEG).

Root dry weight (mg)

The analysis of variance showed that the root dry weight (mg) of 10 days old seedlings was highly significantly influenced by wheat genotypes and different levels of water stress induced by PEG and by the interaction effect of water potential levels and wheat genotypes (Table 3.1.2). The root dry weight was found to decrease with the decrease of water potentials stress. However, root dry weight varied from 5.74 to 17.90 with a mean of 9.37 recorded at control (well watered) condition, intermediate weight varied from 5.33 to 13.63 with a mean of 8.34 was found at moderate water potential (-2 bars) and the lowest was at lower water potentials stress (-4 bars) varied from 3.87 to 10.20 with a mean of 7.29 (Table 3.1.3).

The STI values of thirty wheat genotypes based on root dry weight at moderate water potential stress (-2 bars) are presented in Fig. 13. The STI was calculated based on root weight of stressed plants to that of non-stressed plants. The higher STI values in the wheat genotypes indicate higher tolerance in water deficit stress. The higher STI values (>0.950) were recorded in the BARI Gom 25, BARI Gom 27, BARI Gom 28, E 18, E 28, E 30, E 38 and BAW 1118 genotypes. On the contrary, lower STI (<0.85) producing wheat genotypes were BARI Gom 26, E 24, E 34, BAW 1130, BAW 1143, BAW 1157, BAW 1163 and BAW 1170. Rest of the genotypes provided moderate STI were in-between 0.850 and 0.950 (Fig. 3.1.13). Higher STI providing genotypes were stress tolerant genotypes while the genotypes which provided lower STI were stress susceptible genotypes. At higher water potential stress (-4 bars), the STI of thirty wheat genotypes based on the root dry weight are presented in Fig. 3.1.14. The wider STI values among the genotypes indicate different tolerance to water stress. In this case, wheat genotypes Shatabdi, BARI Gom 25, BARI Gom 28, E 3, E 18, E 23, E 30, E 38 and BAW 1118 provided larger than 0.830 STI, while Sourav, BARI Gom 26,

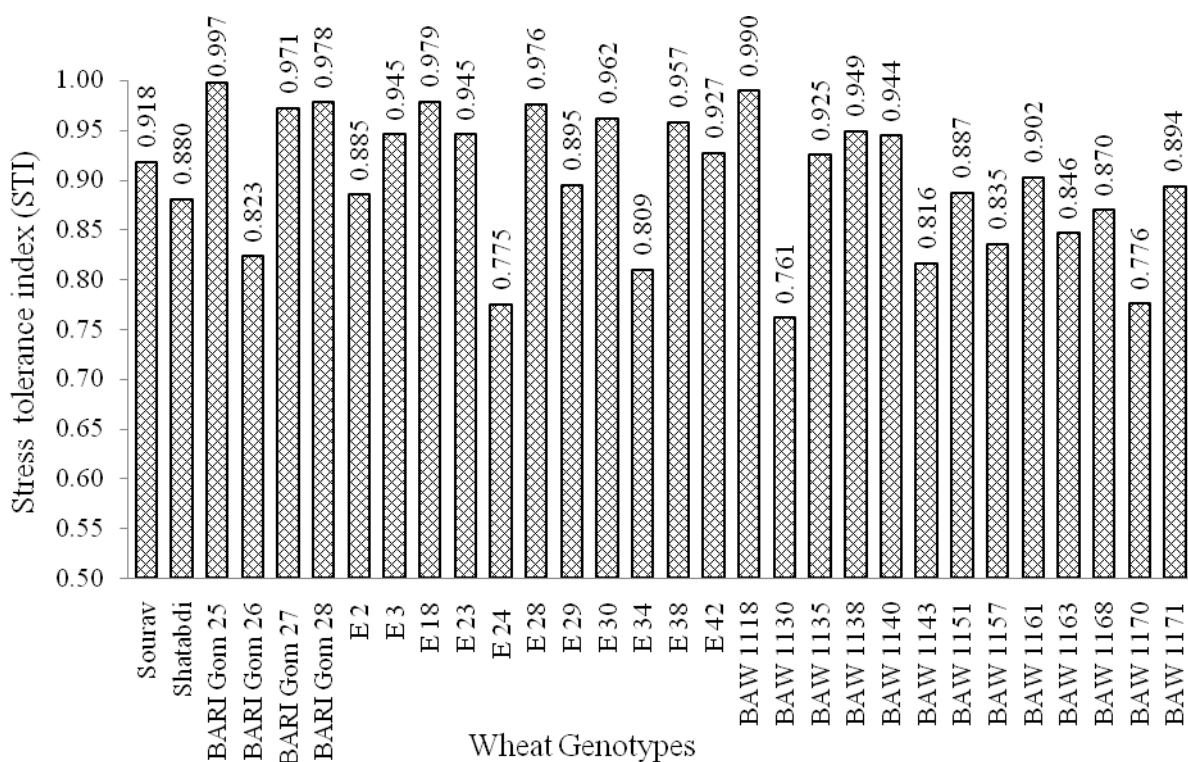


Fig. 3.1.13. Stress tolerance index of 30 wheat genotypes based on individual root dry weight (mg) under moderate water stress (-2 bars)

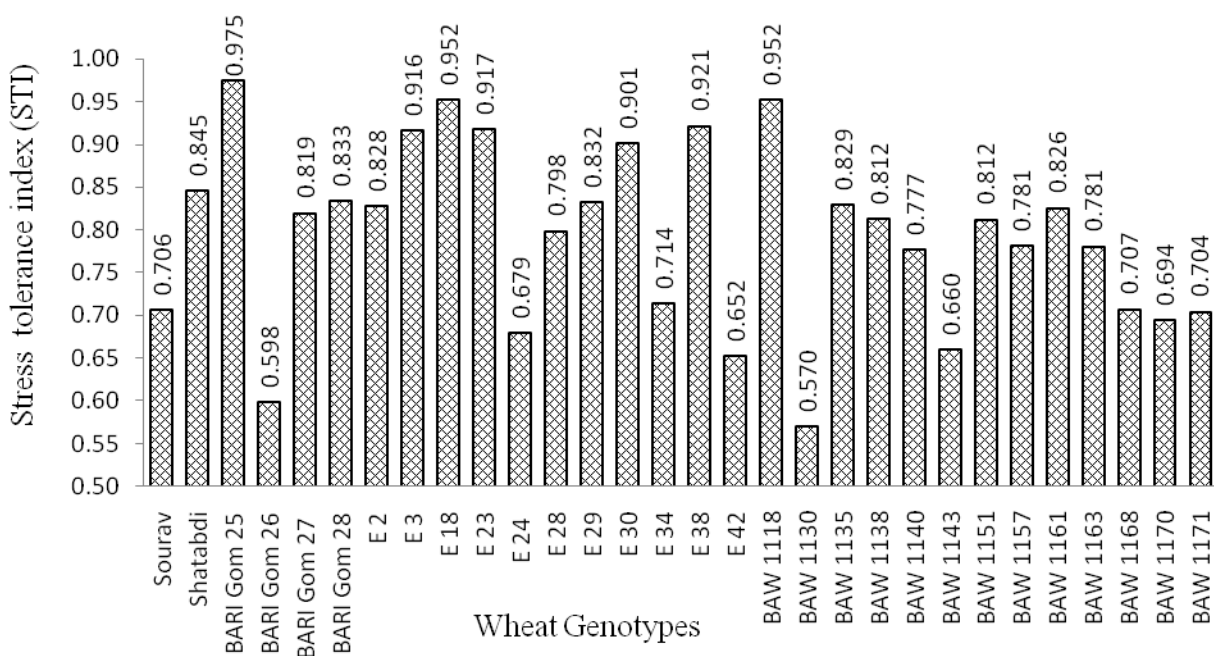


Fig. 3.1.14. Stress tolerance index of 30 wheat genotypes based on individual root dry weight (mg) under higher water stress (-4 bars)

E 24, E 34, E 42, BAW 1130, BAW 1140, BAW 1143, BAW 1168, BAW 1170 and BAW 1171 provided less than 0.780 STI and the other wheat genotypes generated moderate STI in-between 0.830 and 0.780. The STI is a good indicator which notified the level of stress tolerance of the genotypes, and higher the value of the STI indicates higher stress tolerance genotypes.

In contrast, lower STI value indicates stress susceptible genotypes. Seedling growth traits like root fresh weight, root dry weight, and root number were remarkably affected by stresses (0.0, 60, 120, 180, 240 and 300 g/L PEG), and the highest values for most of the parameters were recorded for Sakha 93 and Madini cultivars followed by Yamanei, Kaseemi and Tabokei out of eight cultivars as reported by Almaghrabi (2012). Seedling growth parameters under study can be used as selectable parameters to discrimination between tolerance and sensitive cultivars under drought stress in breeding programs.

Seedling dry weight (mg)

Results of the analysis of variance showed highly significant difference among water potentials levels, wheat genotypes and also their interaction for the seedling dry weight (Table 3.1.2). The maximum seedling dry weight of 23.76 mg (mean) was recorded under well water condition (ranging from 17.18 to 35.10 mg), and the minimum of 15.95 mg was observed at lower water potential (-4 bars) ranging from 12.07 to 20.07 mg and moderate at intermediate seedling dry weight of 19.51 mg (ranging from 14.67 to 22.90 mg) (Table 3.1.3). The results also showed that the seedling dry weight was reduced with the reduction of water potentials stress (Table 3.1.3). Considering the seedling dry weight, the STI value was calculated which indicates the tolerance capability of genotypes against water deficit stress. The STI of thirty wheat genotypes based on seedling dry weight under moderate water stress (-2 bars) are shown in Fig. 3.1.15. The results revealed that the genotypes Sourav, Shatabdi, BARI Gom 25, E 18, E 38, BAW 1118, BAW 1135, BAW 1138, and BAW 1168 showed higher STI values (more than 0.850), whereas the genotypes BARI Gom 26, E 2, E 23, E 24,

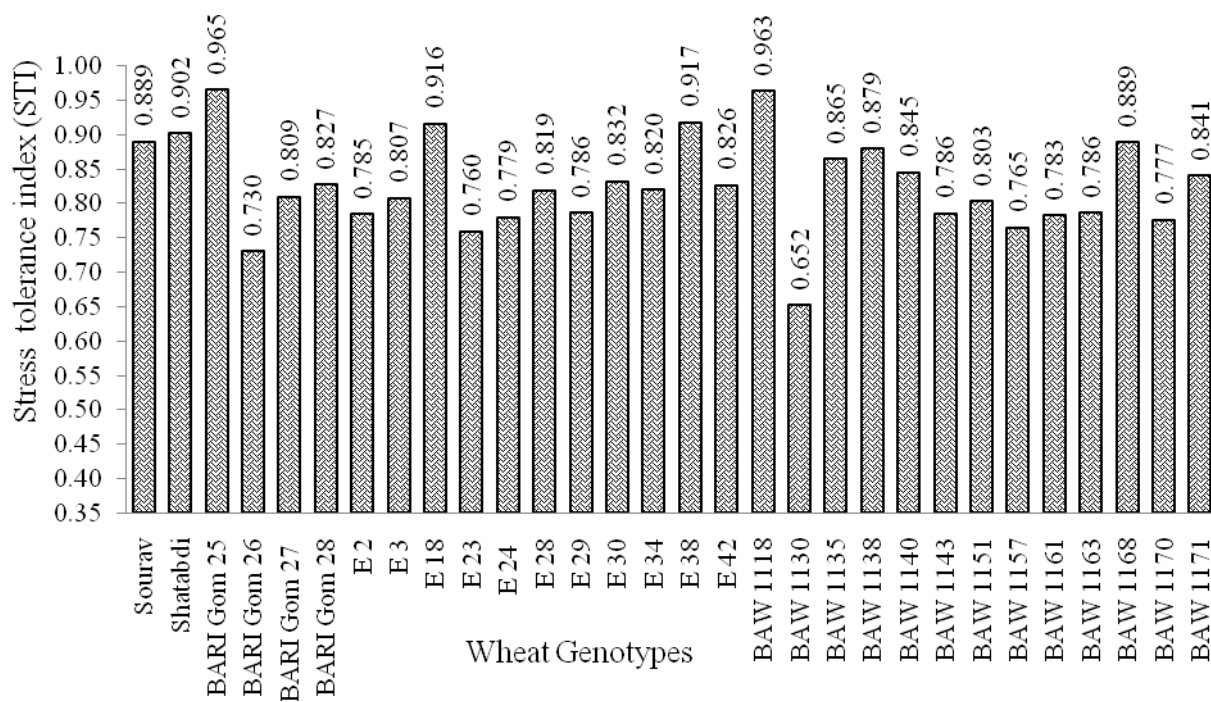


Fig. 3.1.15. Stress tolerance index of 30 wheat genotypes based on individual seedling dry weight (mg) under moderate water stress (- 2 bar)

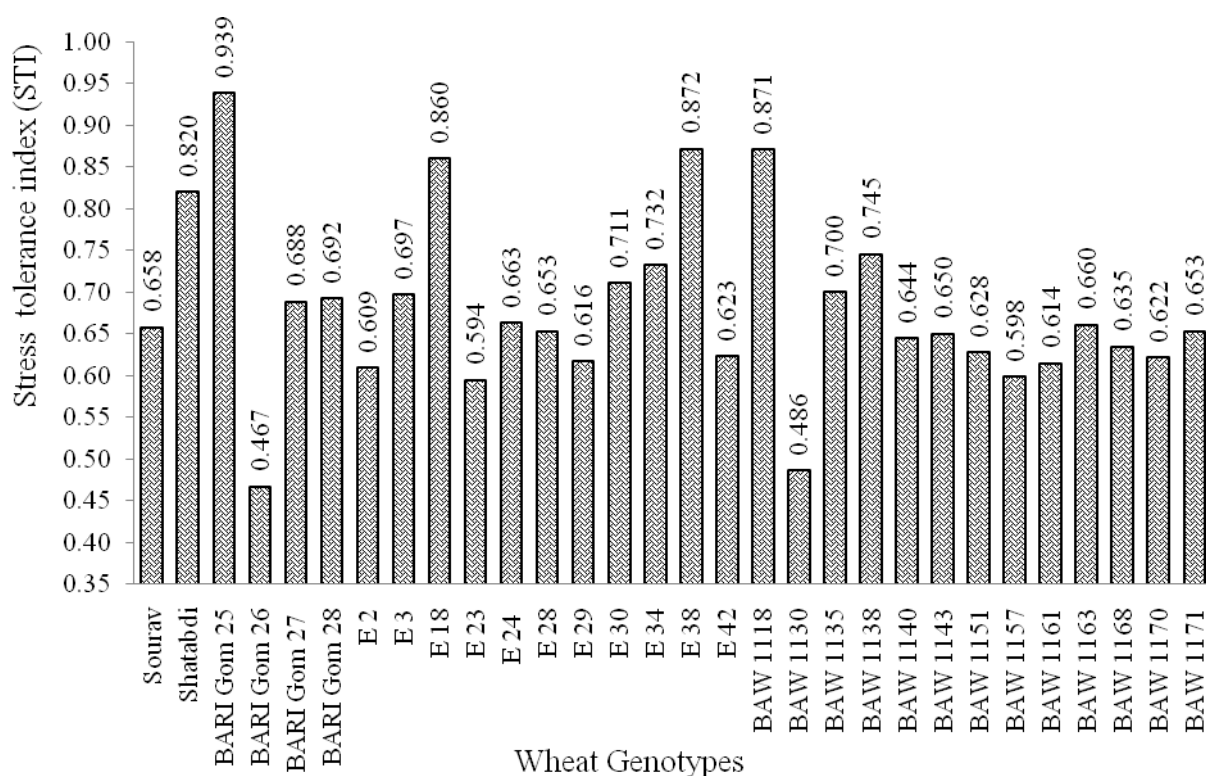


Fig. 3.1.16. Stress tolerance index of 30 wheat genotypes based on individual seedling dry weight (mg) under higher water stress (- 4 bar)

E 29, BAW 1130, BAW 1143, BAW 1157, BAW 1161, BAW 1163 and BAW 1170 showed lower STI values (less than 0.800) indicating drought tolerant genotypes (previous groups) and susceptible genotypes, respectively. Other genotypes showed STI in-between 0.850 and 0.800 which designating moderately tolerant genotypes. STI of thirty wheat genotypes based on higher water deficit stress (-4 bars) expressed in Fig.3.1.16. Higher STI value (STI > 0.700) producing genotypes were Shatabdi, BARI Gom 25, E 18, E 30, E 34, E 38, BAW 1118 and BAW 1138 which can be enchanted as drought tolerant genotypes. Lower STI value (STI < 0.650) providing genotypes are BARI Gom 26, E 2, E 23, E 29, E 42, BAW 1130, BAW 1140, BAW 1151, BAW 1157, BAW 1161, BAW 1168 and BAW 1170 and other genotypes produce moderate STI value ranging from 0.650 to 0.700. Higher STI value indicates higher tolerant to water deficit stress, moderate STI value specifies moderate tolerant to water deficit stress, and lower STI value indicates susceptible to water deficit stress.

Seedling dry weight remarkably decreased with the increasing PEG induced drought stresses and seedling dry weight can be used as major selection criteria for screening genotypes against drought stress (Dhanda *et al.* 2004, Qayyum *et al.* 2012, Almaghrabi 2012). Drought stress adversely affects plant growth and development (Shahbaz *et al.* 2011). The STI values regarding seedling weight decreased and higher values of seedling weight STI be a sign of higher drought tolerant genotype. The STI under study can be used as selectable parameters to discrimination between tolerance and sensitive cultivars under drought stress in breeding programs. Dodig *et al.* (2015) reported that the STI index can be used to choose the drought tolerance genotypes in the seedling stage under a range of stress and non-stress environments. Previous studies, not only in wheat (González and Ayerbe 2011) but also in other cereals such as barley (Moud and Maghsoudi 2008), maize and triticale (Grzesiak *et al.* 2012), showed that seedling growth subjected to water deficit could be used as an indicator of drought tolerance in plants under field conditions.

3.1.11 Grouping of genotypes through cluster analysis and principal component analysis

Cluster analysis

Cluster analysis is one of the multivariate techniques whose main objective is to group individuals or objects based on characteristics they possess, so that individuals with similar description are mathematically gathered into the same cluster. The clusters formed should show higher homogeneity within clusters and heterogeneity between clusters. Thus, if the classification is successful, individuals within a cluster come closer when plotted geometrically and different clusters are plotted apart (Hair *et al.* 1995). Although relative values of the plant characters were used in order to make the more meaningful comparison towards identifying genotypes or groups of genotypes tolerant to water deficit and also cluster analysis was used for grouping the thirty wheat genotypes.

In cluster analysis, 30 wheat genotypes were grouped into 5 clusters based on various germination characters and seedling traits subjected to multivariate analysis (Table 3.1.4). Thirty wheat genotypes were categorized in five clustering using rate of germination, coefficient of germination, vigour index, shoot length, root length, shoot dry weight, root dry weight and seedling dry weight as variables. The cluster analysis results showed that first cluster comprised of five genotypes out of 30 wheat genotypes, these were Shatabdi, BARI Gom 25, E 18, E 38, and BAW 1118 and first cluster comprised 16.67% of the total genotypes, second cluster also included the same number of genotypes, the same as cluster 1 genotypes which represented 16.67% of the total genotypes, namely, E 2, E 23, E 29, BAW 1157 and BAW 1161. The minimum number of wheat genotypes (2), genotype no. 4 (BARI Gom 26) and 19 (BAW 1130) were grouped in cluster III which represented the least 6.67% of total genotypes. The maximum number of genotypes (10) were comprised into cluster V followed by eight (8) in cluster IV. Cluster four enclosed eight genotypes-Sourav, E 24, E 34, E 42, BAW 1143, BAW 1168, BAW 1170 and BAW 1171, these were 26.67% of the total genotypes) and cluster five controlled ten genotypes these included 33.3% of the total

Table 3.1.4. Distribution of 30 wheat genotypes into five different clusters subjected to water deficit stress

Cluster	Number of genotypes	Per cent of total genotypes	Wheat genotypes
I	5	16.67	Shatabdi, BARI Gom 25, E 18, E 38, and BAW 1118
II	5	16.67	E 2, E 23, E 29, BAW 1157 and BAW 1161
III	2	6.67	BARI Gom 26 and BAW 1130
IV	8	26.66	Sourav, E 24, E 34, E 42, BAW 1143, BAW 1168, BAW 1170 and BAW 1171
V	10	33.33	BARI Gom 27, BARI Gom 28, E 3, E 28, E 30, BAW 1135, BAW 1138, BAW 1140, BAW 1151 and BAW 1163
Total	30	100	

genotypes) viz. BARI Gom 27, BARI Gom 28, E 3, E 28, E 30, BAW 1135, BAW 1138, BAW 1140, BAW 1151 and BAW 1163 and this cluster also integrated the highest number of genotypes (Table 3.1.4). The genotypes included within a cluster had less diversity among themselves and the genotypes included in different clusters had more diversity among different clusters.

Principal component analysis

Principal component analysis is a useful technique to be used for the classification of different biological populations at genotypic level and to evaluate comparative influence of various components to the total divergence both at intra- and inter-cluster levels (Zahan *et al.* 2008). Based on the values of principal component scores 1 and 2 obtained from the principal component analysis, a two-dimensional scatter diagram (PC1-PC2) using component score 1 as X-axis and component score 2 as Y-axis was constructed, and then superimposed with clustering which has been presented in Fig. 3.1.17.

The first two principal components contributing almost 91.03% towards the total variance were plotted to observe the relationships between different clusters with PC 1 on X-axis and PC 2 on Y-axis (Fig. 3.1.17). The scatter diagram showed association between different clusters. It could be explained by the fact that a large number of genotypes with varying degree of adaptation against water stress were used, based on different germination characters and seedling traits or some sort of similarity among the genotypes. However, cluster analysis brings together those genotypes showing considerable tolerance against drought stress at one place, and on the basis of yield related traits at other place. The positions of the genotypes in the scatter diagram were apparently distributed into 5 groups, which indicated that there exists considerable diversity among the genotypes. The selection of diverge genotype, from different clusters would produce a broad spectrum of variability for germination characters and seedling traits which may enable further selection and improvement. The variety

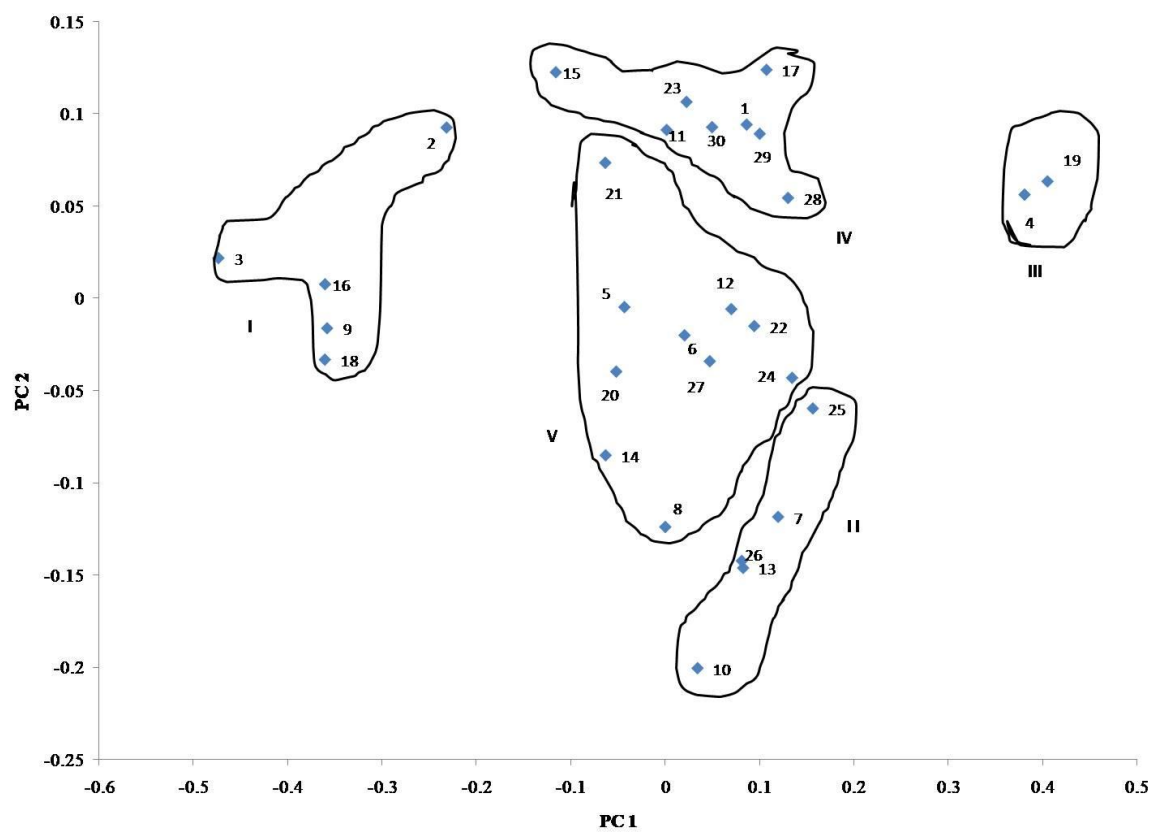


Fig. 3.1.17. Scatter distribution of 30 wheat genotypes based on their principal component scores superimposed with clustering.

developed from the selected genotypes within the limits of compatibility of these clusters may produce high magnitude of heterosis. This would be rewarding in wheat breeding program.

Considering the results of experiment -1, it may be concluded that water deficit stress delayed germination and reduced seedling growth traits and based on germination and seedling growth traits E 3, BAW 1135, E 30, E 34, BAW 1138, Shatabdi, E 18, BAW 1118, E 38 and BARI Gom 25 genotypes were found as more tolerant, while, BAW 1151, E 42, BAW 1170, E 29, BAW 1161, E 2, BAW 1157, E 23, BAW 1130 and BARI Gom 26 were found as more sensitive genotypes.

Experiment II: SCREENING OF WHEAT GENOTYPES FOR DROUGHT PRONE AREA UNDER VARIABLE WATER REGIMES

INTRODUCTION

The total production of wheat in Bangladesh is 1.4 million m tons against the total requirements of 5.6 million m tons but the average grain yield per hectare is less than the desired yield potential (WRC 2017). The production of wheat can be increased either by bringing more area under cultivation or by increasing productivity (Ahmad 2002). Although the high yielding, fertilizer responsive wheat varieties were developed and recent advances in the production technology of wheat have been adopted, but not yet to reach the threshold levels of self-sufficiency (Akram and Iqbal 2004). Environmental stresses are the main factors limiting the world's plant production. Among the environmental stresses severe losses can be caused by drought, a stress common in most arid and semi-arid areas. Drought severely impairs plant growth and development, limits plant production and the performance of crop plants, more than any other environmental factor (Rad *et al.* 2012). With progressive global climatic change and increasing shortage of water resources and worsening environment, wheat production is influenced greatly (Singh and Chaudhary 2006).

There are stress sensitive and resistant plants based on the effectiveness of the protective responses caused by stress. The resistance of the plant to withstand various stress factors plays a vital role for its growth and development. The most important concept of agricultural plant breeding is to gradually form stress resistant crops from stress sensitive cultivars. So management of plants for tolerance to drought needs proper understanding of physiological characteristics and natural variations. Drought stress may occur throughout the growing season, early or late season, but its effect on yield reduction is the highest when it occurs after anthesis (Blum 2005). Moisture shortage in the soil affects the morphological characteristics of wheat (Plaut *et al.* 2004). Water stress not only affects the morphology but also severely

affects the metabolism of the plant. The extent of modification depends upon the cultivar, growth stage, duration and intensity of stress (Araus *et al.* 2002, Mark and Antony 2005). Moisture stress during spike emergence and anthesis has been reported to reduce grain yield up to 20% mainly through reduction in individual grain weight (Hagyo *et al.* 2007). Passioura (2007) also reported that moisture stress during spike emergence and anthesis reduced yield from 7.0 to 3.3 tons ha⁻¹ through reduction in spike m⁻², individual grain weight and number of grain spike⁻¹. Severe water deficit during the vegetative stages results in reduced leaf area and this in turn affects tillering and spike size (Dencic *et al.* 2000). Water stress at anthesis reduces pollination and number of grains per spike which results in reduction in grain yield (Zhang *et al.* 2001). Stress during grain filling reduced yield by 20% mainly due to 16% reduction in individual grain weight (Setter *et al.* 2001).

Selecting wheat genotypes that could tolerate drought stress and produce acceptable yield has been the major challenge for the wheat breeders in the past 50 years (Lopez *et al.* 2003). It is the need of time to develop varieties, which have drought tolerant potential to increase area under cultivation and yield of wheat crop. The relative yield performance of genotypes in drought stress and more favorable environments seems to be a common starting point in the selection of genotypes for use in breeding for dry environments (Clarke *et al.* 1992). Therefore, the present study was conducted to screen out the water deficit tolerant wheat genotypes in relation to relative performance based on yield attributes and yield of thirty wheat genotypes under variable water regimes.

MATERIALS AND METHODS

This chapter describes the materials and methods that were used in performing the experiment. The components under description include location, soil, crop, treatment, experimental design, intercultural operations, data collection etc.

3.2.1 Location and duration

The experiment was carried out at the research field of Wheat Research Center (WRC), Bangladesh Agricultural Research Institute (BARI), Nashipur, Dinajpur, Bangladesh from November 2014 to March 2015 on an upland soil. The experimental site is situated under the Dinajpur Sadar Upazila, and located at 25°39' N latitude and 88°41' E longitude with an elevation of 37.58 meter above the sea level (FAO/UNDP, 1988).

3.2.2 Soil characteristics of the experimental field

The soil of the experimental field belongs to Ranisankil series of Non-calcareous brown floodplain under the Agro-Ecological Zone (AEZ) of Old Himalayan Piedmont Plain (AEZ 1) (FAO/UNDP 1988). The land type of the experimental field is high land with sandy (58%) loam textural classes in surface (Black 1965). As per USDA soil classification system, the experimental soil falls under Inceptisol order. Soils of the experimental sites were analyzed before sowing of wheat (Appendix 1 and Appendix 2).

3.2.3 Climate conditions during the experimental period

The experimental site is situated in the sub-tropical region characterized by heavy rainfall during the months from July to September and scanty or no rainfall in the rest months of the year. Meteorological data on rainfall, temperature and relative humidity during the research period were recorded regularly by the HOBO U12 Family of Data Loggers (MicroDAQ.com) at the meteorological station of WRC, Dinajpur. Climatic parameters are presented in the Appendix 3.

3.2.4 Plant materials

Thirty wheat genotypes including most of the popular varieties and some advanced lines from Wheat Research Centre (WRC) of BARI, Dinajpur was used in the present study. The list of genotypes is presented in Table 3.1.1 in the experiment number 1.

3.2.5 Land preparation

The land was well prepared by repeated ploughing and cross-ploughing with a power tiller followed by laddering for breaking the clods, levelling the lands and collecting the stubbles. The individual plots were prepared by making ridges (8-10 cm high) around the each plot to restrict the lateral run off of fertilizer with irrigation water. To control soil-borne insects, Furadan 5G containing Carbofuran (systemic pesticide; FMC Corp., Philadelphia, PA, USA) was broadcast at 10 kg ha⁻¹ during final land preparation.

3.2.6 Experimental design and treatments

The experiment was conducted in a split-plot design with three replications. The unit plot size was consisted of four rows each of 1 m long having a row to row distance of 20 cm, unit plot to unit plot distance 0.5 m and block to block distance of 2.5 m. The treatments were-

1. Factor A: Main plot: Three water regimes

- i) Well water: Three irrigations at crown root initiation, anthesis and grain filling stage.
- ii) One irrigation: One irrigation was applied at after crown root initiation stage and the crop was protected from rainfall by rainout shelter; and
- iii) No irrigation: No irrigation was applied and the crop was protected from rainfall by rainout shelter

2. Factor B: Thirty wheat genotypes including advance lines and varieties.

3.2.7 Fertilizer application

Fertilizers were applied during final land preparation as WRC recommended doses @100-30-50-20-1.25-1-5000 kg ha⁻¹ of N, P, K, S, Zn, B and cow-dung (well decomposed) (WRC

2013) in the form of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and boric acid, respectively. Two-third of urea and total amount of other fertilizers were applied during final land preparation in the well watered plot. The rest amount of urea was top dressed at crown root initiation stage (CRI) i.e., 18 days after sowing (DAS) followed by first irrigation. Full doses of N, P, K, S, Zn, and B were incorporated thoroughly into the soil as a basal dose in all water stressed plots.

3.2.8 Sowing of seeds

Wheat seeds at the rate of 120 kg ha⁻¹ in case of bolder grain size, and 140 kg ha⁻¹ in case of smaller grain size of wheat were sown in line by hand on November 27, 2014. Seeds were placed continuously in lines by making narrow and shallow furrows and covered with soil by hand. To accomplish excellent germination and protecting against fungal attack during the seedling stage, seeds were pre-treated with a fungicide Provax-200 WP (containing Carboxin and Thiram) an effective fungicide for seeds. Light irrigation at 10 days before sowing of seeds was given to ensure uniform germination of seeds.

3.2.9 Intercultural operation

After sowing, care was taken against birds up to 15 days from sowing. Intercultural operations were done uniformly in each plot to ensure normal growth of the crop. Weeding and mulching were done simultaneously in the experimental plot for two times, firstly at 14 DAS and secondly at 26 DAS. Thinning was also done as required. Three irrigations were given at 19, 53 and 81 DAS in well watered plot. Plant protection measures were taken when some plots were slightly infested by field rat a few days before harvesting. The attack of rats was controlled instantly by using Lanirat or other process.

3.2.10 Harvesting

The crop was harvested on 1 April 2015 when the plants attained full maturity. The crop was cut at the soil surface level. After harvesting the sample were sun dried. Ten plants from each

plot were sampled randomly for data collection. Threshing, cleaning and drying of grains were done separately plot by plot. The weight of grain and straw were recorded plot wise and adjusted at 12% moisture content.

3.2.11 Data collection

The data were recorded when the plant attained full maturity and also at the harvesting stage.

Soil moisture: The soil moisture level was recorded at 18, 53, 70, 78, 85, 92, 99 and 109 days after sowing (DAS) at 15 cm depth and at all DAS moisture was recorded before irrigation.

Plant height: Plant height was recorded from the average of 10 selected plants at maturity. Plant height (cm) was measured by a meter scale from soil surface to the tip of the spike excluding awns and averaged.

Number of spikes m^{-2} : The numbers of developed and underdeveloped spikes was counted from whole plot and then converted into spikes m^{-2} . Counting should be done diagonally at physiological maturity to avoid damage of plants due to walking inside plot.

Spike length: Length of spike from 10 selected plants per plot were recorded in cm and averaged.

Spikelets per spike: From the spikes of 10 plants number of spikelets per spike was recorded.

Grains per spike: From the spikes of the 10 plants, the number of filled and unfilled grains per spike was counted and averaged.

Thousand grain weight: 1000-grains were counted by using automatic seed counter and weights were recorded plot-wise by electrical balance in g on 12% moisture basis.

Grain and straw yields: The plants from whole plot comprising 0.8 m² from each plot were harvested randomly through the soil surface for computation of grain and straw yields. After threshing, cleaning and drying, the grain and straw yields were recorded plot-wise and adjusted at 12% moisture content (MC) as follows. Finally the grain and straw yields were converted into gram m⁻². Data on grain yield (GY) was determined and adjusted to 12% moisture level by the following equation (Hellevang 1995).

$$Y (M_2) = \frac{(100-M_1)}{(100-M_2)} \times Y (M_1)$$

Where,

Y (M₂) = Weight of grain at expected moisture percentage (generally 12% for wheat),

Y (M₁) = Weight of grain at actual moisture percentage,

M₁ = Actual moisture percentage,

M₂ = Expected moisture percentage.

3.2.12 Relative value

Relative value was calculated by the following formula (Asana and Williams, 1965):

$$\text{Relative performance} = \frac{\text{Variable measured under stress condition}}{\text{Variable measured under control condition}}$$

3.2.13 Soil moisture content

The soil samples are collected from desired depth from several places, in air tight containers. The samples are weighed and then they are dried in an oven at 105⁰C for about 24 hours or till constant weight. The samples are then taken out and weighed again and the loss in weight is the amount of water soil.

$$\text{Soil moisture content (\%)} = \frac{\text{Weight of moist sample} - \text{Weight of oven dry sample}}{\text{Weight of oven dry sample}} \times 100$$

3.2.14 Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer using STAR Version 2.0.1 (IRRI 2014). Cluster analysis was done for grouping the wheat genotypes based on relative performance in yield attribute and yield to classify the 30 wheat genotypes subjected to water stress. Relative performance of each character was subjected to multivariate analysis viz Cluster Analysis and Principal Component Analysis (PCA) using GENSTAT 513 (Mahalanobis 1936, Digby *et al.* 1989).

RESULTS AND DISCUSSION

In this study, thirty wheat genotypes were used for screening against three water regimes. The screening criteria of the genotypes were based on the relative performance based on yield contributing attributes and yield under variable water regimes. The tolerance of the genotypes subjected to water deficit throughout the growing period was estimated by comparing the quantitative values of the characteristics of water deficit plants with those of control ones.

3.2.15 Soil moisture content

Moisture content of the soil at 0-15cm depth of well watered, one irrigated, and no irrigated plots at different days after sowing is presented in Fig. 3.2.1. Irrigation was applied at 18, 53 and 80 DAS and moisture contents were recorded at 18, 53, 70, 78, 85, 92, 99 and 106 DAS. Results showed that plots of well watered, one irrigated, and no irrigated maintained more or less similar moisture (13.91, 15.54 and 14.73%, respectively) before first irrigation at 18 DAS (Fig. 3.2.1). However, the highest soil moisture was recorded in well watered plots at all time except 53 DAS than that of one irrigated, and no irrigated plots, while the lowest soil moisture was observed in no irrigated plots at all the recorded time. This figure also shows that the soil moisture contents of no irrigated plots was reduced gradually with the advancement of time after sowing, whereas the soil moisture content at one irrigated plots was reduced progressively with the advancement of time from 53 DAS, but the moisture content in the well watered plots increased with every stage of irrigation.

3.2.16 Variability in quantitative characters

Plant height

Analysis of variance did not reveal any significant differences among water regimes and different wheat genotypes as well as with their interaction for the plant height (Table 3.2.1). The plant height ranged from 83.02 to 119.09 cm with a mean of 92.24 cm in no irrigated plants, while from 86.97 to 104.83 cm with a mean of 95.71 cm in one irrigated plants and from 89.45 to 121.32 cm with a mean of 96.08 cm in well watered plants (Table 3.2.2).

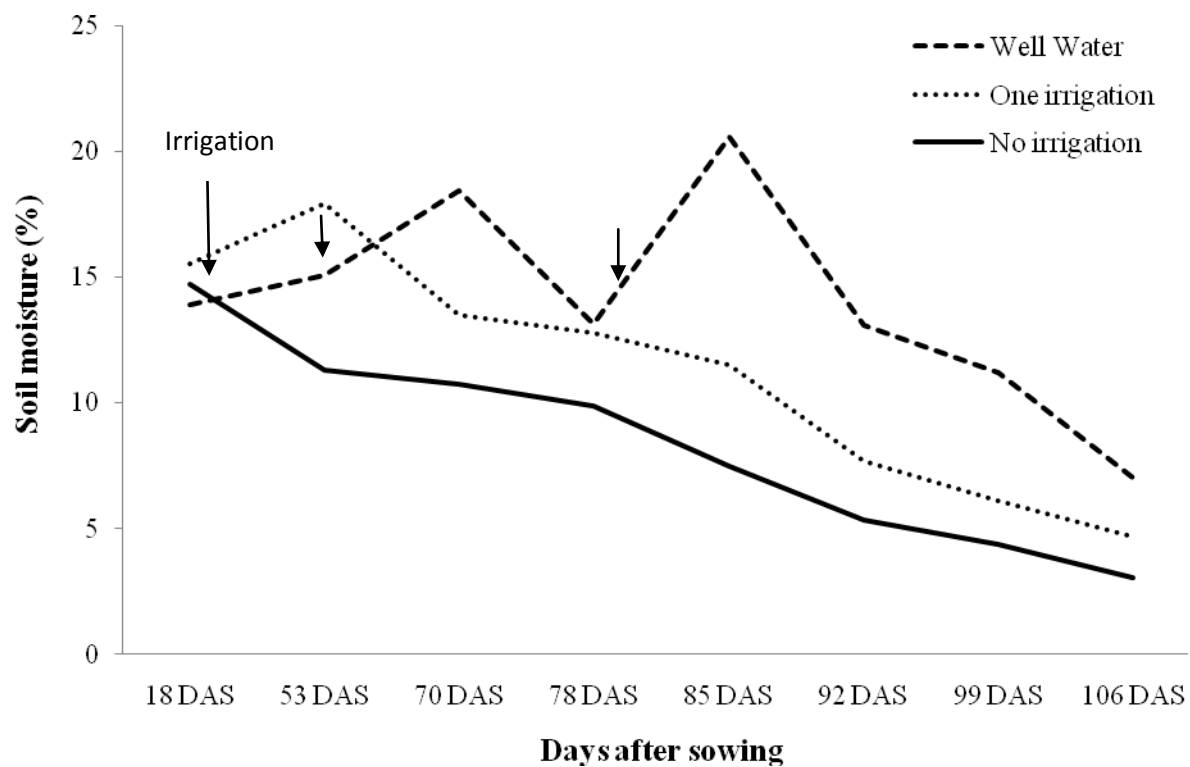


Fig. 3.2.1. Soil moisture content (0-15 cm depth) at different days after sowing (DAS) as influenced by water regimes.

Table 3.2.1. Mean square and co-efficient of variation of different quantitative characters of 30 wheat genotypes as influenced by water regimes and wheat genotypes

Plant Characters	Mean square			CV (%)
	Water regimes (A)	Wheat genotypes (B)	Interaction (A× B)	
Plant height (cm)	403.8128 ^{NS}	136.6974 ^{NS}	95.8262 ^{NS}	10.62
Spike length (cm)	10.3839 *	4.3195**	0.4769 ^{NS}	6.36
Spikelets spike ⁻¹ (no.)	65.1913*	5.3827 **	0.3157 ^{NS}	4.34
Number of spikes m ⁻²	340885.9046 **	9911.4781**	1004.2749 ^{NS}	8.32
No. of grains spike ⁻¹	446.4214 ^{NS}	134.6114 **	14.0292 ^{NS}	8.27
1000-grain weight (g)	45.3572 ^{NS}	76.0524 **	13.6671 ^{NS}	7.88
Grain yield (g m ⁻²)	1896464.0259 **	8184.4573*	7341.1179*	10.53
Biological yield (g m ⁻²)	7940212.8778 **	187496.2176**	37558.9276*	10.38

Table 3.2.2. Range and mean of quantitative characters of 30 wheat genotypes under well water, one irrigation and no irrigation condition

Plant Characters	Well water		One irrigation		No irrigation	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
Plant height (cm)	89.45-121.32	96.08 ± 5.57	86.97-104.83	95.71 ± 4.16	83.02-119.09	92.24 ± 7.81
Spike length (cm)	9.05-12.91	10.33 ± 0.79	8.86-12.23	10.10 ± 0.77	7.95-11.30	9.66 ± 0.73
Spikelets spike ⁻¹ (no.)	15.60-18.63	17.47 ± 0.76	14.57-18.40	17.04 ± 0.81	13.70-17.17	15.83 ± 0.88
Spikes m ⁻² (no.)	396.0-529.0	467. ± 32.82	322.0-516.0	415 ± 41.71	259-420	345 ± 34.01
Grains spike ⁻¹ (no.)	37.69-59.47	48.83 ± 4.44	40.83 - 57.37	46.72 ± 4.12	38.0-54.0	44.38 ± 4.19
1000-grain weight (g)	39.61-52.13	48.27 ± 2.65	43.99 - 52.30	48.63 ± 2.8	38.07-50.57	43.64 ± 4.43
Grain yield (g m ⁻²)	713-904	812 ± 51.13	621-785	720 ± 40.56	434-671	527 ± 57.89
Biol. yield (gm ⁻²)	1406-2176	1775± 194.9	1460-2164	1707 ± 150.68	940-1623	1230 ± 163.86

The height of the no irrigated plants reduced 4% over well watered plants. The result is in agreement with the findings of Bayoumi *et al.* (2008), who reported that the plant height of wheat was reduced by 14.7% due to drought stress. It is reported earlier that the shoot length of wheat genotypes significantly reduced under water stress condition (Khanzada *et al.* 2001, Malik and Hassan 2002). Similarly, Inamullah *et al.* (1999) also observed that the plant height in wheat genotypes reduced significantly under water stress condition as compared with irrigated condition. Reduction in plant height in wheat due to drought was reported by Nouri-Ganbalani *et al.* (2009), Mirbahar *et al.* (2009) and Khakwani *et al.* (2012b). The decrease in plant height in response to water deficit might be due to decrease in relative cell turgidity and dehydration of protoplasm which is associated with a loss of turgor and reduced expansion of cell and cell division (Arnon 1972).

Relative plant height of 30 wheat genotypes at one irrigation condition is presented in the Fig. 3.2.2. The relative value was calculated as the ratio of the height of stressed plants to that of non-stressed plants. These relative values indicated a wide difference in stress tolerance among the wheat genotypes under water deficit condition. Wheat genotypes Shatabdi, E 2, E 3, E 28, E 38, BAW 1130, BAW 1135, BAW 1138, and BAW 1157 showed more than 1.020 relative plant height, the wheat genotypes BARI Gom 25, BARI Gom 26, BARI Gom 27, E 23, E 24, E 29, E 30, E 34,

E 42, BAW 1151, and BAW 1168 provided less than 1.000 relative plant height and the other wheat genotypes showed moderate relative plant height in between 1.020 to 1.000. Fig. 3.2.3 shows the relative value of 30 wheat genotypes based on the plant height at no irrigation. These relative values also indicated a wide difference among the wheat genotypes in water deficit stress tolerance. The wheat genotypes of Shatabdi, E 3, E 18, E 24, E 29, E 34, E 38, E 42, BAW 1130, BAW 1135, BAW 1138, BAW 1140, BAW 1168 and BAW 1170 showed higher relative values (more than 0.960), while the wheat genotypes of BARI Gom 25, BARI Gom 27, BARI Gom 28, E 2, E 23, E 28, E 30, BAW 1143 and BAW 1163 provided

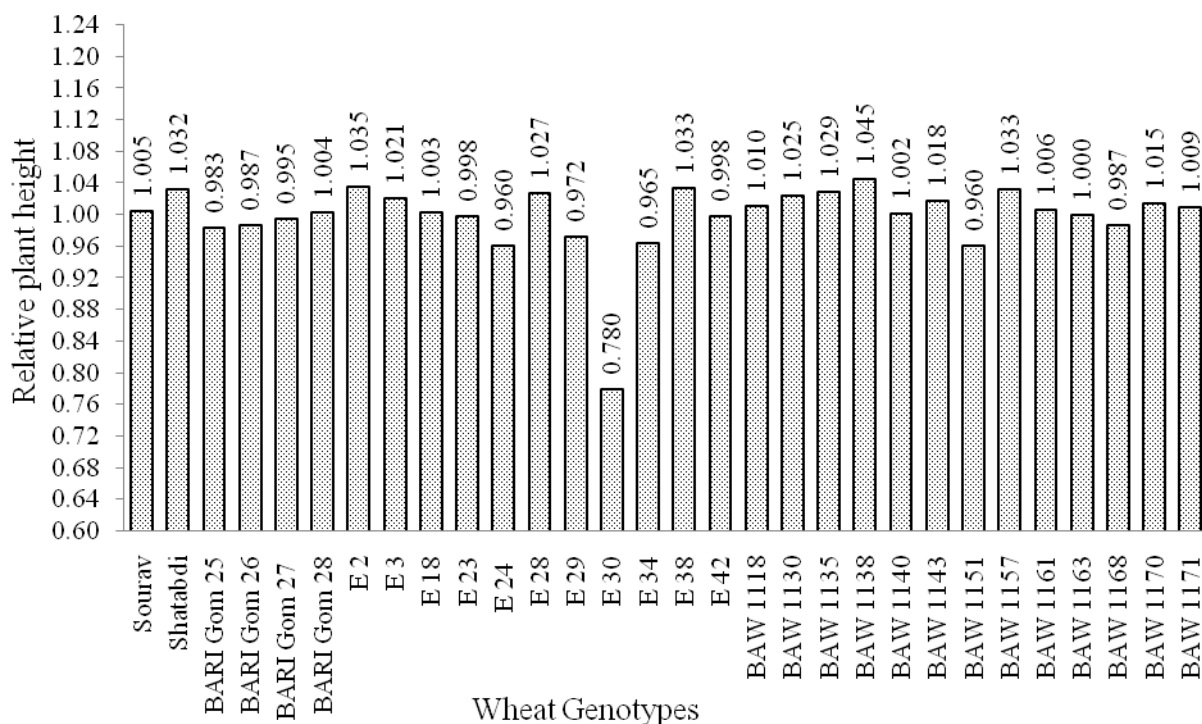


Fig. 3.2.2. Relative plant height of 30 wheat genotypes under one irrigated condition

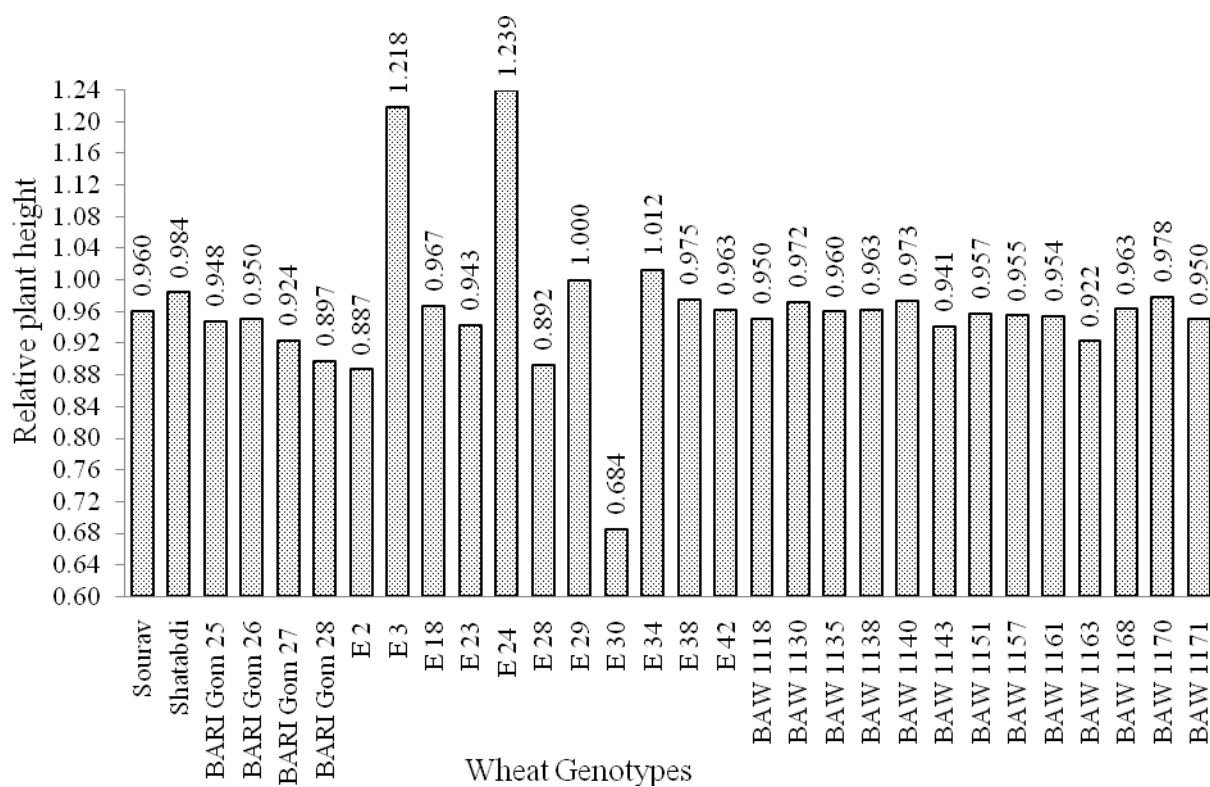


Fig. 3.2.3. Relative plant height of 30 wheat genotypes under no irrigated condition

lower relative values (less than 0.950), and the rest of the wheat genotypes showed moderate relative values (between 0.960 to 0.950).

Spike length

Results of the analysis of variance of the spike length showed a significant difference among water regimes and wheat genotypes but their interaction was insignificant under the study at well water, one irrigation and no irrigation conditions (Table 3.2.1). The spike length in no irrigated plants varied from 7.95 to 11.30 cm with a mean of 9.66 cm, while the spike lengths varied from 8.86 to 12.23 cm with a mean of 10.10 cm in one irrigated plants and varied from 9.05 to 12.91 cm with a mean of 10.33 cm in well watered plants (Table 3.2.2). From this Table it was observed that the spike length reduced from well watered to one irrigated and to no irrigated conditions. These results are in agreement with the findings of Sial *et al.* (2009), Mirbahar *et al.* (2009) and Kiliç and Yağbasanlar (2010) who reported that drought stress significantly reduced the spike length of wheat. Iqbal *et al.* (1999) imposed water stress on durum wheat varieties at various growth stages and reported that drought stress remarkably decreased the spike length while the maximum reduction of spike length was recorded at the flowering.

The relative value of 30 wheat genotypes based on the spike length at one irrigation condition is presented in Fig. 3.2.4. A wide range variation of relative values on the spike length among the wheat genotypes in water deficit condition was observed. However, the higher relative values (more than 1.00) for the spike length were found in the wheat genotypes of Shatabdi, BARI Gom 25, E 28, BAW 1130, BAW 1135, BAW 1138 and BAW 1157 indicating their comparative more drought tolerance capacity, whereas the lower relative values (less than 0.980) were recorded in the wheat genotypes of BARI Gom 26, BARI Gom 27, E 3, E 23, E 24, E 38, BAW 1118, BAW 1140, BAW 1143, BAW 1161, BAW 1168 and BAW 1170 signifying less drought tolerance. The other wheat genotypes showed moderate relative

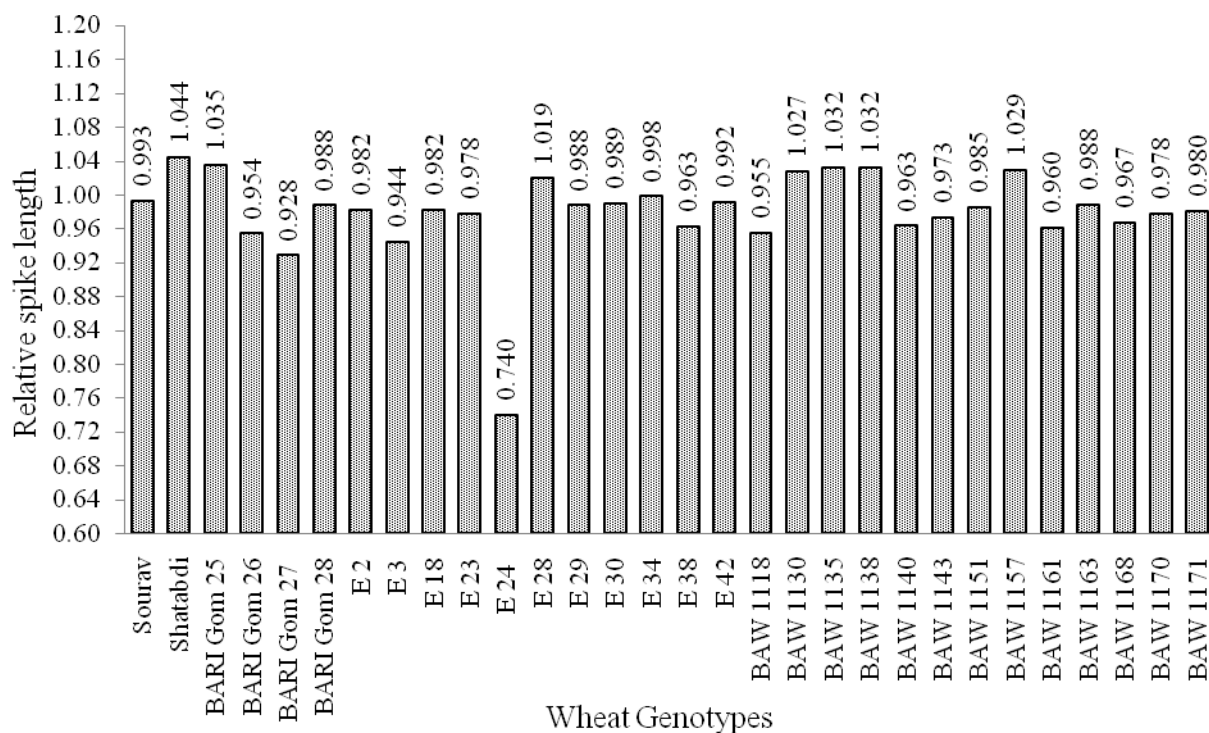


Fig. 3.2.4 Relative spike length of 30 wheat genotypes under one irrigated condition

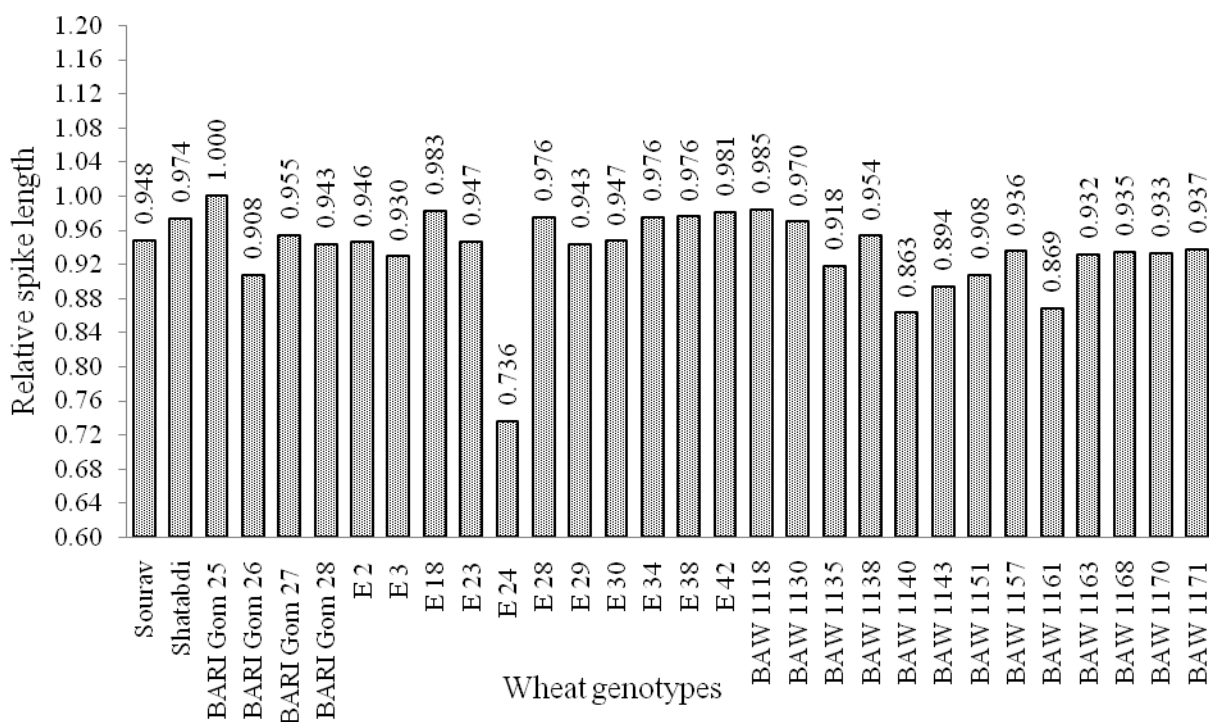


Fig. 3.2.5. Relative spike length of 30 wheat genotypes under no irrigated condition

values in between 1.00 and 0.980 performing their moderate drought tolerance. Fig. 3.2.5 shows the relative values of 30 wheat genotypes based on spike length at no irrigated condition. These relative values indicated an extensive difference among the wheat genotypes in no irrigated condition. However, the relative values observed greater than 0.960 in Shatabdi, BARI Gom 25, E18, E 28, E 34, E 38, E 42, BAW 1118, and BAW 1130 wheat genotypes, whereas the relative values showed lesser than 0.920 in the wheat genotypes BARI Gom 26, E 24, BAW 1135, BAW 1140, BAW 1143, BAW 1151 and BAW 1161, showing their drought susceptibility. The additional genotypes demonstrated moderate relative values in between 0.96 and 0.920. The results in this study are corroborated with the findings of Mirbahar *et al.* (2009) who observed that the spike length of wheat decreased severely in the stress susceptible genotypes and very less in stress tolerant ones. Iqbal *et al.* (1999) reported that water stress at flowering stage remarkably reduced the spike length of durum wheat varieties.

Number of spikelets spike⁻¹

The analysis of variance showed significant differences among the different levels of water regimes and the differences among wheat genotypes were highly significant for the measuring traits on the number of spikelets per spike but their interactions were non-significant (Table 3.2.1). The highest and the lowest number of spikelets spike⁻¹ (18.63 and 15.60, 18.40 and 14.57, 17.17 and 13.70) were recorded at well watered, one irrigation and no irrigation conditions, respectively (Table 3.2.2). Similar view was expressed by Musick and Dusek (1980), and Hussain *et al.* (1987) who reported a decrease in the number of spikelets spike⁻¹ under water stress of wheat at jointing stage of growth. Shalaby *et al.* (1988) reported that drought at late tillering stage in wheat caused a significant reduction in number of spikelets spike⁻¹. Shehzadi (1999) and Dencic *et al.* (2000) also concluded that the number of spikelets spike⁻¹ is more sensitive to drought stress in wheat varieties. The relative values considering the wheat genotypes at one irrigated condition are presented in Fig. 3.2.6. The

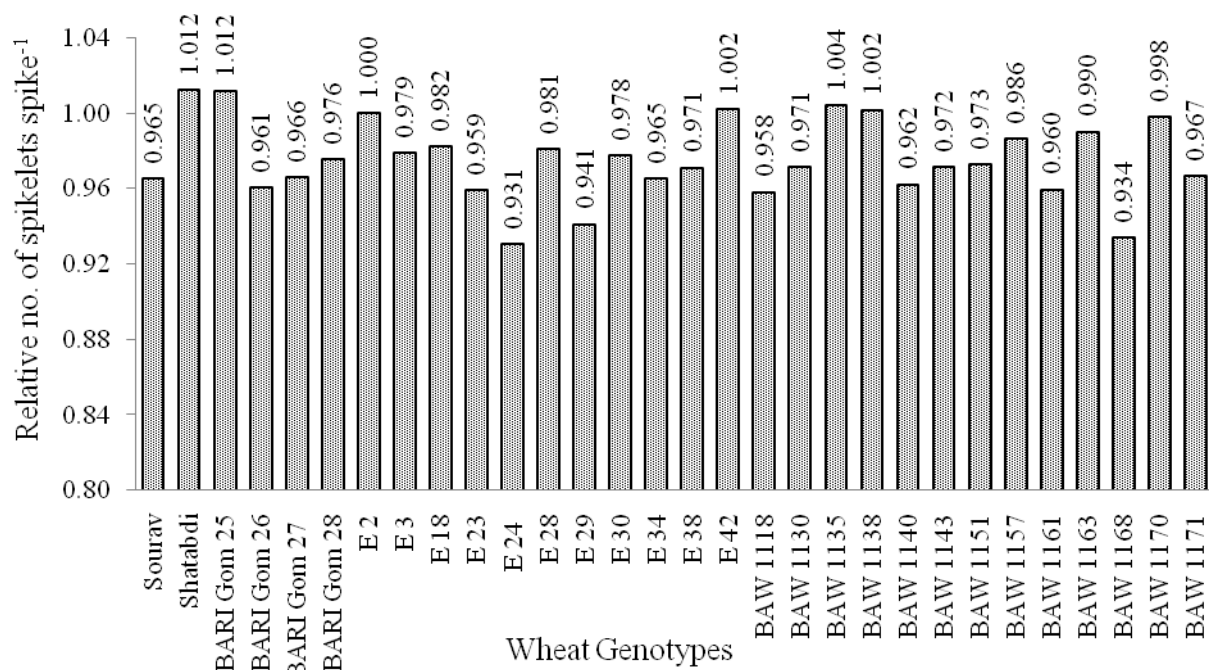


Fig. 3.2.6. Relative number of spikelets spike⁻¹ of 30 wheat genotypes under one irrigated condition

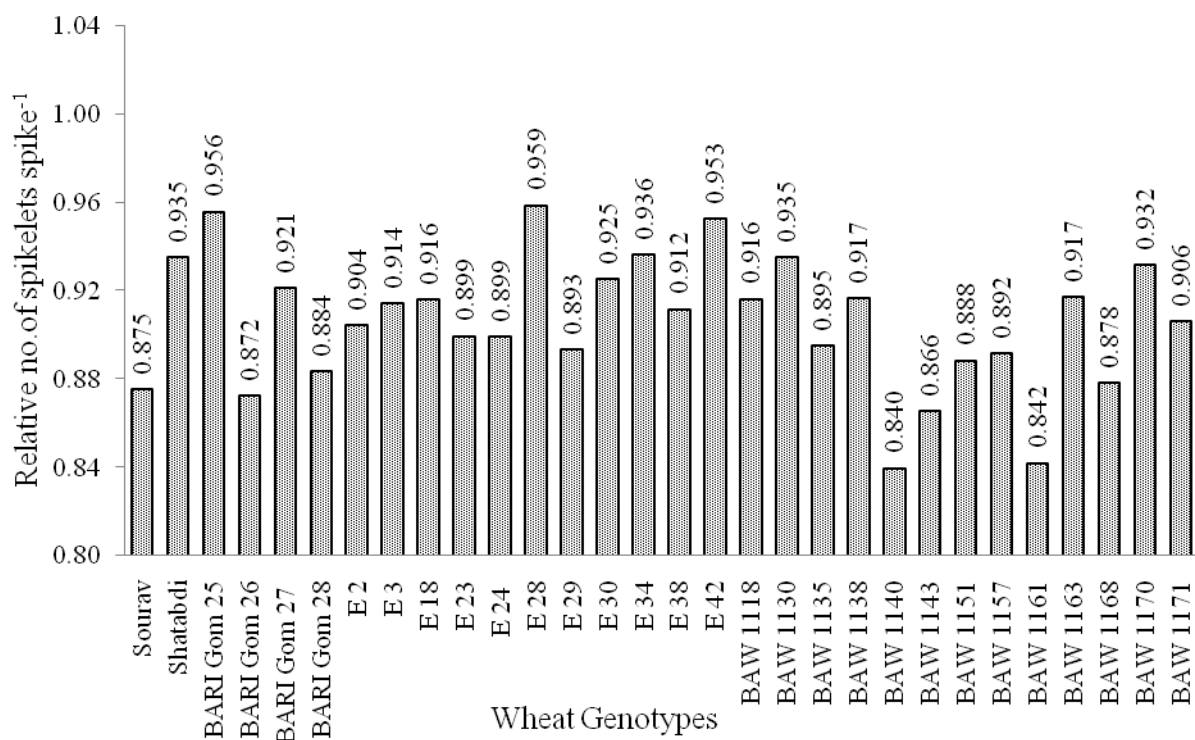


Fig. 3.2.7. Relative number of spikelets spike⁻¹ of 30 wheat genotypes under no irrigated condition

magnitude of differences of the relative values (regarding the number of spikelets spike⁻¹) among the wheat genotypes was higher in water deficit stress tolerance. Nevertheless, in one irrigated condition the wheat genotypes Shatabdi, BARI Gom 25, E 2, E 18, E 28, E 42, BAW 1135, BAW 1138, BAW 1157, BAW 1163 and BAW 1170 showed more than 0.980 relative values, indicating high stress tolerance genotypes, whereas, the wheat genotypes E 23, E 24, E 29, BAW 1118, and BAW 1168 showed less than 0.960 relative values and specifying their less stress tolerance i.e. susceptible genotypes. The other wheat genotypes showed moderate relative values within 0.980 and 0.960. The relative values regarding the number of spikelets spike⁻¹ at no irrigation condition of wheat genotypes demonstrated wide variations (Fig. 3.2.7).

Higher values of relative number spikelets spike⁻¹ under no irrigation condition indicates higher stress tolerance, and the wheat genotypes Shatabdi, BARI Gom 25, BARI Gom 27, E 28, E 30, E 34, E 42, BAW 1130 and BAW 1170, relative values can be treated as tolerant genotypes due to showing their higher values of relative number of spikelets spike⁻¹ (more than 0.920) (Fig. 3.2.7). On the other hand, the genotypes Sourav, BARI Gom 26, BAW 1140 BAW 1143, BAW 1161 and BAW 1168, can be considered as susceptible by counting their less relative values (less than 0.88). The other genotypes showed relative values in between 0.920 and 0.880.

Number of spikes m⁻²

Table 3.2.1 (analysis of variance) showed highly significant differences among the water regimes, and different wheat genotypes, although did not show any significant difference for their interaction on the number of spikes m⁻² under different water stress treatments. The number of spikes m⁻² decreased with the advancement of water deficit conditions. However, the average number of spikes m⁻² of 467 (varied from 396-529), 415 (varied from 322-516) and 345 (varied from 259-420) were recorded at well watered, one irrigated and no irrigated conditions, respectively (Table 3.2.2). The relative value of the number of spikes m⁻² was

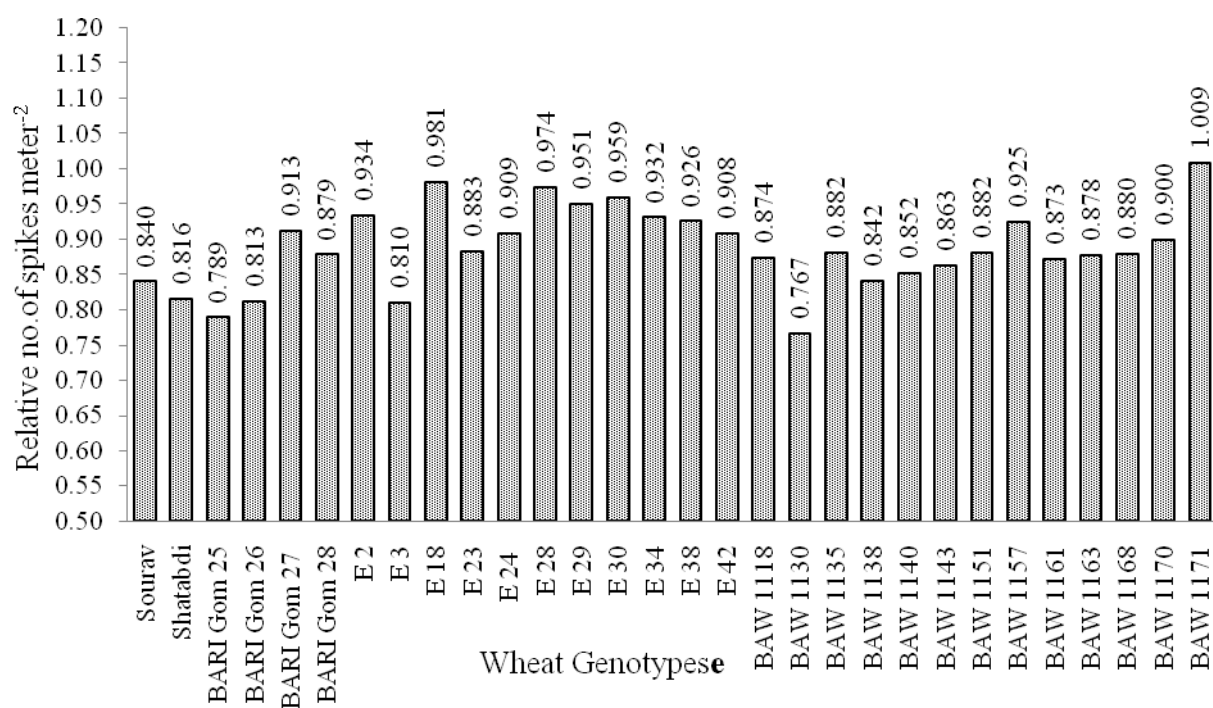


Fig. 3.2.8. Relative number of spikes meter⁻² of 30 wheat genotypes under one irrigated condition

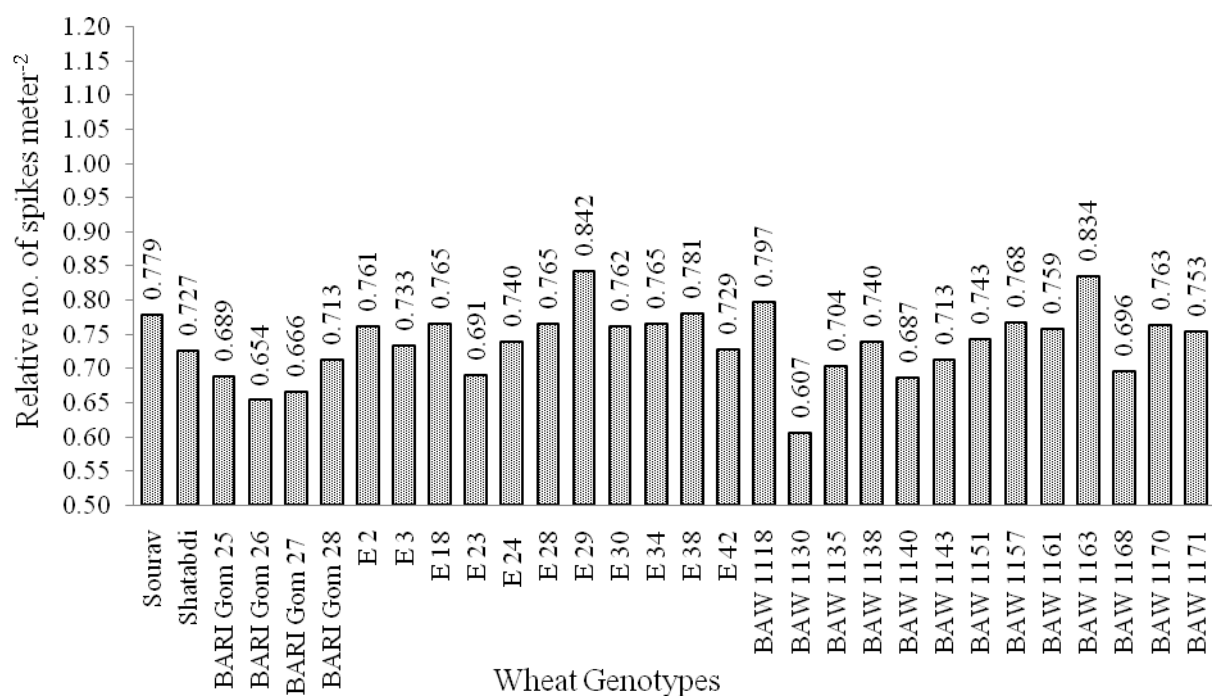


Fig. 3.2.9 Relative number of spikes meter⁻² of 30 wheat genotypes under no irrigated condition

calculated as the ratio of the number of spikes of stressed plants to that of non-stressed plants, and the relative value was calculated on the basis of relative performance. Drought stress caused a reduction in the number of effective tillers plant⁻¹ by 36.3% (Bayoumi *et al.* 2008) and 35% (Khakwani *et al.* 2012b). Akram (2011) observed that the number of tillers m⁻² was affected significantly by different water stress treatments. The relative values of 30 wheat genotypes based on the number of spikes m⁻² at one irrigated condition are presented in Fig. 3.2.8. The relative number of spikes m⁻² of wheat genotypes was calculated based on relative value for the aforesaid trait among the wheat genotypes, and the relative values indicated a spacious difference in water deficit stress tolerance. In one irrigation condition, the wheat genotypes of BARI Gom 27, E 2, E 18, E 24, E 28, E 29, E 30, E 34, E 38, E 42, BAW 1157, and BAW 1171 showed more than 0.900 relative values, and higher relative values indicating their drought tolerance, while the wheat genotypes of Sourav, Shatabdi, BARI Gom 25, BARI Gom 26, E 3, BAW 1130 and BAW 1138, provided less than 0.850 relative values showing drought susceptible genotypes. The other wheat genotypes showed relative values in between 0.900 and 0.850 which designate moderate level of drought tolerance at the same condition.

Fig. 3.2.9 shows the relative values of 30 wheat genotypes based on number of spikes m⁻² at no irrigated condition. These relative values also indicated a wide difference in water deficit stress tolerance among the wheat genotypes. Wheat genotypes Sourav, E 2, E 18, E 28, E 29, E 30, E 34, E 38, BAW 1118, BAW 1157, BAW 1163 and BAW 1170 showed more than 0.760 relative values, the wheat genotypes BARI Gom 25, BARI Gom 26, BARI Gom 27, E 23, BAW 1130, BAW 1140, and BAW 1168 provided less than 0.700 relative values, and the other wheat genotypes showed relative values in between 0.760 and 0.700, signifying their maximum, minimum, and moderate drought tolerance genotypes, respectively.

Number of grains spike⁻¹

The results of the analysis of variance showed that the water regimes did not influence the number of grains per spike but it varied significantly among genotypes. The interaction effect of water regimes and wheat genotypes was insignificant for the number of grains per spike (Table 3.2.1). However, the plants under three levels of water regimes like well water, one irrigation and no irrigation conditions produced the mean number of grains per spike of 48.83 (ranging from 37.69 to 59.47), 46.72 (ranging from 40.83 to 57.37), and 44.38 (ranging from 38.0 to 54.0), respectively. The results revealed that the number of grains per spike gradually decreased with increasing water deficit stress (Table 3.2.2). Water stress throughout vegetative and reproductive stages caused a significant reduction in the number of grains spike⁻¹ in wheat as reported earlier by Qadir *et al.* (1999) and Khanzada *et al.* (2001). The maximum reduction in number of grains spike⁻¹ in wheat due to moisture stress at flowering stage has been reported by Warriar and Bhardwaj (1987) and Iqbal *et al.* (1999). Khannachopra *et al.* (1994) also reported the reduction of number of grains spike⁻¹ in wheat under water stress, but the extent of reduction was varied with nature of genotypes. Elhafid *et al.* (1998) demonstrated that drought stress reduced the pollination and consequently the reduced the number of grains spike⁻¹. Tompkins *et al.* (1991) reported a significant suppressive effect of water stress on number of grains spike⁻¹. Well watered plants produced 10% higher grains spike⁻¹ as compared to drought stress at anthesis stage (Akram 2011). Aggarwal and Sinha (1987) reported that the wheat varieties having low yield potentials which were susceptible to drought generated lower number of grains spike⁻¹ and thereby produced lower yield. A huge difference of relative values among the wheat genotypes was observed in one irrigated conditions (Fig. 3.2.10). Wheat genotypes of Sourav, Shatabdi, BARI Gom 25, BARI Gom 28, E 3, E 23, E 30, BAW 1135, BAW 1143, BAW 1168 and BAW 1170, showed more than 0.980 relative values be a sign of drought tolerant genotypes. Contrary, the wheat genotypes BARI Gom 26, BARI Gom 27, E 2, E 29, E 34, E 38, BAW

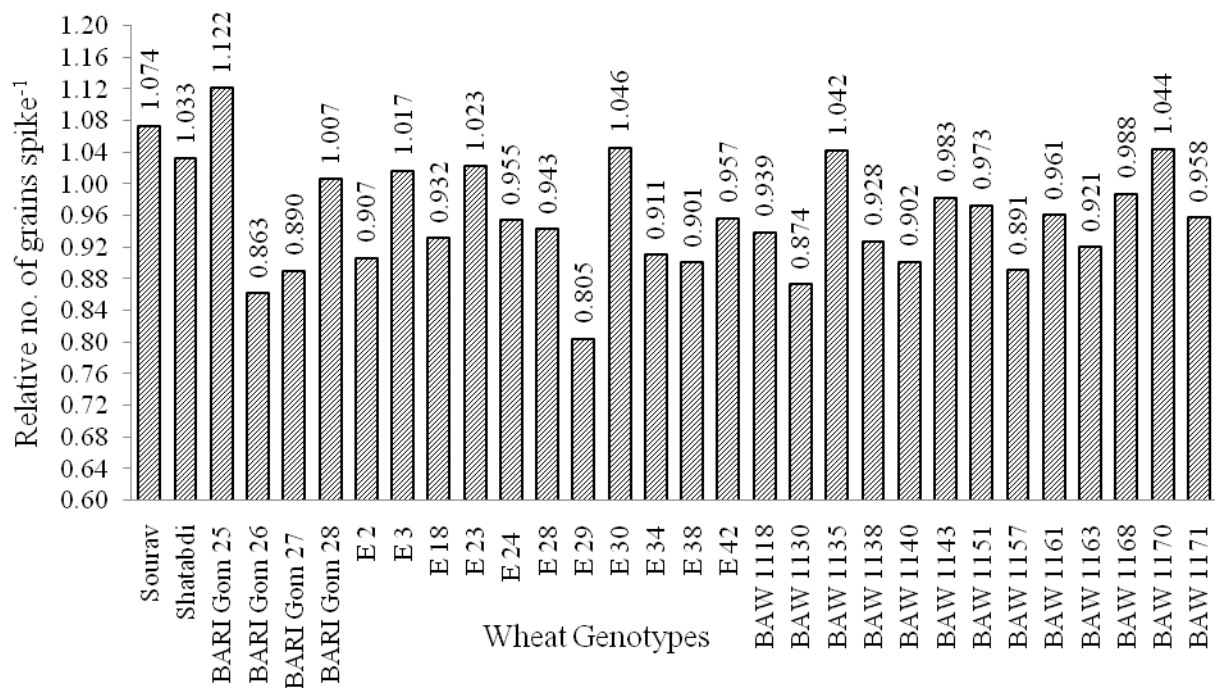


Fig. 3.2.10. Relative number of grains spike⁻¹ of 30 wheat genotypes under one irrigated condition

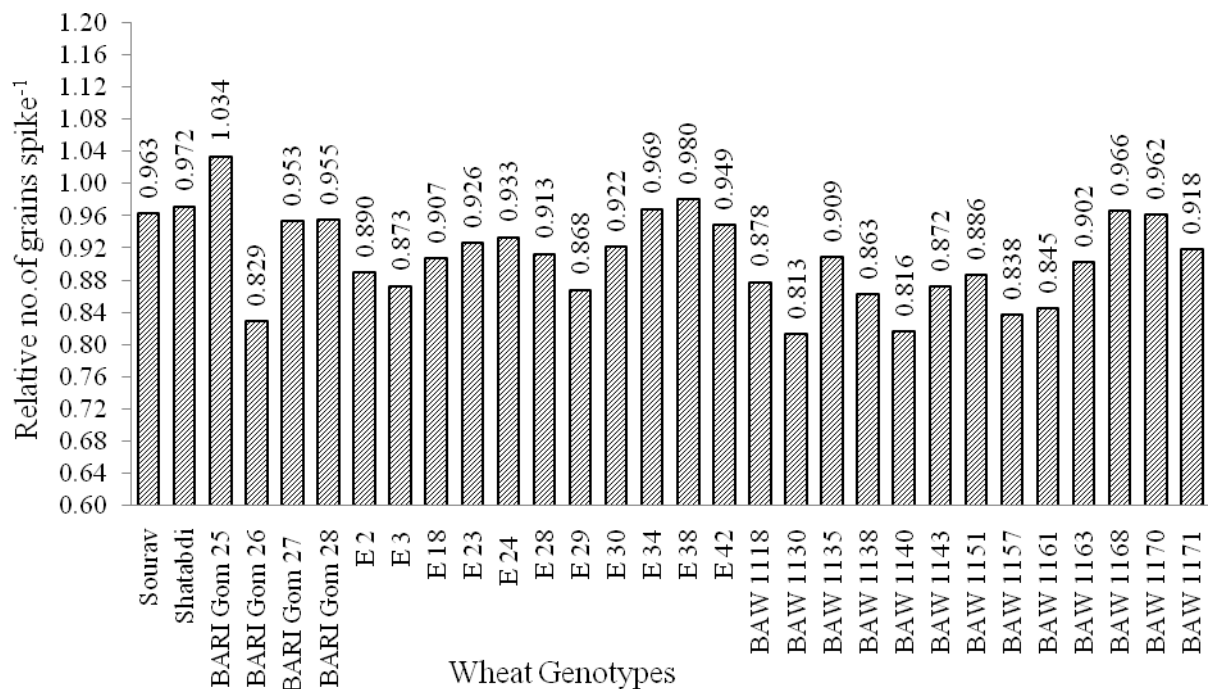


Fig. 3.2.11. Relative number of grains spike⁻¹ of 30 wheat genotypes under no irrigated condition

1163, BAW 1130, BAW 1140 and BAW 1157, exhibited less than 0.920 relative values showing drought susceptible genotypes, and rest of the genotypes showed medium relative values in between 0.980 to 0.920. Fig. 3.2.11 shows the relative values of thirty wheat genotypes based on the number of grains spike⁻¹ at no irrigated conditions. These relative values indicated an extensive difference in water deficit stress tolerance among the wheat genotypes. The higher relative values (> 0.930) were recorded in the wheat genotypes of Sourav, Shatabdi, BARI Gom 25, BARI Gom 27, BARI Gom 28, E 24, E 34, E 38, E 42, BAW 1168 and BAW 1170 whereas the lower relative values (> 0.880) were obtained in the genotypes of BARI Gom 26, E 3, E 29, BAW 1118, BAW 1130, BAW 1138, BAW 1140, BAW 1143, BAW 1157, and BAW 1161. The moderate relative values (from 0.930 to 0.880) produce the other remaining genotypes, and the higher and lower relative values generating genotypes can be treated as tolerant and susceptible genotypes.

Thousand grain weight

The analysis of variance on producing the thousand grain weight showed that there was no significant difference among water regimes but showed a highly significant difference among genotypes although their interaction effect was non-significant (Table 3.2.1). In wheat genotypes, variable water regimes caused remarkable variation in 1000-grain weight which varied from 38.07 to 50.57 with a mean of 43.64 in no irrigated plants, 43.99 to 52.30 with a mean of 48.63 in one irrigated plants and from 39.61 to 52.13 with a mean of 48.27, respectively in well watered plants throughout the growing season (Table 3.2.2). Drastic decrease in 1000-grain weight in wheat was recorded during terminal drought followed by post flowering drought (Mirbahar *et al.* 2009). This result is in agreement with those reported by Khan *et al.* (2005) and Qadir *et al.* (1999) who observed that 1000-grain weight in wheat was reduced mainly due to increasing water stress.

The decrease in 1000-grains weight under stress condition might be caused due to disturbed nutrient uptake efficiency and photosynthate translocation (Iqbal *et al.* 1999) that produced

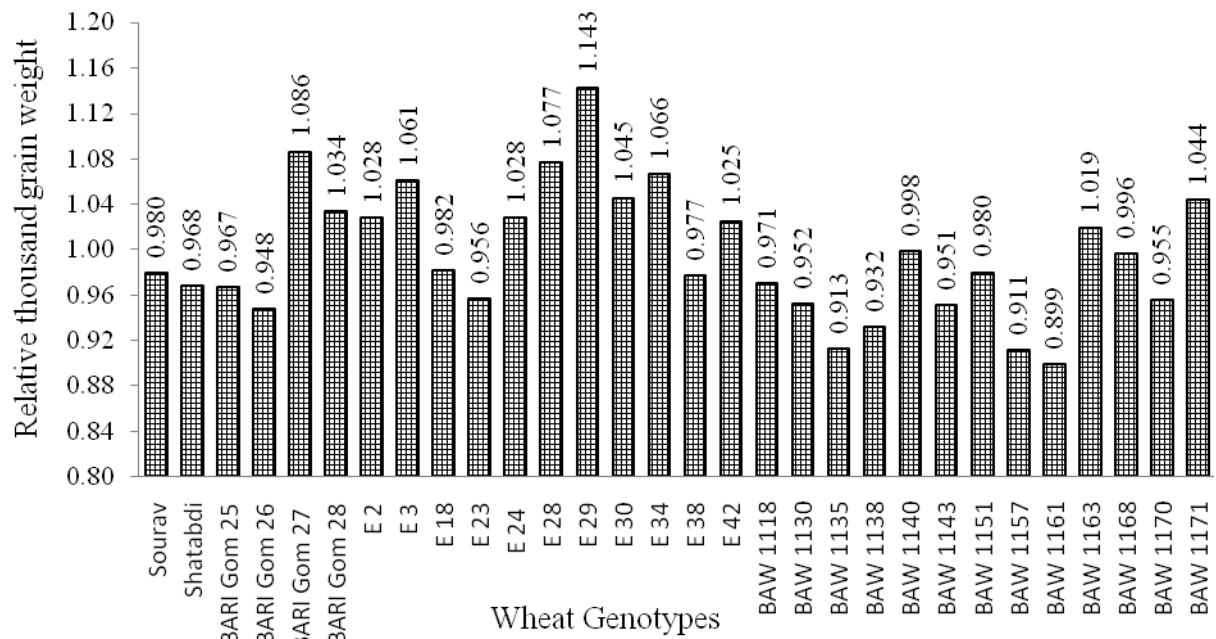


Fig. 3.2.12 Relative thousand grain weight of 30 wheat genotypes under one irrigated condition

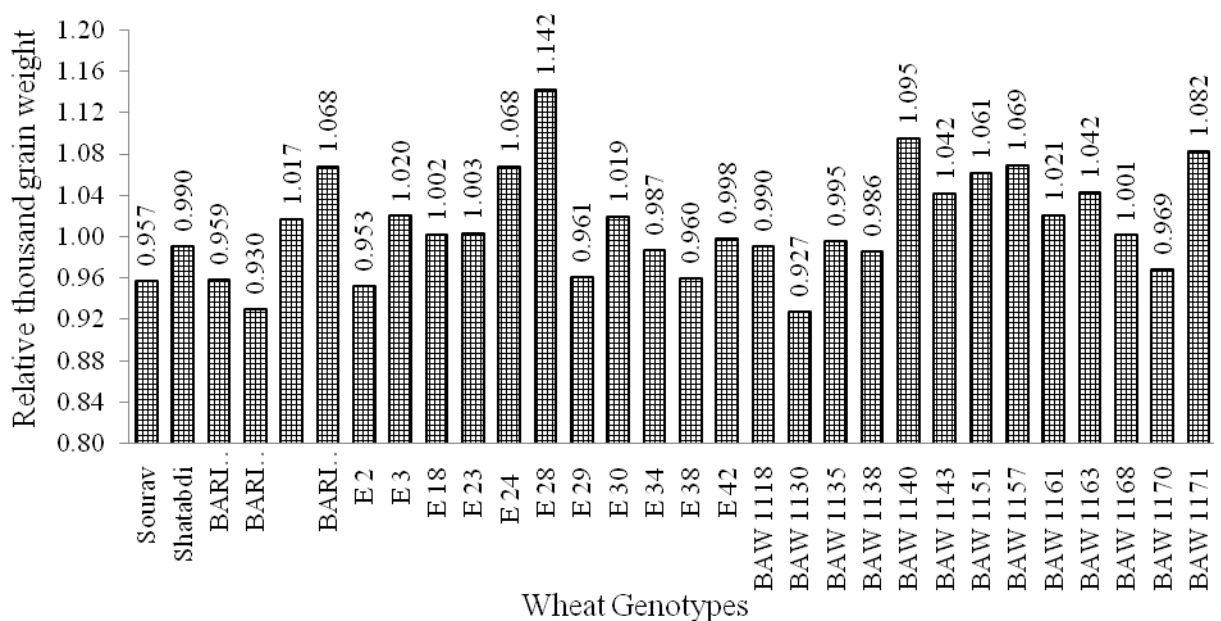


Fig. 3.2.13. Relative thousand grain weight of 30 wheat genotypes under no irrigated condition

shrivelled grains by accelerating maturity of the plant. This is possible due to the shortage of moisture which forces plant to complete its grain formation in relatively lesser time (Riaz and Chowdhry 2003). The relative performance of 1000-grain weight calculated as the ratio of grain weight of stressed plants to that of non-stressed plants. The relative thousand grain weight of 30 wheat genotypes was calculated based on the relative performance for the traits number of thousand grain weight at one irrigated condition is presented in Fig. 3.2.12. These relative values indicated a vast difference in water deficit stress tolerance among the wheat genotypes. Wheat genotypes BARI Gom 27, BARI Gom 28, E 2, E 3, E 24, E 28, E 29, E 30, E 34, E 42, BAW 1163 and BAW 1171 showed more than 1.020 relative value, the wheat genotypes BARI Gom 26, E 23, BAW 1130, BAW 1135, BAW 1138, BAW 1143, BAW 1157 BAW 1161 and BAW 1170 showed less than 0.960 relative values and the other wheat genotypes showed relative values in between 1.020 and 0.960.

Fig. 3.2.13 shows relative thousand grain weight of 30 wheat genotypes at no irrigated conditions. These relative values indicated an extensive difference in water deficit stress tolerance among the wheat genotypes. In genotypes BARI Gom 28, E 24, E 28, BAW 1140, BAW 1143, BAW 1151, BAW 1157, BAW 1161, BAW 1163 and BAW 1171 showed higher relative values more than 1.020 , and the genotypes Sourav, BARI Gom 25, BARI Gom 26, E 2, E 29, E 34, E 38, and BAW 1130, BAW 1138 and BAW 1170 showed less than 0.990 and genotypes E 42, Shatabdi, BARI Gom 27, E 3, E 18, E 23, E 30, BAW 1118, BAW 1135 and BAW 1168 lies the relative values between 1.020 to 0.990. The decrease in TGW might be caused due to disturbed nutrient uptake efficiency and photosynthate translocation that resulted in shriveled grains accelerating plant maturity (Iqbal *et al.* 1999). This is possible due to the shortage of moisture which forces plant to complete its grain formation in relatively lesser time (Riaz and Chowdhry 2003). The result of this study is in agreement with the findings of Iqbal *et al.* (1999) and Bayoumi *et al.* (2008) who reported that compared to well-watered genotypes, drought caused reductions in TGW by 31.98% and 16.4%, respectively. Similar results were also reported by Mirbahar *et al.* (2009), Khan *et al.* (2005) and Qadir *et al.* (1999) who found that the TGW of wheat was reduced mainly due to increasing water stress.

Grain yield

Results of the analysis of variance on grain yield showed a highly significant difference among the water regimes, a significant difference among wheat genotypes and also varied widely with their interaction effect (Table 3.2.1). The grain yield ranged from 434 to 671 g m⁻² with a mean of 527 g m⁻² in no irrigated plants, 621 to 785 g m⁻² with a mean of 720 g m⁻² in one irrigated plants and from 713 to 904 g m⁻² with a mean of 812 g m⁻² in well watered plants (Table 3.2.2). From this Table, it was observed that the grain yield decreased with increase of water deficit condition in soil. The reason for lower grain yield under water stress condition was mainly due to reduction of yield traits. The reduced number of effective tillers plant⁻¹, length of spike, number of grains spike⁻¹ and 1000-grain weight are the main reasons for reducing the grain yield of wheat. Blum (2005) mentioned that drought stress may occur throughout the growing season either early or late growth phases of the crop, but its effect on yield reduction is the most prominent when it occurs after anthesis. The average yield loss of 17-70, 43.20 and 58-82% in wheat due to drought stress was estimated by Edmeades *et al.* (1994), Bayoumi *et al.* (2008) and Khakwani *et al.* (2012a), respectively. Chandler and Singh (2008) also reported that both grain yield and biological yield in wheat showed maximum sensitivity to moisture stress.

The relative value of grain yield calculated as the ratio of grain weight of stressed plants to that of non-stressed plants. The relative grain yield of wheat genotypes was calculated based on relative value for the trait number of grain yield at one irrigated condition are presented in Fig. 3.2.14. The relative values indicated a vast difference in water deficit stress tolerance among the wheat genotypes. Wheat genotypes E 18, E 23, E 24, E 30, E 42, BAW 1118, BAW 1135, BAW 1168, BAW 1170 and BAW 1171 showed more than 0.900 relative values indicating drought tolerant genotypes, on the other hand, Shatabdi, BARI Gom 27, BARI Gom 28, BAW 1130, BAW 1138, BAW 1140, BAW 1143 and BAW 1163 showed less than 0.850 relative values designating drought susceptible genotypes, and the other wheat

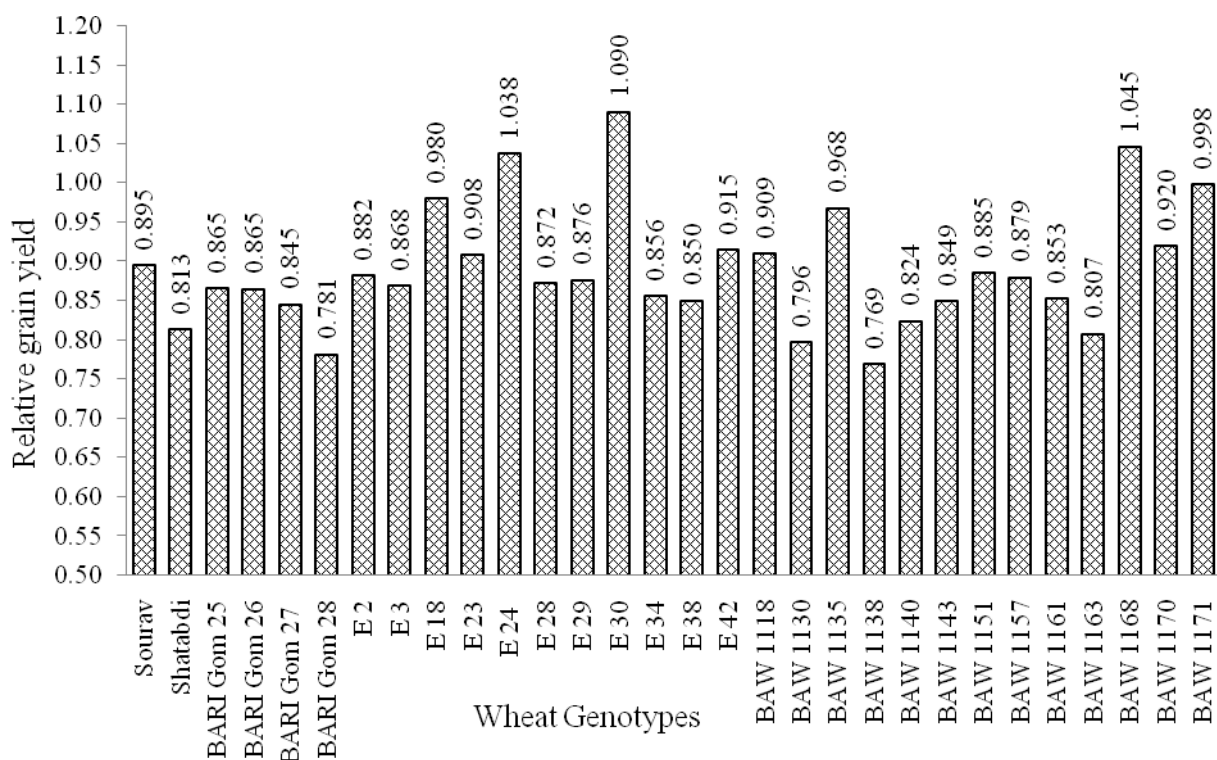


Fig. 3.2.14. Relative grain yield of 30 wheat genotypes under one irrigated condition

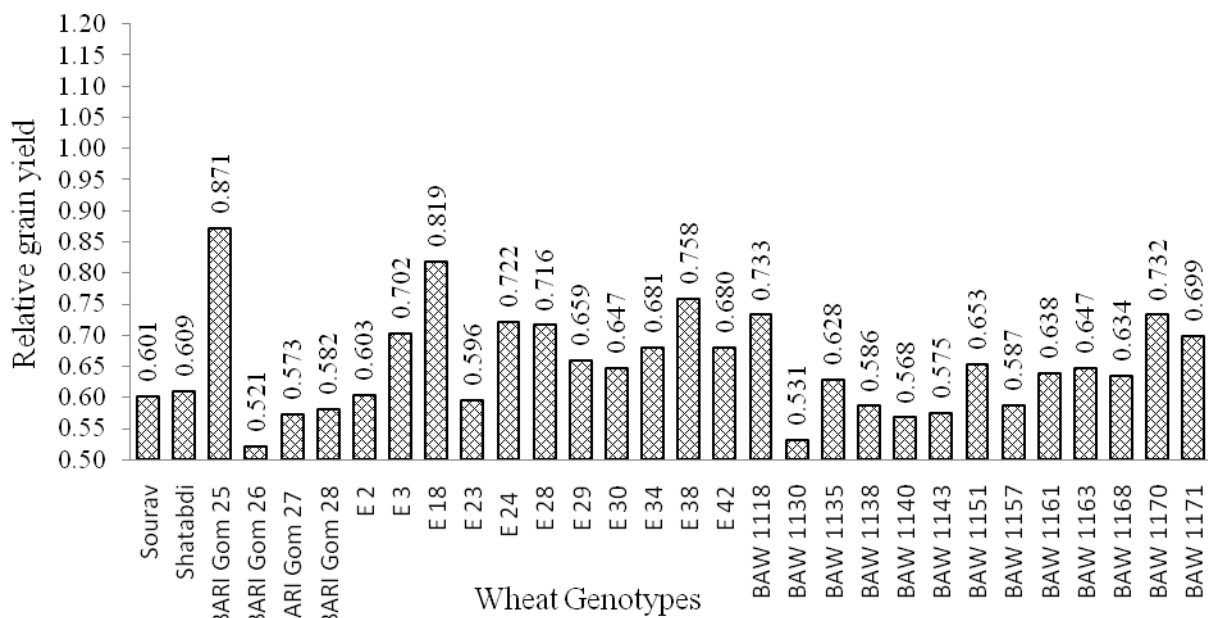


Fig. 3.2.15. Relative grain yield of 30 wheat genotypes under no irrigated condition

genotypes provided relative values in between 0.900 and 0.850 showing moderate genotypes. The relative grain yield of wheat genotypes based on relative value for the traits number of grain yield at no irrigated conditions are presented in Fig. 3.2.15. However, wheat genotypes provided an extensive relative values in no irrigated condition. In no irrigated condition, higher relative values (>0.680) were recorded in the wheat genotypes of BARI Gom 25, E 3, E 18, E 24, E 28, E 34, E 38, BAW 1118, BAW 1170 and BAW 1171, which can be delighted as drought tolerant genotypes and the highest relative value was in BARI Gom 25 followed by E 18, E 38, BAW 1118, BAW 1170, E 24, E 28, E 3, BAW 1171 and E 34. On the other hand, lower relative values (<0.600) were obtained in the genotypes of BARI Gom 26, BARI Gom 27, BARI Gom 28, E 23, BAW 1130, BAW 1138, BAW 1140, BAW 1143 and BAW 1157, these genotypes can be treated as drought susceptible and the lowest relative value was in BARI Gom 26 followed by BAW 1130, BAW 1140, BARI Gom 27, BAW 1143, BARI Gom 28, BAW 1138, BAW 1157, and E 23. Moreover, the other genotypes showed relative value in between 0.680 and 0.600 indicating moderate drought tolerant genotypes.

The average grain yield of wheat genotypes was reduced by 43.2% (Bayoumi *et al.* 2008) and 50% (Nouri-Ganbalani *et al.* 2009) under the drought stress conditions. Edmeades *et al.* (1994) have also estimated that the average grain yield loss by 17 to 70% due to drought stress. Drought stress after anthesis severely reduced the grain yield (Blum 2005). Water stress at anthesis reduces pollination and thus forms less number of grains per spike which results in the reduction of grain yield (Ashraf 1998). Adequate water at or after anthesis period not only allows the plant to increase photosynthesis rate but also gives extra time to translocate the carbohydrate to grains (Zhang and Oweis 1998) which improves grain size and thereby leads to increase in grain yield.

Biological yield

Among water regimes results of the analysis of variance showed highly significant difference and highly significant difference among genotypes and also significant in interaction for the biological yield (g m^{-2}) under study at well water, one irrigated and as

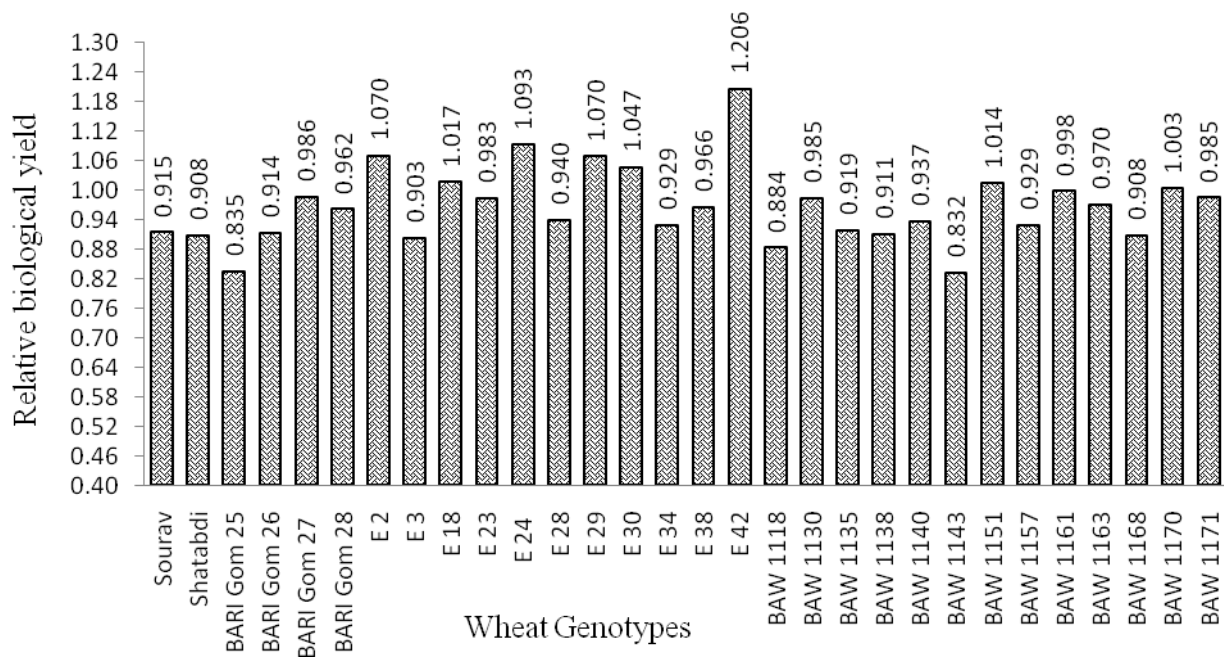


Fig. 3.2.16. Relative biological yield of 30 wheat genotypes under one irrigated condition

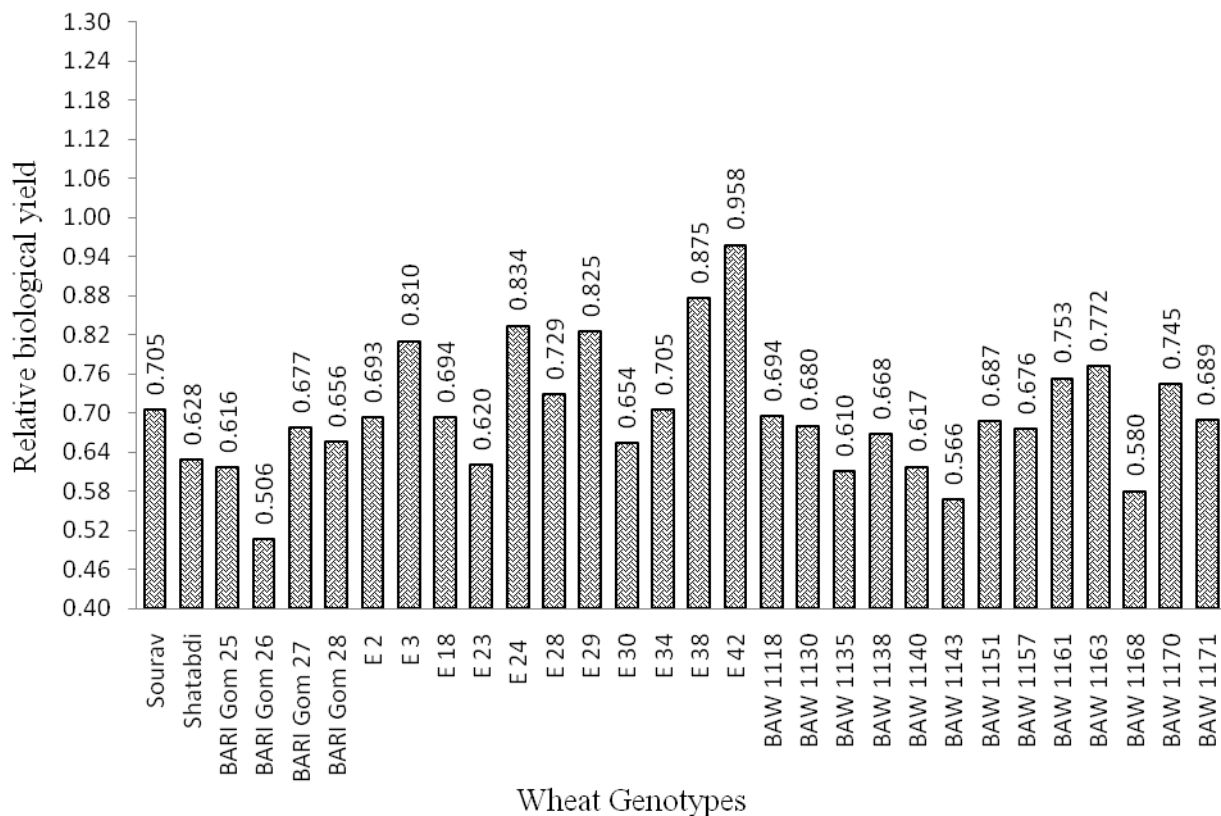


Fig. 3.2.17. Relative biological yield of 30 wheat genotypes under no irrigated condition

well as no irrigated conditions (Table 3.2.1). Biological yield (g m^{-2}) ranged from 940 to 1623 g m^{-2} with a mean of 1230 g m^{-2} in no irrigated plants, 1460 to 2164 g m^{-2} with a mean of 1707 g m^{-2} in one irrigated plants and from 1406 to 2176 g m^{-2} with a mean of 1775 g m^{-2} in well watered plants (Table 3.2.2). This table also showed that biological yield (g m^{-2}) range and mean decreased with increase water stressed condition in soil. Mirbahar *et al.* (2009) concluded that biological yield plant^{-1} was reduced by 39 to 48% under moisture stress condition. The results of the present study are in agreement with the findings of Bayoumi *et al.* (2008) who reported that drought cause reduction of biological yield by 32.9%. Biological yield per plant decreased under stressed environment which is also mentioned by Chandler and Singh (2008) who reported that the grain yield and biological yield particularly showed maximum sensitivity to moisture stress. The relative biological yield of 30 wheat genotypes at one irrigation condition is presented in Fig. 3.2.16. Relative performance was calculated on the biological yield (g m^{-2}) of stressed plants to that of non-stressed plants, and relative value was calculated on the basis of relative performance, these relative values indicated a spacious difference in water deficit stress tolerance. Wheat genotypes BARI Gom 27, E 2, E 18, E 23, E 24, E 29, E 30, E 42, BAW 1130, BAW 1151, BAW 1161, BAW 1170 and BAW 1171 showed > 0.980 relative values, the wheat genotypes Sourav, Shatabdi, BARI Gom 25, BARI Gom 26, E 3, BAW 1118, BAW1135, BAW 1138, BAW 1143 and BAW 1168, provided < 0.920 relative values. Figure 3.2.17 shows the relative values of 30 wheat genotypes based on biological yield (g m^{-2}) at no irrigated condition. These relative values also indicated a wide difference in water deficit stress tolerance among the wheat genotypes. Wheat genotypes Sourav, E 3, E 24, E 28, E 29, E 34, E 38, E 42, BAW 1161, BAW 1163, and BAW 1170 showed > 0.700 relative values, the wheat genotypes Shatabdi, BARI Gom 25, BARI Gom 26, E 23, BAW 1135, BAW 1140, BAW 1143 and BAW 1168 provided < 0.650 relative values and rest genotypes showed within 0.700 to 0.650.

It was observed that the genotypes which possessed the higher relative value based on the yield traits and yield are affected less by water deficit stress and these genotypes can be treated as drought tolerant genotypes i.e. these genotypes are stress tolerance genotypes. Contrary, the genotypes provided less relative values are less affected by water deficit stress and these genotypes can be designated as stress susceptible genotypes. The relative performance based on relative values of the plant characters were used in order to make the more meaningful comparison towards identifying genotypes or groups of genotypes tolerant to water deficit.

3.2.17. Grouping of genotypes through cluster analysis and principal component analysis

Cluster analysis

Cluster analysis is one of the multivariate techniques main objective of which is to group individuals based on their characteristics, so that individuals with similar description are mathematically gathered into the same cluster. The clusters formed should show higher homogeneity within clusters and heterogeneity between clusters. Thus, if the classification is successful, individuals within a cluster come closer when plotted geometrically and different clusters are plotted apart (Hair *et al.* 1995). Hierarchical clustering methods are generally used in analysis of genetic diversity in crop species. Cluster analysis was used for grouping the 30 wheat genotypes used for screening of water deficit tolerance. Although relative values of the plant characters were used in order to make the more meaningful comparison towards identifying genotypes or groups of genotypes tolerant to water deficit and also cluster analysis was used for grouping of 30 wheat genotypes.

Wheat genotypes were categorized in five clustering using the relative plant height, spike m^{-2} , number of grains spike $^{-1}$, 1000-grain weight, spike length, spikelets spike $^{-1}$ and grain yield as variables. The results showed that out of 30 genotypes, the first cluster comprised only two

Table 3.2.3. Distribution of 30 wheat genotypes into five different clusters subjected to water deficit stress

Cluster	Number of genotypes	Per cent of total genotypes	Wheat genotypes
I	2	6.67	E 3 and E 24
II	11	36.66	Sourav, Shatabdi, BARI Gom 26, BARI Gom 27, BARI Gom 28, E 2, E 23, BAW 1130, BAW 1135, BAW 1138 and BAW 1168
III	4	13.33	E 28, E 30, BAW 1163 and BAW 1171
IV	8	26.67	BARI Gom 25, E 18, E 29, E 34, E 38, E 42, BAW 1118 and BAW 1170
V	5	16.67	BAW 1140, BAW 1143, BAW 1151, BAW 1157 and BAW 1161
Total	30	100	

genotypes namely, E 3 and E 24 and the first cluster comprised 6.67% of the total. The second cluster included the highest number (11) of genotypes (36.67%) viz. Sourav, Shatabdi, BARI Gom 26, BARI Gom 27, BARI Gom 28, E 2, E 23, BAW 1130, BAW 1135, BAW 1138 & BAW 1168, indicating overall genetic similarity among them. The third cluster contained four genotypes of E 28, E 30, BAW 1163 & BAW 1171 (13.33%), while the fourth cluster enclosed eight genotypes of BARI Gom 25, E 18, E 29, E 34, and E 38, E 42, BAW 1118 & BAW 1170 (26.67%), and the fifth cluster controlled five genotypes of BAW 1140, BAW 1143, BAW 1151, BAW 1157 & BAW 1161 (16.67%) (Table 3.2.3). The genotypes included within a cluster had less diversity among themselves and the genotypes included in different cluster had more diversity among different clusters. The number of genotypes in each cluster varied with the environments (Naidu and Satyanarana 1991). Chaturvedi and Gupta (1995) worked with 44 genotypes of wheat and grouped into 13 clusters where the maximum number of genotypes (19) was included in cluster IV followed by cluster II (14) and cluster I (7 genotypes). Genetic diversity is generally associated with geographical diversity. The genotypes within the same cluster although formed specific clusters but collected from different places, indicated that the geographical distribution and genetic divergence did not follow the same trend. Murty and Arunachalam (1966) stated that genetic drift and selection in different environment could cause greater diversity than geographical distance.

Principal component analysis

The conservation and exploitation of genetic resources could be made by partitioning the total variance into its components. It provides opportunity for utilization of appropriate germplasm in crop improvement for particular plant traits (Sneath and Sokal 1973, Pecetti *et al.* 1996). The principal component (PC) analysis divides the total variance into different factors. Principal Component Analysis (PCA) also helps in assessment of diversity in multivariate scales. Based on the values of principal component scores 1 and 2 obtained from

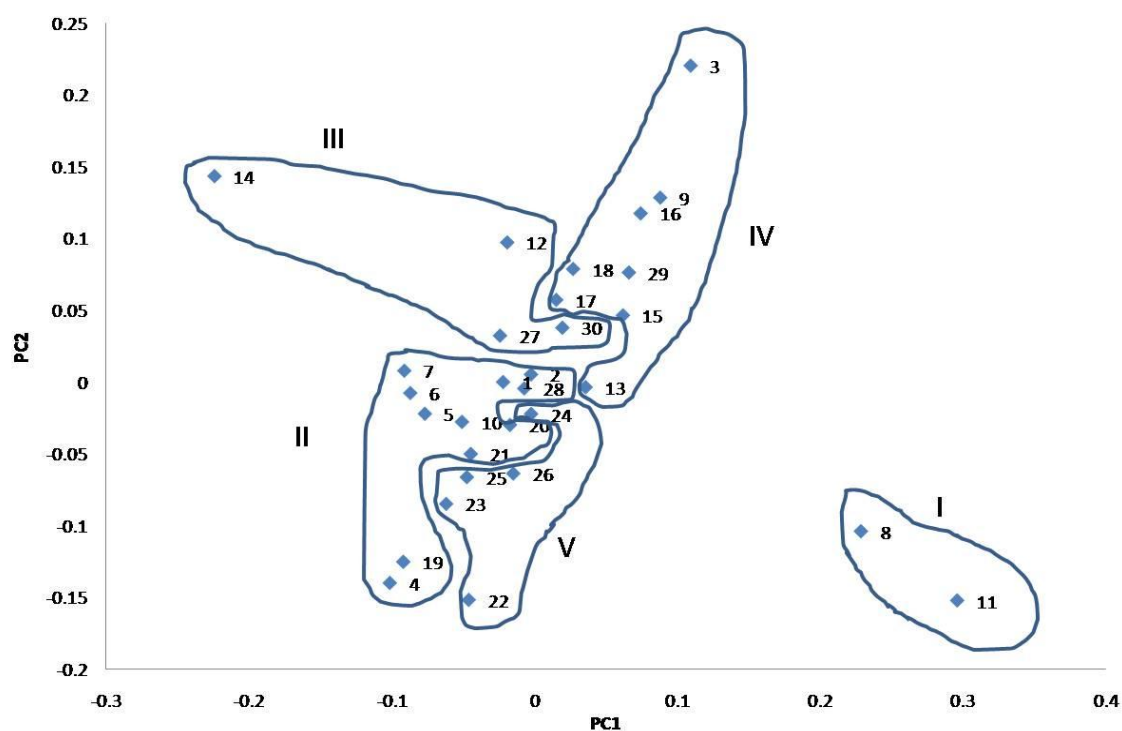


Fig.3.2.18. Scatter distribution of 30 wheat genotypes based on their principal component scores superimposed with clustering.

the principal component analysis, a two-dimensional scatter diagram (PC1-PC2) using component score 1 as X-axis and component score 2 as Y-axis was constructed, and then superimposed with clustering which has been presented in Fig. 3.2.18. The first two principal components contributing almost 68% towards the total variance were plotted to observe the relationships between different clusters with PC 1 on X-axis and PC 2 on Y-axis (Fig. 3.2.18). The scatter diagram showed association between different clusters. It could be explained by the fact that a large number of genotypes with varying degree of adaptation against water stress were used, based on different morpho-physiological traits or some sort of similarity among the genotypes. However, cluster analysis brings together those genotypes showing considerable tolerance against drought stress at one place, and on the basis of yield related traits at other place. The positions of the genotypes in the scatter diagram were apparently distributed into 5 groups, which indicated that there exists considerable diversity among the genotypes. The selection of diverge genotype, from different clusters would produce a broad spectrum of variability for morphological and quality traits which may enable further selection and improvement. The variety developed from the selected genotypes within the limits of compatibility of these clusters may produce high magnitude of heterosis. This would be rewarding in wheat breeding program.

Considering the results of the experiment II, it may be concluded water deficit stress reduced the yield traits and consequently reduced the yield of all genotypes but the reduction was lower in wheat genotypes-BARI Gom 25, E 38, BAW 1118 and E 18, while higher reduction was recorded in BARI Gom 26 and BAW 1130.

From the results of experiment I, it was observed that considering seedling dry weight at higher water deficit stress, BARI Gom 25, E 38, BAW 1118, E 18, Shatabdi, BAW 1138, E 34, E30, BAW 1135 and E 3 showed higher STI value and among these genotypes-Shatabdi, BARI Gom 25, E 18, E 38, and BAW 1118 cover in a similar cluster (cluster no. I). Wheat

genotypes- BAW 1151, E 42, BAW 1170, E 29, BAW 1161, E 2, BAW 1157, E 23, BAW 1130 and BARI Gom 26 showed lower STI value and among these genotypes BARI Gom 26 and BAW 1130 fall in an alike cluster (cluster no. III).

From the results of experiment II, it also showed that considering grain yield at no irrigation condition the genotypes BARI Gom 25, E 18, E 38, BAW 1118, BAW 1170, E 24, E 28, E 3, BAW 1171 and E 34 showed higher relative values and among these genotypes-BARI Gom 25, E 18, E 29, E34, and E 38, E 42, BAW 1118 and BAW1170 falls in a similar cluster (cluster no. IV) and BARI Gom 26, BAW 1130, BAW 1140, BARI Gom 27, BAW 1143, BARI Gom 28, BAW 1138, BAW 1157, E 23 and Sourav showed lower relative values and among these genotypes Sourav, Satabdi, BARI Gom 26, BARI Gom 27, BARI Gom 28, E 2, E 23, BAW 1130, BAW 1135, BAW 1138 and BAW1168 also scatter in an alike a cluster (cluster no. II). From experiment I and experiment II, four genotypes of BARI Gom 25, E 18, E 38 and BAW 1118 were considered as tolerant and two genotypes BARI Gom 26 and BAW 1130 were considered as susceptible genotypes and these six wheat genotypes were used for further physiological study in experiment III.

Experiment III: EFFECT OF WATER STRESS DEFICIT ON THE PHYSIOLOGICAL AND YIELD ATTRIBUTES OF WHEAT GENOTYPES

INTRODUCTION

Abiotic stresses are serious problem in many parts of the world especially for rainfed agriculture in circumstances of rapid changes in climatic conditions. Among prevailing abiotic stresses, drought is the most significant and severe factor inhibiting plant growth and production (Naeem *et al.* 2015). Plants' vegetative and reproductive stages are intensively influenced by drought stress. Physiological responses include closure of stomata, decrease in the activity of photosynthesis, development of oxidative stress, alteration in the integrity of cell wall, production of metabolites which are toxic and cause plants' death (Bray 2002), signal recognition of roots, turgor loss and adjustment of osmosis, reduction in water potential of leaf, decrease in stomata conductance to CO₂, reduction of internal CO₂ concentration, and reduction of growth rates (Clark and McCaig 1982 and Ritchie *et al.* 1990) and integrity of membrane (Kaur *et al.* 1988, and Sairam *et al.* 1990). Drought can also cause pollen sterility, grain loss, accumulation of abscisic acid in spikes of drought-susceptible wheat genotypes, and abscisic acid synthesis genes in the anthers (Ji *et al.* 2010). Dat *et al.* (2000) claimed that increase in reactive oxygen species (ROS) can be caused by drought stress in which oxidative balance of the cell is changed. A rise in the generation of ROS prompts to the generation of ABA (abscisic acid) which is a general signal under drought (Davies and Zhang 1991, Shinozaki and Yamaguchi-Shinozaki 1997, Pel *et al.* 2000, and Guan *et al.* 2000) and can consequently regulate the antioxidant genes expressions by producing superoxide dismutase (SOD) and catalase (CAT) (Jiang and Zhang 2002). Drought stress during the grain filling period is known to induce grain abortion and to reduce grain filling capacity (Rajala *et al.* 2009), a reduction in grain filling occurs due to a reduction in the assimilate partitioning and activities of sucrose and starch synthesis enzymes (Anjum *et*

al. 2011a), reduces plant growth and development leading to hamper flower production and grain filling and thus smaller and fewer grains (Yeganehpour *et al.* 2016). Chlorophyll content can determine the photosynthetic rate and reflect photosynthetic potential and primary yield of crops (Anjum *et al.* 2011a). It is noted that the chlorophyll reduction is identified as a drought response mechanism to minimize light absorption by chloroplasts (Pastenes *et al.* 2005, Guerfel *et al.* 2009).

The study of physiological responses of wheat varieties to water stress is a useful tool to understand the mechanisms of drought resistance. 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 (Naeem *et al.* 2015). Almeselmani *et al.* (2012b) reported significant reduction in physiological, yield and yield contributing traits were recorded in the drought susceptible durum wheat varieties compared to other varieties. Zaharieva *et al.* (2001) reported that physiological traits are helpful in the selection of best performing drought resistant wheat genotypes in arid areas. Currently, there are no economically viable technological means to facilitate crop production under drought stress conditions. Development of crop plants with drought tolerance, however, requires awareness in future food security. The knowledge of the physiological mechanisms and genetic controls of the contributing traits at different plant developmental stages is considered a promising approach, which may help to develop a drought tolerant crop variety. Therefore, the present study was carried out with following objectives-

1. To evaluate the sensitivity of physiological traits of wheat resulting reduced grain yield under water deficit stress,
2. To know the growth phenomena related to yield attributes and yield of wheat genotypes under water deficit condition.

MATERIALS AND METHODS

3.3.1 Location and duration

The experiment was conducted in an experimental field of the Wheat Research Center (WRC), Nashipur, Dinajpur, Bangladesh during November 2015 to April 2016. The experimental site is situated under the Dinajpur Sadar Upazila and located at 25°39' N latitude and 88°41' E longitude with an elevation of 37.58 m above the sea level.

3.3.2 Soil and climate

The experimental field was a medium high land belonging to the non-calcareous dark gray flood plain soil under the Agro-Ecological Zone (AEZ) of Old Himalayan Piedmont Plain (AEZ-1) (FAO and UNDP, 1988). The soil is sandy loam under the order of Inceptisol. The experimental site is situated in the sub-tropical region characterized by heavy rainfall during the months from May to September and scanty rainfall in the rest of the year. Details of the soil characteristics of the experimental site is presented in Appendix 1 and Appendix 2 and minutiae of the meteorological data in respect to temperature, rainfall and relative humidity during the growing period of the experimental site are presented in the Appendix 4.

3.3.3 Experimental design and layout

The experiment was arranged in a split plot design with three replications. The unit/sub-plot size was 4 m x 2 m. The distance between unit/sub plots was 0.5 m, main plot to main plot distance was 2.5 m and block to block distance was 2.5 m. The two growing conditions were assigned in the main plots as main plot treatments whereas six wheat genotypes were placed randomly in the sub-plots as sub plot treatments.

3.3.4 Experimental treatments

The treatments were-

A. Main plot: Two water regimes

1. Well water condttion: Three irrigations were applied at i) crown root initiation (CRI),
ii) anthesis and iii) grain filling stages.

2. Water deficit stress: No irrigation was applied and the crop was protected from rainfall by rainout shelter.

B. Sub-plot: Six wheat genotypes including four tolerant and two susceptible selected based on experiments 1 and 2 such as 1) BARI Gom 25, 2) E 38, 3) BAW 1118, 4) E 18, 5) BARI Gom 26, and 6) BAW 1130.

3.3.5 Land preparation

The land was ploughed by a power tiller and was levelled by harrowing and laddering carefully. The weeds and stubble were removed, and then main plots, sub-plots and blocks were prepared, and irrigation channels were made around each block.

3.3.6 Fertilizer application

Fertilizers was applied during final land preparation as WRC recommended fertilizer doses (RDF) @100-30-50-20-1.25-1-5000 kg ha⁻¹ of N, P, K, S, Zn, B and cow-dung (well decomposed) (WRC 2013) in the form of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and boric acid, respectively. The cow dung was applied at the beginning of land preparation. After land preparation, full dose of P, K, S, Zn, B and two third of N were incorporated thoroughly into the soil as basal dose in the well watered plot. The remaining amount of N was applied after the first irrigation at crown root initiation stage (CRI) i.e., 18 days after seedlings emergence. In case of water deficit stressed plot, full doses of N, P, K, S, Zn, B were incorporated thoroughly into the soil as a basal dose. To control soil-borne insects, Furadan 5G containing Carbofuran (systemic pesticide; FMC Corp., Philadelphia, PA, USA) was broadcasted at 10 kg ha⁻¹ during final land preparation.

3.3.7 Sowing of seed

Seeds of six wheat genotypes (BARI Gom 25, E 38, BAW 1118, E18, BARI G 26 and BAW 1130) were sown on 6 December, 2015 in rows of 20 cm apart, at the rate of 120 kg ha⁻¹. To achieve excellent germination and protecting against fungal attack during the seedling stage, seeds were pre-treated with a fungicide (Provax-200 WP).

3.3.8 Irrigation

Half of plots (well watered) were irrigated three times (at 18, 57 and 74 DAS) but the remaining plots (water stressed) were not irrigated throughout the growing period to maintain water deficit stress condition and the crop was protected from rainfall by rainout shelter.

3.3.9 Intercultural operations

After sowing, care was taken against birds up to 15 days. Intercultural operations were done when required and depending on treatments. Weeding was done 4-5 days after top dressings of urea to break the soil crusts, the plots were kept free from weeds which ensure sufficient nutrition for individual plant.

3.3.10 Sampling/ data collection

3.3.10.1 Spike dry matter accumulation

At anthesis 80 main shoots were tagged from each plot. Four tagged main shoot spikes were harvested at every 4th day beginning from anthesis to quantify spike dry matter accumulation pattern. Collection of main shoot spike in all genotypes was continued up to 44 days after anthesis (DAA) for both well watered and water deficit stress conditions. The harvested spikes were kept in oven at 70°C for 72 hours. After oven drying, spikes were weighted with an analytical balance (AND Electronic Balance Model EK 300 i).

3.3.10.2 Estimation of proline

Proline content of flag leaf and kernel at 16 DAA in all wheat genotypes grown in two different growing conditions were estimated. Flag leaves and spike from each replication of each genotype were collected and immediately kept in the ice-bag and brought to Crop Physiology and Ecology Laboratory of HSTU for proline estimation. The kernels from spike were separated and 0.5g of fresh weight of both flag leaf and kernels were taken for proline estimation. Subsequently proline was estimated as Bates (1973).

At first ninhydrin reagent was prepared in such a way so that it was utilized for proline estimation within two hours of preparation. To prepare Ninhydrin reagent, addition of 30 ml glacial acetic acid and 20 ml 6M orthophosphoric acid was mixed with 1.25 g of Ninhydrin. It was subsequently heated and stirred gently to dissolve but the temperature was not allowed to exceed 70°C. Proline standards were prepared for 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 µg/ml with distilled water. Fresh sample of 0.5 g was crushed in mortar and paste and homogenized the material in 10 ml 3% sulphosalicylic acid until no large segments of plant material remained. Homogenate was filtered through Whatman No. 2 filter paper. Two ml of the filtrate and each standard proline solutions were then reacted with 2 ml of ninhydrin reagent and 2 ml of glacial acetic acid in a Pyrex test tube, boiled for one hour at 100°C in water bath covering the tube with aluminium foil to prevent excess evaporation. Subsequently, it was cooled in ice bath and 4 ml of toluene was added to each tube using a dispenser. Each tube was then shaken vigorously for 15 to 20 seconds in an electrical shaker and allowed the layer to separate for 30 minutes. The absorbance of layer was measured through spectrophotometer (SPECTRO UV-VIS RS Spectrophotometer, Labo Med, Inc.) at 520 nm with pure toluene as a blank. The proline content was determined from a standard curve and calculated on a fresh weight basis as follows:

$$\mu\text{moles proline/g fresh plant sample} = \{(\mu\text{g proline/ml} \times \text{ml toluene}) / 115.5 \mu\text{g}/\mu\text{moles} / (\text{g sample}/5)$$

3.3.10.3 Estimation of soluble sugar and starch

The soluble sugar and starch contents of flag leaf, collected at 16 DAA in case of all wheat genotypes in both growing conditions, were determined as the method of Yoshida *et al.* (1976).

Sugar estimation: The dried flag leaf samples were ground finely in mortar and pestle. Finely ground sample of 50 mg was placed into a 15 ml centrifuge tube and 10 ml of 80% ethanol was added. The tubes were covered with aluminium foil and were kept in a water bath at 80-85°C for 30 minutes. Then the samples were centrifuged and decanted into a 50 ml

beaker. This extraction was repeated three times. The alcohol extract was evaporated on a water bath at 80-85°C until most of the alcohol was removed (e.g. the volume was reduced to 3 ml). The volume was made up to 25 ml with distilled water. Sugar extract of 5 ml was transferred to a 100 ml volumetric flask and made up to volume with distilled water. This diluted sugar extract of 5 ml was taken into a pyrex test tube and then these tubes containing the glucose standards of 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 mg/5ml were put into an ice bath. To each tube 10 ml of anthrone reagent (2 g of anthrone was dissolved in one liter of conc. sulphuric acid and was stored in a refrigerator). A fresh solution was prepared, allowing the reagent to run down the side of the test tube. The solution was stirred slowly with a glass rod. The tubes were put into boiling water bath for exactly 7.5 minutes and were cooled immediately in ice. Then the absorbance was measured at 630 nm and sugar content as mg/g dry weight was estimated using standard curve.

Starch estimation: The residue left in the centrifuge tube after collecting sugar extract was dried in an oven at 80°C and 2 ml of distilled water was added to each centrifuge tube. The tubes were put in a boiling water bath for 15 minutes and stirred occasionally. The tubes were allowed to cool and 2 ml of 9.2 N HClO₄ was added to each tube while stirring constantly. Then the solution was stirred occasionally for 15 minutes. The suspension was then made up to about 10 ml and centrifuged. The supernatant was collected and 2 ml of 4.6 N HClO₄ was added to the residue. This suspension was stirred for 15 minutes and was made up to 10 ml with distilled water. Then the suspension was centrifuged and the supernatants were combined. The combined supernatants were made up to 50 ml with distilled water. Five ml of starch extract was transferred to a 50 ml volumetric flask and made up to volume with distilled water. This diluted starch extract of 5 ml was taken into a Pyrex test tube. Then these tubes and the tubes containing glucose standards (0, 1, 2, 3, 4, and 5 mg/5ml including 0.6 ml 0.46 N HClO₄ solution for each tube) were put into ice bath. Anthrone reagent of 10 ml was added in each tube slowly allowing the reagent to run down the side of the test tube. The solution was stirred slowly with a glass rod. Then tubes were put in a boiling water bath for

7.5 min. and were cooled immediately in ice. Then the absorbance was measured at 630 nm, and starch content was estimated as mg/g dry weight using standard curve.

3.3.10.4 Estimation of chlorophyll

Chlorophyll content of the flag leaf at 8 and 24 DAA was estimated according to Witham *et al.* (1986). Fresh flag leaf tissue of 0.25 g was taken from middle position of the flag leaf in a brown bottle containing 25 ml of 80% aqueous acetone and kept in dark for 48 hours. The optical density of this green colored solution was determined against 80% acetone as blank using spectrophotometer (SPECTRO UV-VIS RS Spectrophotometer, Labo Med, Inc.) at 645 and 663 nm. Total chlorophyll of fresh leaf was determined using following formula-

$$\text{Total chlorophyll (mg g}^{-1} \text{ FW)} = [20.2(D_{645}) + 8.02(D_{663})] \times [V/(1000 \times W)]$$

Where, V = Volume of 80% aqueous acetone (ml), W = Weight of fresh leaf (g),

D_{645} = Absorbance at 645 nm wave length, D_{663} = Absorbance at 663 nm wave length

3.3.10.5 Relative leaf water content

Relative flag leaf water content was determined at 16 DAA. Five flag leaves for each treatment combination collecting from the field was sealed immediately in plastic bags and quickly transferred to the laboratory. Fresh weight was taken within 2 hours after excision. Turgid weight was obtained after soaking leaves in distilled water in test tubes for about 16 to 18 hours at room temperature. Dry weight was obtained after oven drying the leaf samples at 70°C for 72 h. Relative leaf water content was calculated using the following formula according to Barrs and Weatherly (1962).

$$\text{RLWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.3.10.6 Water retention capacity

Water retention capacity of the flag leaves was measured at 16 days after anthesis. For this purpose, the leaves were collected in tightly fastened polythene bags. Five flag leaves from each plot was collected at 9:00 am and there fresh weight (FW) was taken immediately. Then

the leaves were kept at room temperature in a plastic tray. Fresh weight of the leaves was taken at 2 hours interval for 4 times. Finally, leaves were dried in an oven at 70°C for 72 hours and their dry weight (DW) was taken with the help of an electrical balance. The water retention capacity of leaves was calculated using the following formula according to Sangakkara *et al.* (1996).

$$\text{Water retention capacity (\%)} = \frac{\text{FW} - \text{DW}}{\text{FW}} \times 100$$

Here, FW = Fresh weight of leaf, DW = Dry weight of leaf

3.3.10.7 Canopy temperature Depression (CTD)

The difference between ambient air temperature and canopy temperature in degree centigrade is known as canopy temperature depression (CTD). Canopy temperatures (CT) were taken with the infrared thermometer (Model LT-300, Sixth sense) held 0.5-1.0 m from the edge of the plot and approximately 50 cm above the canopy at a 30° angle from the horizon. The canopy temperatures were recorded at 16 days and 24 DAA during noon period under bright sunlight and less wind and at the same time air temperature also recorded. The presented data are means of three sets of measurements, which was taken, between 12 and 16 h (Reynolds *et al.* 1994).

3.3.10.8 SPAD value

Five main shoots were selected from each unit plot at the time of anthesis and tagged. The SPAD (Soil Plant Analyses Development) value was taken from middle portion of the flag leaf of the tagged main shoot at 8, 16, 24 and 32 DAA through using self-calibrating Minolta chlorophyll meter (Model: SPAD-502, Minolta Co. Ltd., Japan). Measurements at each experimental plot consisted of average of five readings (Reynolds *et al.* 1998).

3.3.10.9 Cell membrane stability

For estimating cell membrane stability (CMS), artificial desiccation was induced by polyethylene glycol (PEG-6000) method as proposed by Sullivan (1971). Flag leaves from

each experimental unit were collected and were cut into 1cm pieces. One gram of leaf pieces was put into a 25 mm × 150 mm test tube and washed slowly with three changes of deionized distilled water for about 90 min. to remove surface adhered electrolytes. Following the washing, the leaf pieces were submerged in 30 ml of PEG-6000 solution (30% PEG) and allowed to stand in the solution for 24 hours at a cool temperature of about 10°C to minimize secondary effects. The PEG-6000 was used in this study. The concentration of the solution and the duration were adjusted to the severity of desiccation desired. After the treatment period, the leaf pieces were washed quickly for three times with deionized distilled water. Thirty ml of deionized distilled water were then added and kept for 24 hours at 10°C. Then the test tubes were warmed to 25°C, shaken well and the electrical conductivity was measured. Following the conductivity measurement, the leaf tissues were killed by autoclaving for 15 minutes, warmed again to 25°C and then the electrical conductivity was measured for the second time. Desiccation treatment and non-desiccated control were consisted of three replications. The PEG treatment affects membrane integrity, which permits electrolyte leakage. Degree of membrane stability to stress is evaluated by ion leakage. The percentage of injury occurred to leaf tissues by desiccation was calculated using the first and second electrical conductivity measurements according to Blum and Ebercon (1981).

$$\% \text{ injury} = [1 - (1 - T_1/T_2) / (1 - C_1/C_2)] \times 100$$

Where, T_1 = First conductivity measurement, T_2 = Second conductivity measurement,
 C_1 = First conductivity measurement of control, C_2 = Second conductivity measurement of control

3.3.10.10 Shoot length

Shoot length was measured from the base to tip of the plant/spike. Five plant samples from each plot were taken at 40, 55 and 70 DAS and means were calculated.

3.3.10.11 Leaf area index

Leaf area was calculated with an Automatic Leaf Area Meter (Model AAM-9, Hayashi Denko Co. Ltd., Tokyo, Japan) at 40, 55 and 70 DAS collected leaf sample from a line of 1 m

length. The leaf area index (LAI) of the crop at different growth stages was calculated using the following equation as described by Radford (1967).

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

3.3.10.12 Tillers per meter square

The number of tillers was counted manually at maximum tillering stage (45 DAS) from an area of one meter square from each plot (5 lines and each line had 1 meter length).

3.3.10.13 Phenological attributes

Days to heading (days): Days to heading was recorded by counting the number of days from the date of sowing when the 80% of the spikes were appeared.

Days to anthesis (days): Days to anthesis was recorded by counting the number of days from the date of sowing to the day when 80% of spikes were in flowering stage (eye estimation) or 3 days after heading.

Days to physiological maturity (days): The number of days from sowing to the day when the peduncle and the spike became completely yellow (loss of green color) from 80% of the ear-bearing culms of a plot).

3.3.10.14 Plant height

Plant height was measured from the base of the plant to the tip of the spike excluding the awn at maturity. Ten plants sample from each treatment were taken (excluding the line from where grain yield was taken) and means were calculated.

3.3.10.15 Spike characteristics

Ten spikes from the main shoot were collected randomly per plot (excluding the line from where grain yield was taken) to collect data on spike characters. The number of spikelets per spike and number of grains spike⁻¹ was counted.

Spike length: Length of ten spikes per plot (excluding awn) was measured manually using scale and were recorded in cm and averaged.

Spikelets per spike: From that ten spikes number of spikelets per spike was counted manually.

Grains per spike: From that ten spikes number of filled and unfilled grains per spike was counted and averaged.

3.3.10.16 Number of spikes m⁻²: The numbers of developed and under developed spikes of 1 m² land area were counted from each plot.

3.3.10.17. Thousand grain weight: From each plot thousand grains were counted randomly, dried and weighed by electrical balance in g on 12% moisture basis.

3.3.10.18 Grain and biological yields

Yield sample was taken from a 3.5 × 1 m area (i.e. 5 middle rows) when the plants reached to harvest maturity, and grains became hard. The plants from five lines of 3.5 m length comprising 3.5 m² from each plot were harvested and threshed for computation of grain yield and above ground biological yields. After threshing, cleaning and drying, the grain yield and biological yield were recorded plot-wise and at the same time moisture percent also recorded by a moisture meter. Finally the grain and biological yields were converted into tons hectare⁻¹.

Data on grain yield (GY) was determined and adjusted to 12% moisture level by the following equation (Hellevang 1995).

$$Y (M_2) = \frac{(100-M_1)}{(100-M_2)} \times Y (M_1)$$

Where, Y (M₂) = Weight of grain at expected moisture percentage (generally 12% for wheat),

Y (M₁) = Weight of grain at actual moisture percentage,

M₁= Actual moisture percentage,

M₂= Expected moisture percentage.

3.3.10.19 Soil moisture content

The soil samples were collected from desired depth from several places, in air tight containers. The samples were weighed and then they were dried in an oven at 105⁰C for about 24 hours. The samples were then taken out and weighed again and the loss in weight was the amount of water soil.

$$\text{Soil moisture content (\%)} = \frac{\text{Weight of moist sample} - \text{Weight of oven dry sample}}{\text{Weight of oven dry sample}} \times 100$$

3.3.10.20. Stress susceptibility index

Stress susceptibility index (SSI) was calculated for grain yield as described by Fisher and Maurer (1978). Higher SSI indicates greater susceptibility.

$$\text{SSI} = (1 - Y/Y_p) / (1 - X/X_p)$$

Where, Y = Grain yield of genotype in a stress environment,

Y_p = Grain yield of genotype in a stress-free environment,

X = Mean Y of all genotypes,

X_p = Mean Y_p of all genotypes.

3.3.10.21. Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer using MSTAT-C program. The treatment means were compared using Duncun's Multiple Range Test (DMRT) at P ≤ 5% level.

RESULTS AND DISCUSSION

3.3.11 Soil moisture content

Figure 3.3.1 represents the moisture content (MC) of the soil at 0-15cm depth of well watered and water stressed plots at different DAS. Irrigation was applied at 18, 57 and 74 DAS in well watered plot and moisture contents were recorded at 40, 55, 70, 85, 100 and 115 DAS at an interval of 15 days. The results showed that the well watered plot maintained higher soil MC (17.69 to 25.38%) than water stressed plot (3.21 to 12.32%) through out the study period. In the well watered plot, soil MC was 18.85% at 40 DAS and it was increased at 55 DAS thereafter it was decreased at 70 DAS. After that the soil MC was increased up to 100 DAS and then decreased sharply at 115 DAS. Decrease in soil MC at 70 DAS might be due to more water requirement of the crop in this stage. The increase in MC at 85 and 100 DAS was due to application of irrigation at 74 DAS. Sharp decrease in MC after 100 DAS was due to rise in temperature and no irrigation at this stage. This figure also shows that the soil MC of water stressed plots was the highest (12.32%) at 40 DAS and it reduced gradually with the advancement of time. The results in soil MC indicated that the crop grown in the plot where irrigation was not applied suffered from water deficit stress.

3.3.12 Chlorophyll content in the flag leaf

Chlorophyll (Chl) is one of the major components responsible for photosynthesis and relative Chl content has a positive relationship with photosynthetic rate (Manivannan *et al.* 2007, Rahdari *et al.* 2012). Flag leaf Chl content is an indicator of photosynthetic activity and its stability indicates the conjugation of assimilates biosynthesis (Bijanazadeh and Emam 2010). The decrease in Chl content under drought stress has been considered a typical symptom of pigment photooxidation and Chl degradation (Anjum *et al.* 2011b). In this study, different wheat genotypes, water regimes and their interaction significantly influenced the flag leaf Chl content at 8 DAA (Table 3.3.1). Under well water condition wheat genotypes contained

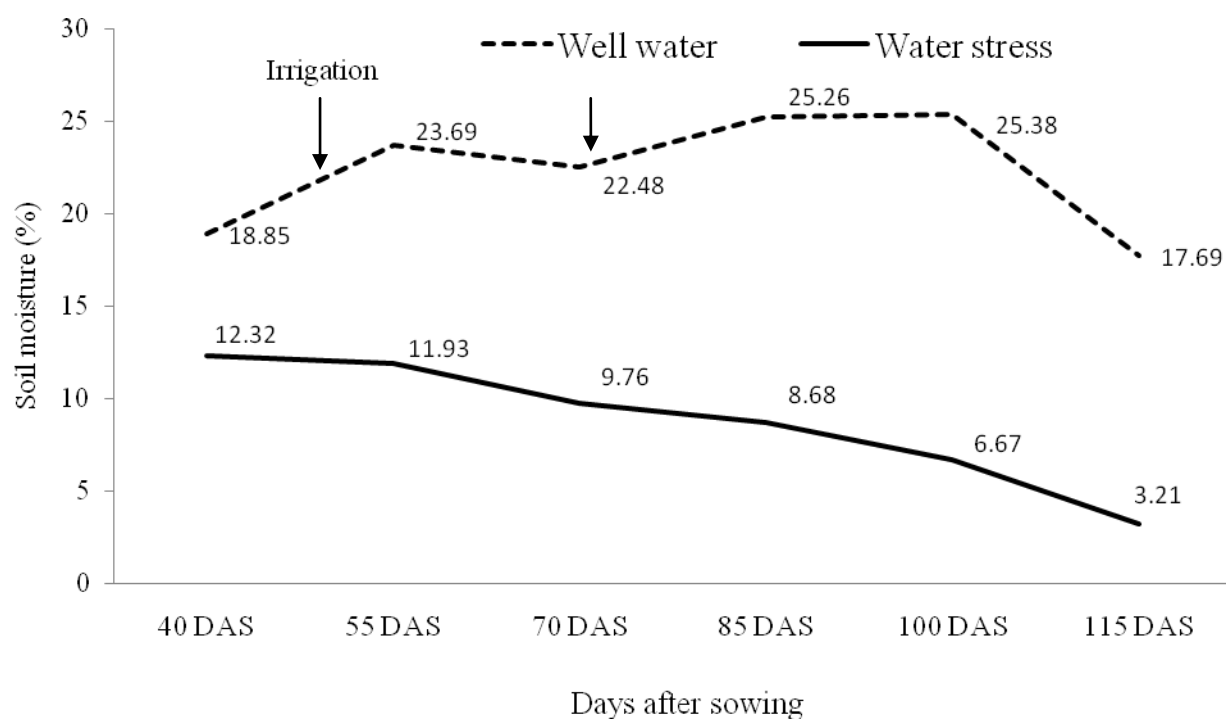


Fig. 3.3.1. Soil moisture content (0-15 cm depth) at different days after sowing as influenced by water regimes.

Table 3.3.1. Flag leaf chlorophyll (mg g⁻¹ FW) content of different wheat genotypes as influenced by water regimes

Wheat genotypes	Water regimes	Flag leaf chlorophyll content at 8 DAA		Flag leaf chlorophyll content at 24 DAA	
		mg g ⁻¹ FW	Change over control (%)	mg g ⁻¹ FW	Change over control (%)
BARI Gom 25	Well water	1.58 de	-	1.51d	-
	Water stress	1.86 abc	+17.72	1.39 e	- 7.95
E 38	Well water	1.42 e	-	1.49 d	-
	Water stress	1.79 abcd	+25.79	1.40 e	- 6.05
BAW 1118	Well water	1.71 cd	-	1.78 a	-
	Water stress	2.00 a	+17.34	1.62 c	- 9.00
E 18	Well water	1.76 bcd	-	1.61 c	-
	Water stress	2.01 a	+14.18	1.45 de	- 9.96
BARI Gom 26	Well water	1.92 abc	-	1.7 b	-
	Water stress	1.98 ab	+3.13	1.51d	- 11.35
BAW 1130	Well water	1.97 ab	-	1.74 ab	-
	Water stress	2.00 a	+1.37	1.48 d	-15.09
Level of significance		**	-	**	-
CV (%)		4.78		1.11	

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$

** indicates significant at 1% level of probability

DAA indicates days after anthesis

FW indicates fresh weight

Chl ranging from 1.42 to 1.97 mg g⁻¹ FW in their flag leaves. The Chl content was increased due to water deficit stress in all the wheat genotypes and they maintained 1.79 to 2.01 mg g⁻¹ FW Chl in flag leaves.

But the increment of Chl content was not similar in all wheat genotypes due to water deficit stress. The remarkable increment was noted in E 38 (25.79%) followed by BARI Gom 25 (17.72%), BAW 1118 (17.34%) and E 18 (14.18%), at the same time a minor increment in Chl was recorded in BARI Gom 26 (3.13%) and BAW 1130 (1.37%) due to water deficit stress. Wheat genotypes, water regimes and their interaction also significantly influenced the Chl content in the flag leaf at 24 DAA (Table 3.3.1). The Chl content of wheat flag leaves varied from 1.49 to 1.78 and 1.39 to 1.62 mg g⁻¹ FW under well water condition and water deficit stress, respectively. Due to water deficit stress the Chl content was decreased in all the wheat genotypes. But the two sensitive genotypes BAW 1130 and BARI Gom 26 were found to affect more than the tolerant genotypes (BARI Gom 25, E 38, BAW 1118 and E 18) regarding Chl degradation in the present study. Terminal drought reduced Chl contents by affecting its synthesis and damaging the photosynthetic organelles (chloroplast) of plants cells (Iturbe Ormaetxe *et al.* 1998). Drought stress progressively hampered the disruption of electron flow and formation of oxidizing radicals of chlorophyll resulting reduction of Chl content (Allahverdiyev 2015). This results is in agreement with the findings of Ashraf *et al.* (1994), Khosh and Ando (1995), Iturbe-Ormaetxe *et al.* (1998), Podsiado (1999), Karim *et al.* (2000) Deora *et al.* (2001), Teng *et al.* (2004), Dulai *et al.* (2006), Keyvan (2010), Mafakheri *et al.* (2010), Nikolaeva *et al.* (2010), Moaveni (2011), Almeselmani *et al.* (2012a), Farshadfar *et al.* (2014), and Allahverdiyev (2015).

3.3.13 SPAD value

The SPAD value has been well recognized as a mean of determining the onset of senescence process in a leaf (Rajcan and Tollenaar 1999). The senescence of leaf can be determined using SPAD meter. The sharp decrease in SPAD value indicates the onset of leaf senescence.

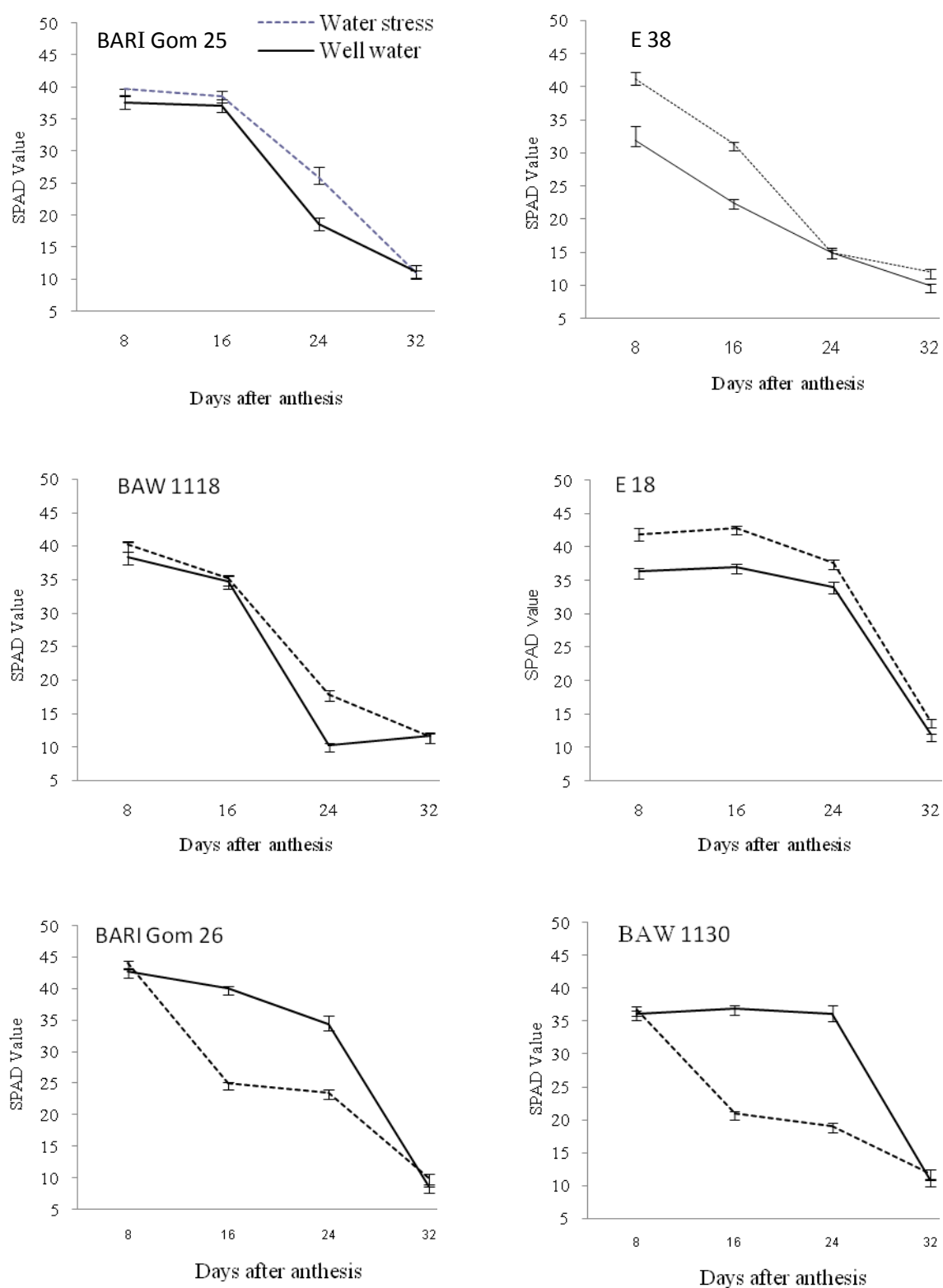


Fig: 3.3.2. SPAD value (mean $\pm$ SE) of different wheat genotypes at different days after anthesis as influenced by water deficit stress.

The SPAD reading was taken from the middle portion of flag leaf at 8, 16, 24 and 32 DAA in fully expanded flag leaf as shown in the Fig. 3.3.2. The SPAD value in the flag leaf was the maximum near anthesis (8 DAA) after that it was decreased with the advancement of time in all wheat genotypes both under well water and water deficit stress conditions. In water deficit stress tolerant, wheat genotypes (BARI Gom 25, E 38, BAW 1118 and E 18), the SPAD value decreased gradually after 8 DAA in both conditions.

In stress susceptible genotypes (BARI Gom 26 and BAW 1130), the SPAD value decreased gradually in well water condition but it was decreased sharply in water stressed condition. This may be due to the water stress susceptible genotypes cannot maintain their greenness more time than that in the water stress tolerance genotypes. A slow decrease in SPAD value under control might be due to optimum irrigation that ensured higher leaf chlorophyll content by N uptake which delayed the senescence and increased the green area duration. Saeedipour (2012) reported that water deficits enhanced the senescence by accelerating loss of leaf chlorophyll and soluble proteins, and the loss was more in sensitive one than tolerant one. Genotypes possessing the ability to maintain green leaf area duration throughout grain filling are the potential ones to assure yield in semi-arid regions (Hoang and Kobata 2009, Larbi and Mekliche 2004). Crops with longer leaf area duration such as sorghum has also been reported to have increased yield in water limited conditions because they are able to keep their stalk transporting system functioning under severe drought conditions (Xu *et al.* 2000). Mohi-Ud-Din *et al.* (2007) found that the onset of flag leaf senescence of two wheat cultivars was indicated by the SPAD value reaching below 30. This might be due to forced senescence of leaf irrespective of varieties. The Chl content declined from 13 to 15% in water-stressed wheat compared with well watered plants (Nikolaeva *et al.* 2010). The Chl synthesis was inhibited under water deficit conditions. The SPAD value decreased with the decreased of chlorophyll content.

3.3.14 Flag leaf and kernel proline content

Proline (Pro) is well known to occur extensively in higher crop plants and accumulates in higher concentration in response to different abiotic environmental stresses specially drought stress (Kavi-Kishore *et al.* 2005). Accumulation of higher Pro concentration in crop plant under water deficit condition is highly associated with drought tolerance and drought tolerance genotypes depict its concentration much higher than drought sensitive genotypes (Ashraf 1994, Ali *et al.* 1999, Rhodes *et al.* 1999, Ozturk and Demir 2002, Hsu *et al.* 2003 and Kavi Kishore *et al.* 2005). The proline content of flag leaf and kernel at 16 DAA was significantly influenced by water regimes and wheat genotypes and also by their interaction effect in the present study (Table 3.3.2).

Flag leaf proline content in different wheat genotypes varied from 5.97 to 12.77 $\mu\text{mole g}^{-1}$ FW irrespective of water regimes. Due to water deficit stress, flag leaf Pro level was increased from 4.52 to 113.74% in stress tolerant genotypes (BARI Gom 25, E 38, BAW 1118 and E 18) but it was even decreased in sensitive genotypes of BARI Gom 26 (10.14%) and BAW 1130 (11.66%). Kernel proline content in different wheat genotypes varied from 7.88 to 15.25 $\mu\text{mole g}^{-1}$ FW irrespective of water regimes. Due to water deficit stress, kernel proline level was increased in stress tolerant genotypes BARI Gom 25 (7.71%), E 38 (59.14%), BAW 1118 (13.85%) and E 18 (10.99%) but it was even decreased in sensitive genotypes of BARI Gom 26 (12.98%) and BAW 1130 (15.54%). Bayoumi *et al.* (2008) suggests that the high proline content in wheat genotypes is probably a positive adaptive mechanism for overcoming the water stress effect. Moreover, after the severe damage of stresses, proline contents provide adequate reducing agents that assist in mitochondrial oxidative phosphorylation and production of adenosine triphosphate (ATP) for revival from damages of various stresses (Hare *et al.* 1998). Vendruscolo *et al.* (2007) found that the proline is involved in tolerance mechanisms against oxidative stress and this was the main strategy of plants to avoid detrimental effects of water stress. Accumulation of Pro under stress in many

plant species has been correlated with stress tolerance, and its concentration has been known to be usually higher in stress tolerant than in stress sensitive plants (Ashraf and Foolad 2007).

3.3.15 Soluble sugar content in the flag leaf and kernel

Soluble sugars (SS) produced during photosynthesis play a significant role in plant growth, development and osmotic adjustment which is widely regarded as adaptive response to water stress conditions (Turner and Jones 1980, Kameli and Loesel 1993, 1995). The SS content in flag leaf and kernel at 16 DAA was significantly influenced by water regimes and wheat genotypes and also by their interaction effect in the present study (Table 3.3.3). Flag leaf SS content in different wheat genotypes varied from 20.71 to 43.81 mg g⁻¹ DW irrespective of water regimes. Due to water deficit stress, the flag leaf SS level was increased from 12.70 to 23.88% in stress tolerant genotypes (BARI Gom 25, E 38, BAW 1118 and E 18) but it was even decreased in sensitive BARI Gom 26 (5.39%) and BAW 1130 (13.93%). Kernel SS content in different wheat genotypes varied from 25.52 to 60.69 mg g⁻¹ DW irrespective of water regimes.

Due to water deficit stress, the kernel SS level was decreased from 14.61 to 32.81% in different wheat genotypes but the increment was inconsistent between tolerant and sensitive genotypes. The increase of total SS in plant may help to tolerate under drought stress as stated by Kameli and Losel (1993). The synthesis of osmotically active organic substances like soluble sugars, glycine-betaine, proline alcohols, and organic acids etc. is the ability of plant to adjust the external osmotic conditions and to maintain water balance under drought stress (Farooq *et al.* 2009, Mohammadkhani and Heidari 2008). Total SS accumulation due to drought stress has been earlier reported by different scientists in various crops such as rice (Mostajeran and Rahimi-Eichi 2009, Zain *et al.* 2014), wheat (Akladios 2012, Al-Tabbal and Kafawin 2005, Nazarli and Faraji 2011, Chorfi and Taibi 2011), corn (Homayouni and Khazarian 2014), potato (Farhad *et al.* 2011), canola cultivars (Nosrati *et al.* 2014).

Table 3.3.2. Flag leaf and kernel proline content of different wheat genotypes at 16 days after anthesis as influenced by water regimes

Wheat genotypes	Water regimes	Flag leaf proline content		Kernel proline content	
		$\mu\text{mole g}^{-1}$ FW	Change over control (%)	$\mu\text{mole g}^{-1}$ FW	Change over control (%)
BARI Gom 25	Well water	8.86 cd	-	11.81 cd	-
	Water stress	9.73 b	+ 9.82	12.72 bc	+ 7.71
E 38	Well water	5.97 f	-	7.88 f	-
	Water stress	12.77 a	+ 113.74	12.54 bc	+ 59.14
BAW 1118	Well water	5.98 f	-	10.90 d	-
	Water stress	6.25 f	+ 4.52	12.41 bc	+13.85
E 18	Well water	6.25 f	-	9.74 e	-
	Water stress	6.75 f	+ 8.00	10.81 d	+10.99
BARI Gom 26	Well water	8.48 d	-	15.25 a	-
	Water stress	7.62 e	-10.14	13.27 b	-12.98
BAW 1130	Well water	9.52 bc	-	11.07 d	-
	Water stress	8.41 de	-11.66	9.35 e	-15.54
Level of significance		**	-	**	-
CV (%)		4.21	-	3.79	-

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

DAA indicates days after anthesis

FW indicates fresh weight

Table 3.3.3. Soluble sugar content in the flag leaf and kernel of different wheat genotypes at 16 DAA as influenced by water regimes

Wheat genotypes	Water regimes	SS content in leaf		SS content in kernel	
		mg g^{-1} DW	Change over control (%)	mg g^{-1} DW	Change over control (%)
BARI Gom 25	Well water	30.45 e	-	35.83 de	-
	Water stress	34.95 bc	+14.78	25.52 f	-28.77
E 38	Well water	26.88 f	-	37.35 de	-
	Water stress	33.30 cd	+23.88	26.04 f	-30.28
BAW 1118	Well water	36.10 b	-	53.52 b	-
	Water stress	43.81 a	+21.36	45.70 c	-14.61
E 18	Well water	31.42 de	-	39.11 d	-
	Water stress	35.41 bc	+12.70	27.64 f	-29.33
BARI Gom 26	Well water	21.89 g	-	33.28 e	-
	Water stress	20.71 g	-5.39	27.33 f	-17.88
BAW 1130	Well water	36.40 b	-	60.96 a	-
	Water stress	31.33 de	-13.93	40.96 cd	-32.81
Level of significance		**	-	**	-
CV (%)		3.51	-	5.48	-

3.3.16 Starch content in kernel

The biosynthesis and accumulation of starch in kernel is a key process for determining grain yield and quality in wheat (Hurkman *et al.* 2003). Starch level in wheat kernel at 16 DAA was influenced significantly by the interaction effect of wheat genotypes and water regimes (Fig. 3.3.3.). The starch content in the kernel varied from 37.77 to 59.90 mg g⁻¹ DW in well water condition and it was varied from 49.01 to 63.98 mg g⁻¹ DW in water deficit conditions. Due to water deficit stress, the kernel starch content was increased in all wheat genotypes except in BAW 1118 but the increment was not similar among the five wheat genotypes. The highest increment was recorded in E 18 (+42.60%) followed by BAW 1130 (30.73%), E 38 (+20.91%), BARI Gom 26 (+6.06%) and BARI Gom 25 (+2.08%), whereas 28.53% reduction in starch content was observed in BAW 1118. EL Sabagh *et al.* (2017) reported reduction in kernel starch content in wheat due to water stress.

3.3.17 Relative water content

Relative water content (RWC) in wheat plants is an important and direct indicator of plant water contents under water deficit conditions (Merah 2001, Lugojan and Ciulca 2011). The interaction effect of wheat genotypes and water regimes significantly influenced the RWC in the flag leaf at 16 DAA (Fig. 3.3.4). Under well water condition, BAW 1118 showed the highest RWC (95.33%) while the lowest RWC (85.33%) was obtained in the BAW 1130. Due water deficit stress the RWC was decreased in all wheat genotypes but the degree of reduction in RWC was different in different genotypes. The genotype E 38 provided the lowest reduction of the RWC (0.72%) due to water stress followed by BARI Gom 25 (4.36%), BAW 1118 (5.94%), E 18 (6.19%) and BARI Gom 26 (8.10%), whereas, the genotype BAW 1130 showed the highest reduction in RWC (8.90%) due to water deficit stress. A decrease in the RWC in response to drought stress has been noted in wide variety of plants as reported by Nayyar and Gupta (2006). Plants those are able to maintain high levels of RWC under water deficit conditions are less affected by stress and are capable of continuing normal growth and

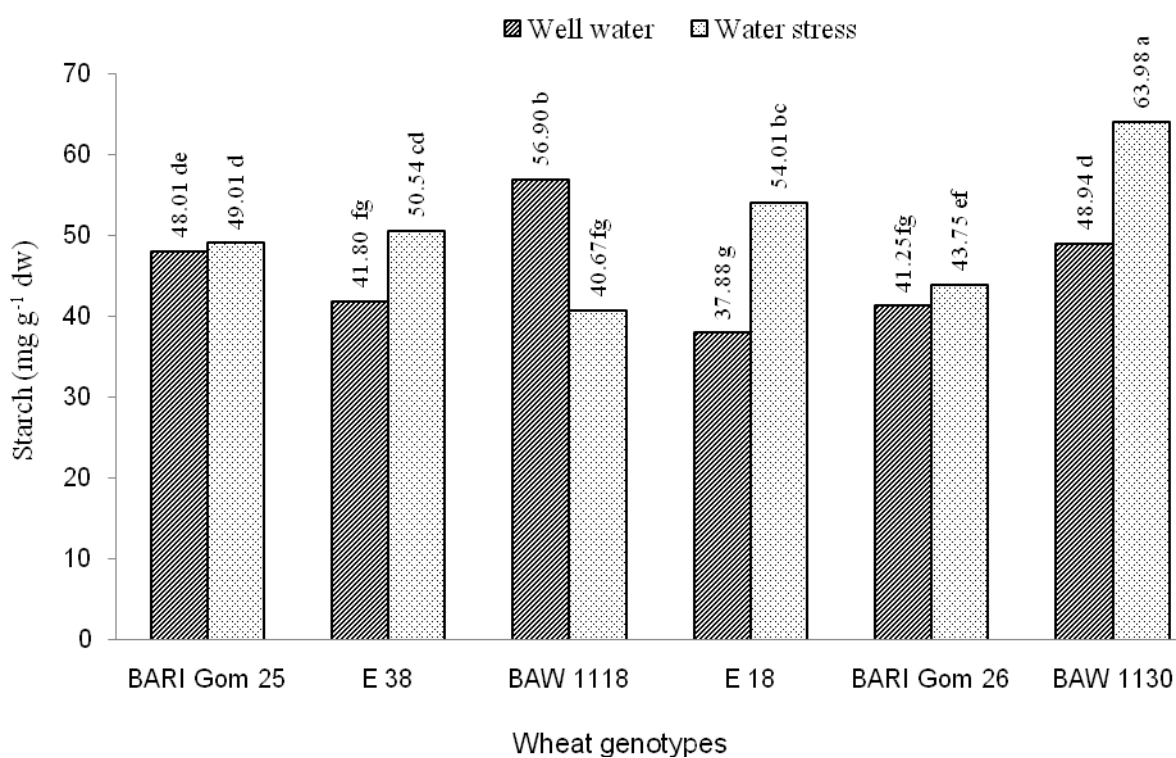


Fig. 3.3.3. Starch (mg g⁻¹dw) content in kernel of different wheat genotypes at 16 days after anthesis influenced by water deficit stress

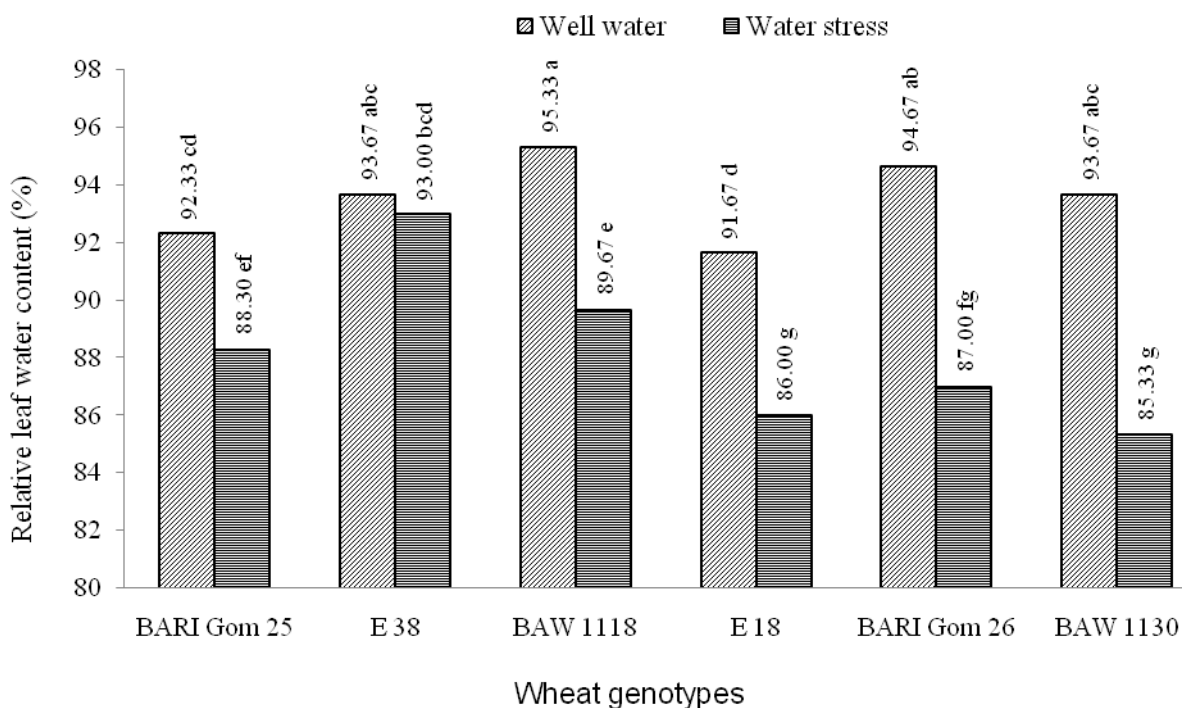


Fig. 3.3.4. Relative water content of flag leaf of different wheat genotypes at 16 days after anthesis as influenced by water deficit stress

yield (Beltrano *et al.* 2006). Adejare and Umebese (2007) reported that the values of RWC were significantly reduced under water stress treatments at the booting, anthesis and soft dough growth stages in the bread and durum wheat plants. These results are in agreement with the findings of Molnár *et al.* (2004), Dulai *et al.* (2006), and Moayedi *et al.* (2011a) who reported that wheat plants exhibited a large reduction of RWC and water potential when subjected to drought stress.

3.3.18 Water retention capacity

The cell structure of plant determines the water retention capacity (WRC). The WRC of different wheat genotypes were found higher at morning and reduced gradually with the advancement of time both under the well watered and water stressed plants (Fig. 3.3.5). Water stress tolerance genotypes (BARI Gom 25, E 38, BAW 1118 and E 18) showed higher WRC as compared to water stress susceptible genotypes (BARI Gom 26 and BAW 1130) both in water deficit stress condition and well water condition. Due to water deficit stress water retention capacity was reduced in all wheat genotypes but the degree of reduction in WRC was found more in water stress susceptible genotypes (BARI Gom 26 and BAW 1130) than that in water stress tolerance genotypes (BARI Gom 25, E 38, BAW1118 and E 18). Plants grown under high moisture regimes maintain a higher WRC, which might be due to the lower destruction of plant tissues by moisture deficit (Sangakkara *et al.* 1996). Similar findings for the WRC were reported by Choudhury (2009) in French bean and Martinez *et al.* (2007) in *Phaseolus vulgaris*. Tasmina *et al.* (2016) reported that the WRC decreased markedly in wheat due to water stress at booting, anthesis and grain filling stages.

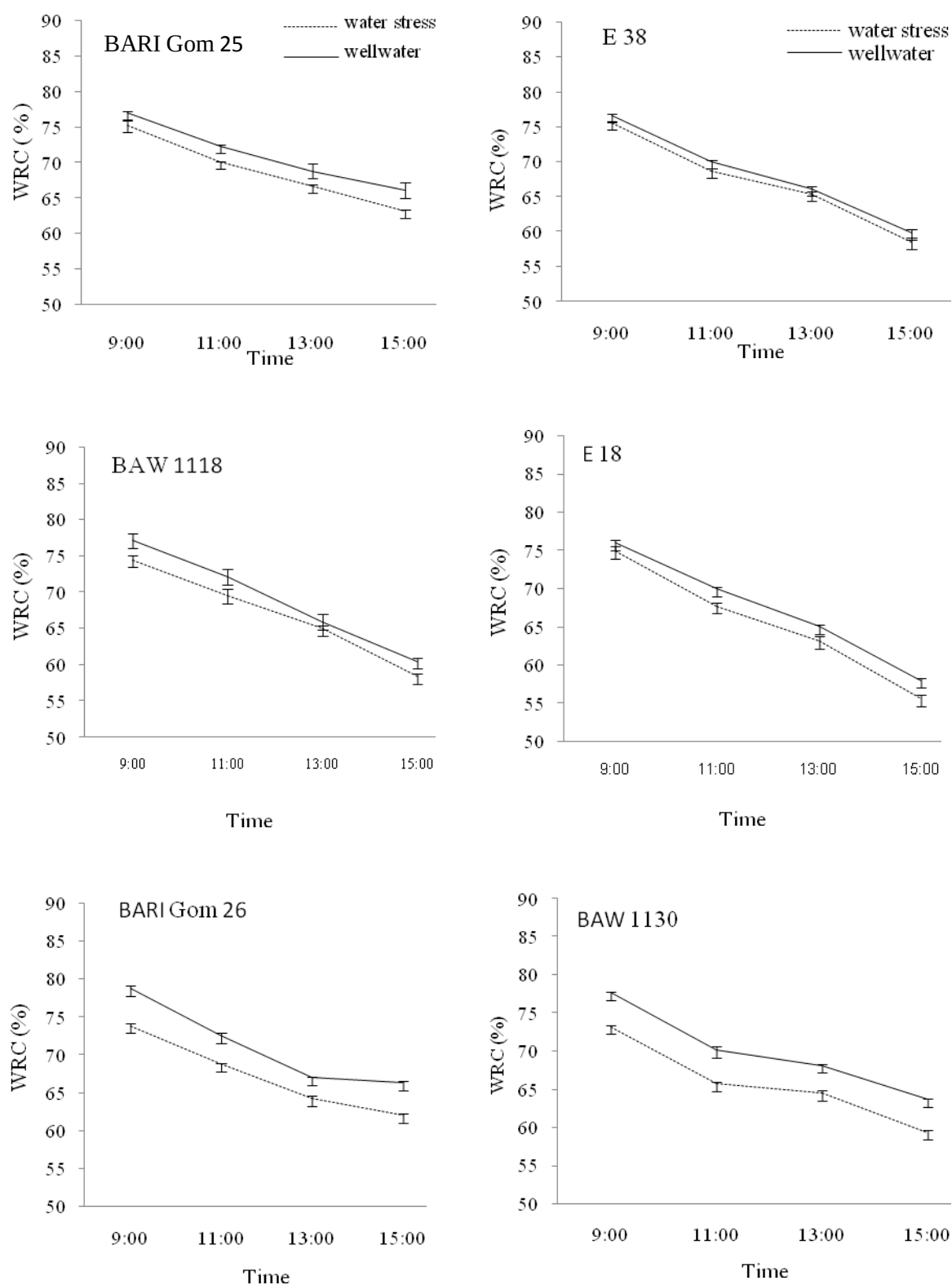


Fig. 3.3.5. Water retention capacity (mean $\pm$ SE) of different wheat genotypes as influenced by water deficit stress

3.3.19 Canopy temperature depression

Canopy temperature depression (CTD) is the difference between air temperature and canopy temperature. It is reported in different studies that the CTD is a superior indicator of a genotype for physiological suitability to drought tolerance and higher values of CTD be a sign of drought tolerance (Fischer *et al.* 1998, Rashid *et al.* 1999, Ayeneh *et al.* 2002). It has been used in many practical evaluations of plant response to water deficit stress. Recently, Balota *et al.* (2007) reported the appliance of CTD to estimate crop yield and to rank genotypes for tolerance to drought. In this study, the CTD was influenced significantly by the interaction effects of the different water regimes and wheat genotypes at 16 DAA {Fig. 3.3.6(a)}. Wheat genotypes maintained 6.69 to 11.27°C and 2.59 to 6.83°C CTD under well water condition and water stress conditions, respectively. The CTD was reduced significantly in all wheat genotypes due to water deficit stress and the magnitude of reduction was dissimilar in different wheat genotypes. However, the highest reduction (77.02%) was recorded in the genotype BAW 1130 indicating its stress susceptible followed by the genotype BARI Gom 26 (48.74%), whereas the lowest reduction (25.52%) was observed in wheat genotype of E 38, specifying it most drought tolerant followed by the genotype of BAW 1118 (28.23%), BARI Gom 25 (29.00%) and E 18 (31.11%) comparing with the well water condition. The CTD at 24 DAA was also influenced significantly by the interaction effect of wheat genotypes and water regimes {Fig: 3.3.6(b)}. Wheat genotypes maintained 4.19 to 10.48°C CTD under well water condition. Due to water deficit stress, the CTD was decreased in all the wheat genotypes and they maintained 1.54 to 5.98°C CTD. But the reduction in the CTD due to water deficit stress was not similar in all the wheat genotypes. The reduction of CTD was significant in all the wheat genotypes and the highest reduction (84.63%) was observed in BAW 1130 indicating the most drought sensitive followed by BARI Gom 26 (54.01%) and the lowest was in E 38 (30.31%) signifying the most tolerant genotype followed by BAW 1118 (31.58%), BARI Gom 25 (33.33%) and E 18 (35.63%). The CTD

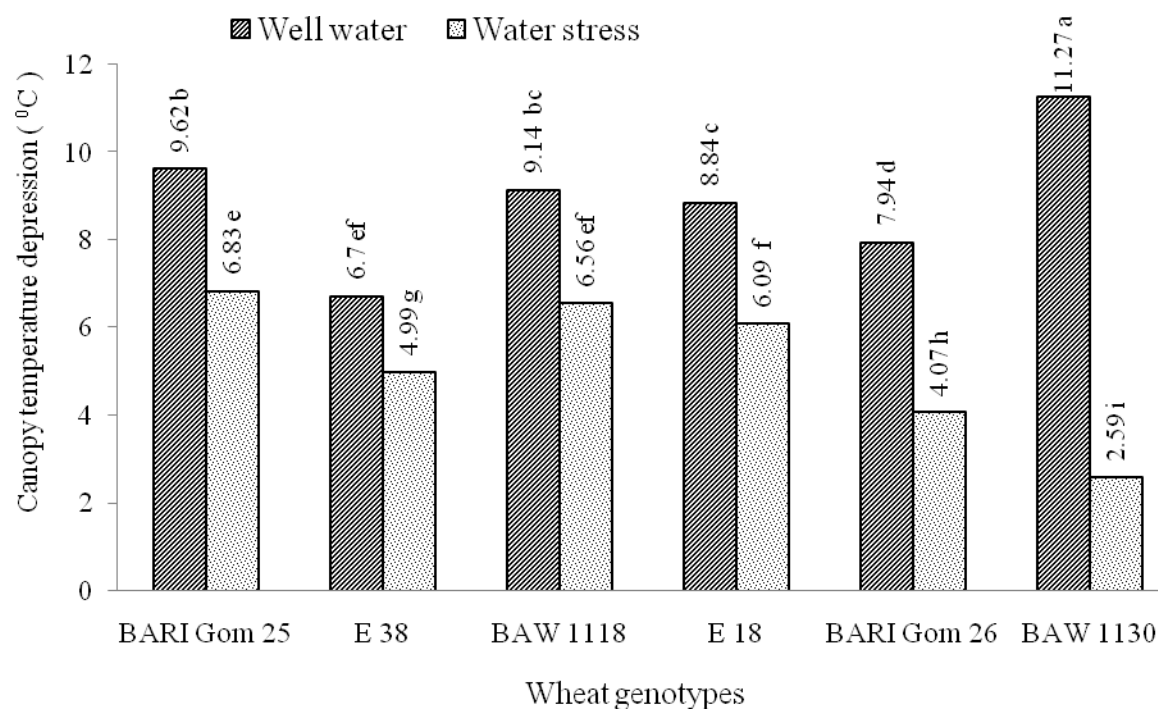


Fig: 3.3.6(a). Canopy temperature depression (°C) of different wheat genotypes at 16 days after anthesis influenced by water deficit stress

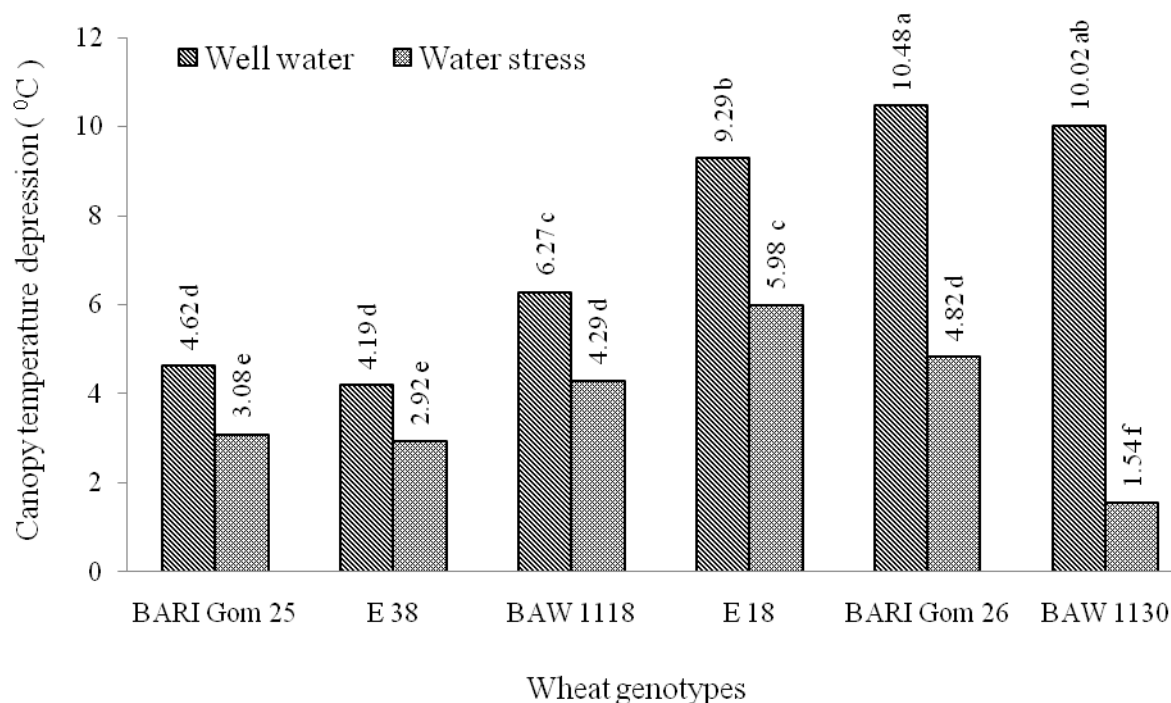


Fig. 3.3.6(b). Canopy temperature depression (°C) of different wheat genotypes at 24 days after anthesis influenced by water deficit stress.

decreased under drought stress is probably due to an increase in respiration and a decrease in transpiration as a result of stomatal closure. The results of the present study indicated that the sensitive genotypes failed to retain their canopy cooler than that in tolerant genotypes under water deficit stress. It is reported that stressed wheat plants retained higher canopy temperature as compare to non-stressed plants (Buttar *et al.* 2005, Olivares-Villegas *et al.* 2007, Lopes and Reynolds 2010).

3.3.20 Cell membrane stability

The ability of plants to maintain their membrane integrity under drought determines tolerance towards drought (Vieira da Silva *et al.* 1974). The rate of injury to cell membranes by water stress may be estimated by measuring electrolyte leakage from cells. The cell membrane stability (CMS) was measured as the percentage of injury in the PEG test of leaf tissues in six wheat genotypes at anthesis (Fig. 3.3.7) The highest injury was obtained in the genotype BARI Gom 26 (68%) which was almost similar to the genotype of BAW 1130 (63%). On the other hand, the lowest injury was recorded in the genotype E 38 (22%) and this is near to BARI Gom 25 (25%).

Percentage injury was lower i.e. the CMS was higher in the genotypes indicated that these genotypes were more tolerant to water deficit stress. Chandrasekar *et al.* (2000) reported that the membrane stability in wheat was reduced under drought conditions. The greater water loss corresponded to greater membrane damage also reported by Kocheva *et al.* (2004). Many researchers opined that the CMS has been extensively used as selection criterion for different abiotic stresses including drought and high temperature in wheat (Blum *et al.* 2001, Bajji *et al.* 2002 and Rahman *et al.* 2006a), rice (Tripathy *et al.* 2000), mustard (Hashem *et al.* 1998), cotton (Ullah *et al.* 2006 and Rahman *et al.* 2006b) and sorghum (Premachandra *et al.* 1992). Sairam and Saxena (2000) found the membrane stability index of leaves decreased with increasing water deficit stress as well as plants age. The water stress induced decrease in

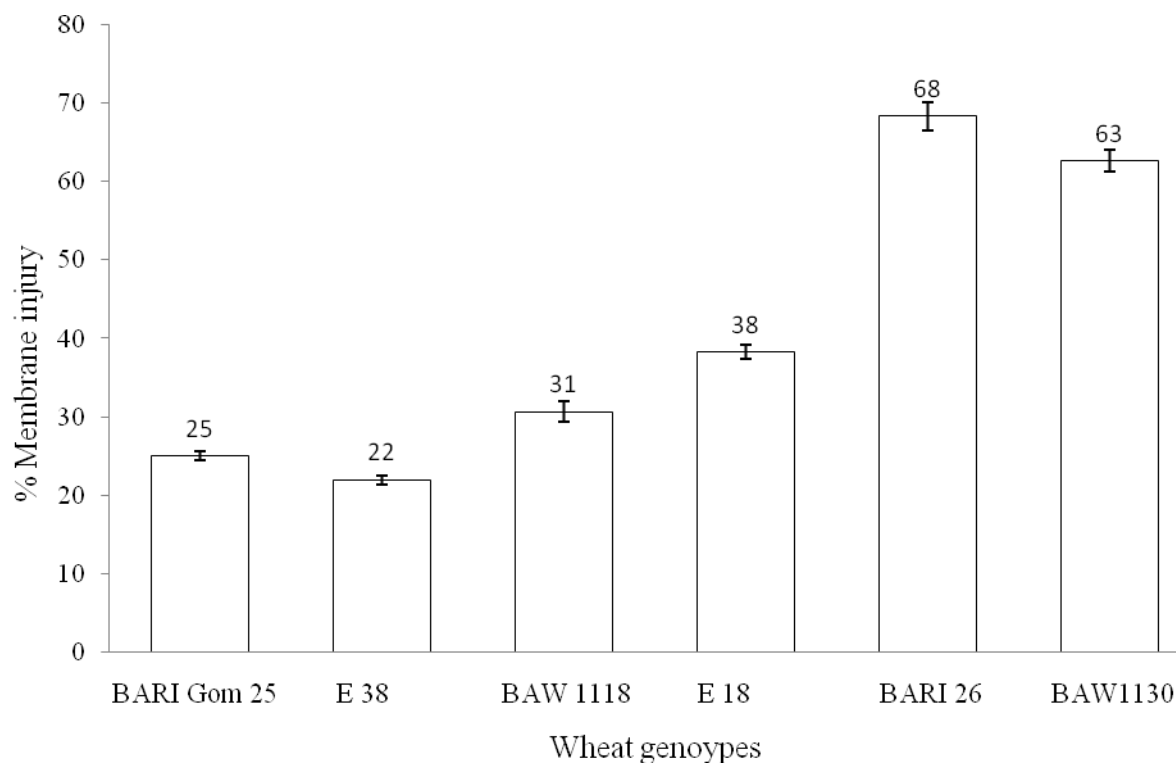


Fig. 3.3.7. Per cent membrane injury of different wheat genotypes as influenced water deficit stress.

membrane stability indicates the extent of lipid peroxidation caused by reactive oxygen species (Dhindsa *et al.* 1981, Pastori and Trippi 1992, Baisak *et al.* 1994, and Menconi *et al.* 1995). Lower lipid peroxidation and higher membrane stability (lower ion leaching) have also been reported in tolerant genotypes of wheat (Kraus *et al.* 1995), and maize (Pastori and Trippi 1992). The wheat genotypes with higher cell membrane stability (71-80%) have been observed to tolerate better under drought condition (Shafeeq *et al.* 2006). A significant positive correlation was found between cell membrane stability and grain yield in the stress condition by Farshadfar *et al.* (2011).

3.3.21 Spike dry matter accumulation

A typical sigmoid pattern of dry matter accumulation in spike was found in all wheat genotypes under well water and water deficit stress condition (Fig. 3.3.8.) and (Appendix 11). This is might be argued that spike development proceeded slowly at the beginning but increased sharply later on. The sharp rise in grain development at later stage is presumably because of increased translocation and partitioning of photosynthates in response to the greater sink demand. The declining tendency in dry matter after attaining the highest level could be due to respiratory loss of spike. The tolerant genotypes required equal time (days) to attain maximum spike dry weight in well water and water stress condition and it was 36 days in BARI Gom 25, 32 days in E 38, 36 days in BAW 1118 and 36 days in E 18. In sensitive genotypes (BARI Gom 26 and BAW 1130) maximum spike dry weight attained 4 days earlier in water deficit condition compared to well water condition. Similar pattern of spike dry matter accumulation in wheat was also found by Hasan *et al.* (2007) under heat stress condition, and Chowdhury (2012) under water stress condition.

3.3.22 Shoot length

The shoot length i.e. plant height is a major agronomic character used in the selection of cultivars for performance and adaptability (Jatoi *et al.* 2011). The shoot length plays an important role in photosynthesis. In this study, the shoot length was influenced significantly

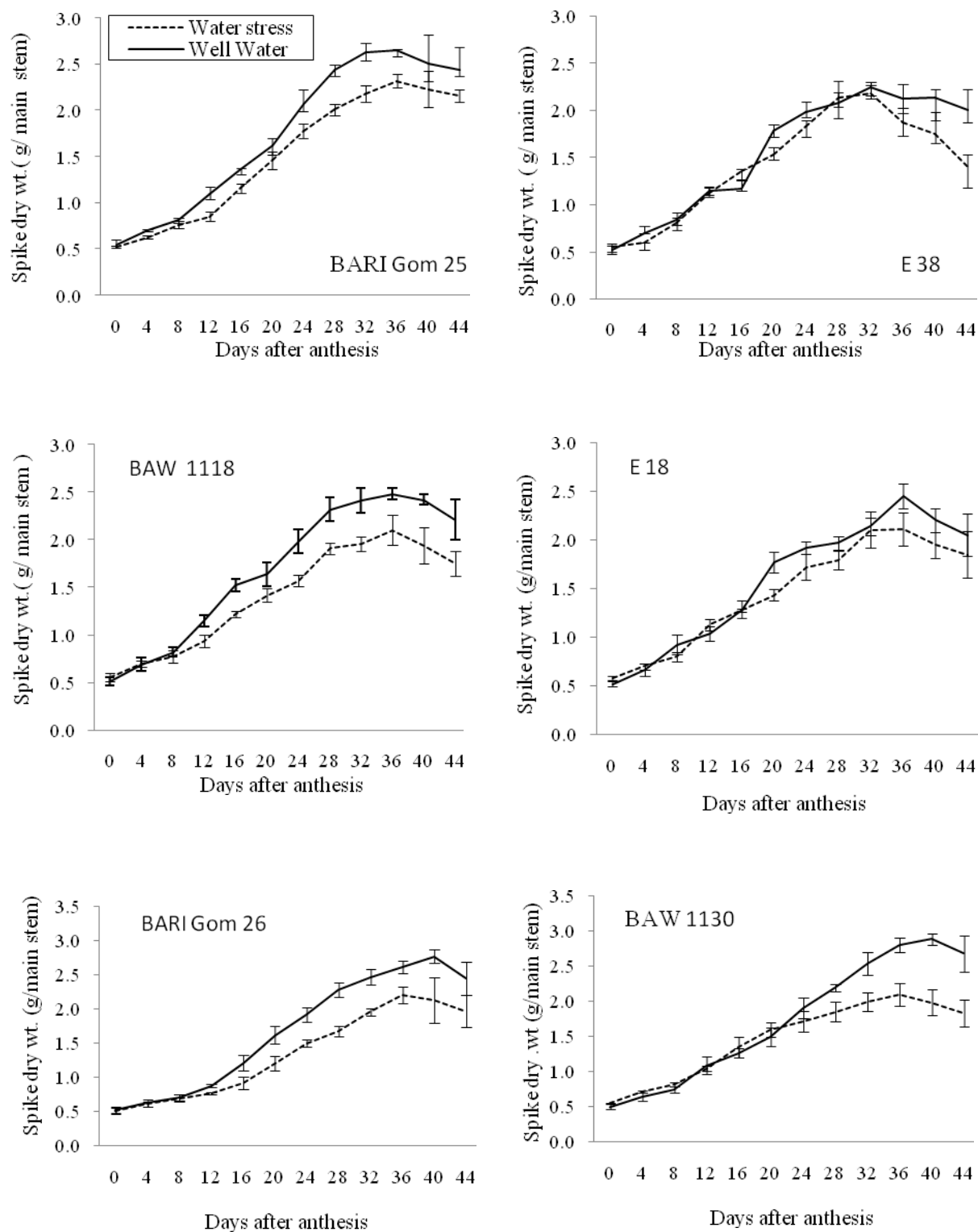


Fig.3.3.8. Spike dry matter accumulation (mean $\pm$ SE) in different wheat genotypes at different days after anthesis as influenced by water deficit stress

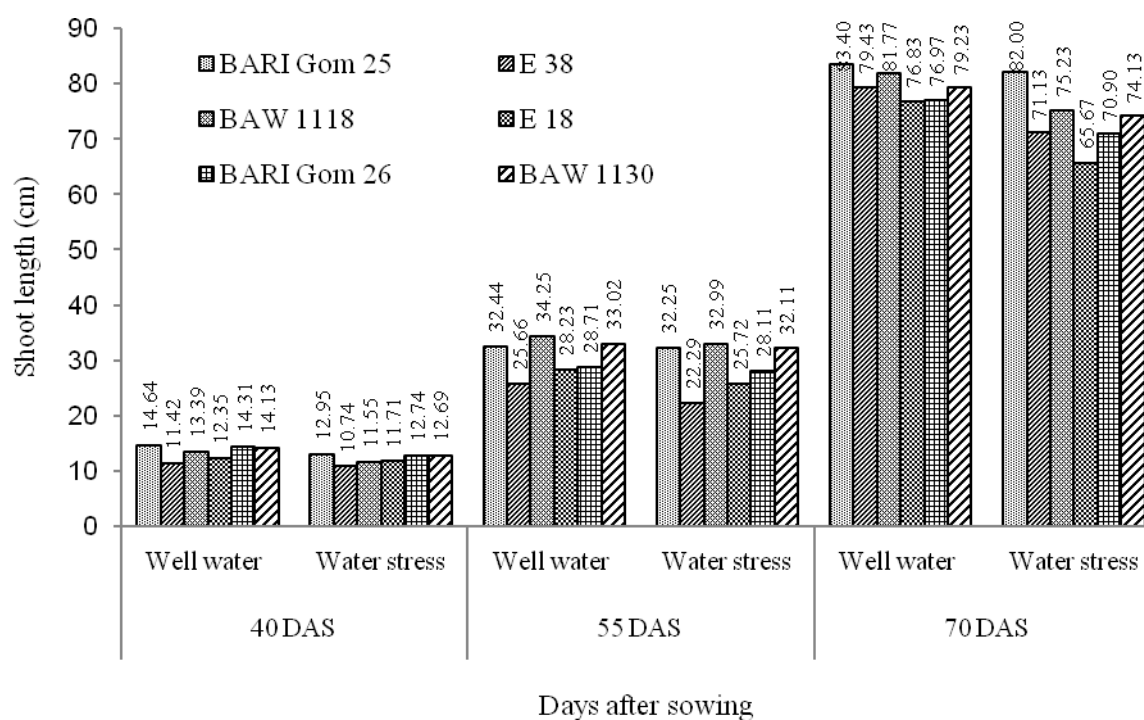


Fig. 3.3.9. Shoot length (cm) of different wheat genotypes at different days after sowing influenced by water deficit stress

by wheat genotypes at all the stages of plant growth (40, 55 and 70 DAS) and at the later stage of plant growth (55 and 70 DAS), the shoot length influenced extensively by the water regimes as well as wheat genotypes but their interaction effects regarding this issue were statistically ignorable at all observation stages (Fig. 3.3.9 and Appendix 7). Water stress did not decrease the plant height remarkably at the early stage of plant growth (at 40 DAS), it might be due to sufficient residual soil moisture of monsoon at this stage. At the later stage of plant growth (55 and 70 DAS), the shoot length was reduced in all wheat genotypes due to water stress compared to well water condition. Several authors also reported that plant height was significantly reduced due to water stress in wheat (Inamullah *et al.* 1999, Gupta *et al.* 2001, Malik and Hassan 2002, and Khakwani *et al.* 2012b).

The decrease in plant height might be due to decrease in relative turgidity and dehydration of protoplasm resulting of drought stress which is associated with a loss of turgor and reduced expansion of cell and cell division (Arnon 1972). Manivannan *et al.* (2007) also mentioned that the reduction in plant height could be attributed to decline in the cell enlargement and more leaf senescence in the plant under water stress. Bhatt and Srinivasa-Rao (2005) also reported that the decline in plant height is related with a decrease in cell enlargement in wheat.

3.3.23 Leaf area index

Leaf area index (LAI) is the ratio of leaf area and its ground area (Radford 1967) and it is the functional size of the standing crop on unit land (Hunt 1978). Crop growth depends on adequate formation of leaf area for effective interception of light (Wilson 1981). In this study, wheat genotypes and water regimes significantly affected the LAI at different DAS (Fig. 3.3.10). At 40 DAS, the LAI varied from 1.419 in BAW 1118 under water deficit condition to 3.338 in BARI Gom 26 under well water condition. At 55 days after sowing, the LAI varied from 2.262 in BAW 1130 under water deficit condition to 6.086 in E 38 under well

water condition. At 70 days after sowing, the LAI varied from 1.975 in BARI Gom 26 under water deficit condition to 5.115 in E 38 under well water condition.

The results revealed that water stress imposed at any developmental stage significantly reduced LAI compared with the well water treatment and the magnitude of reduction in LAI was inconsistent between tolerant and sensitive genotypes (Fig. 3.3.10). Reduction in LAI due to water stress is attributed to lower leaf area and leaf expansion (Zhang *et al.* 1998). The lower LAI of the stressed treatment could be ascribed to the reduced number of leaves per plant, diminished leaf expansion and smaller leaf size (Abayomi and Wright 1999). The decline in LAI after 55 DAS might be due to senescence of leaves from the base of the stem approaching upward. Many studies are in line with the findings of the present study that drought at tillering stage (Hussain *et al.* 1987), during vegetative growth (Mossad *et al.* 1995, and Qadir *et al.* 1999) and at crown root plus booting stage (Qamar *et al.* 2012) caused reduction in LAI significantly in wheat than other irrigation treatments.

3.3.24 Number of tillers

Tiller production is reliant on the genetic and environment factors including management, and thereby varied the number of tillers (Innes *et al.* 1981). At 45 DAS, the number tillers was influenced significantly by the interaction effect of wheat genotypes and water regimes (Fig. 3.3.11). The number of tiller was ranged from 436 to 685.6 m⁻² and 248 to 383.6 m⁻² under well water and water deficit stress condition, respectively. The results revealed that tillers m⁻² reduced due to water stress compared to well water treatment in all wheat genotypes but the reduction was not similar for all wheat genotypes. The tolerant- BARI Gom 25 showed 38.06% reduction, E 38 showed 35.01% reduction, BAW 1118 showed 43.12% reduction and E 18 showed 41.31% reduction whereas the stress sensitive BARI Gom 26 showed 44.05% reduction and BAW1130 showed 45.74% reduction due to water stress. So, the genotypes can be arranged based on the magnitude of reduction in total tillers m⁻² as which be a sign of drought tolerance order. The number of tillers is reduced through

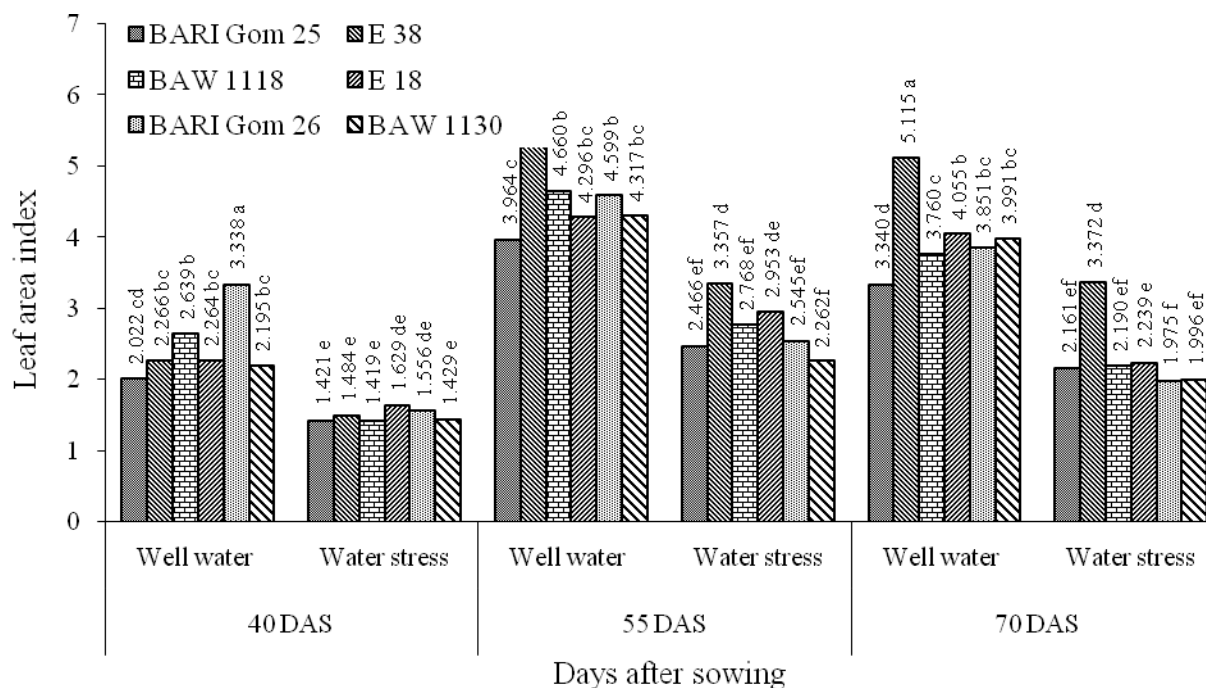


Fig. 3.3.10. Leaf area index of different wheat genotypes at different days after sowing influenced by water deficit stress

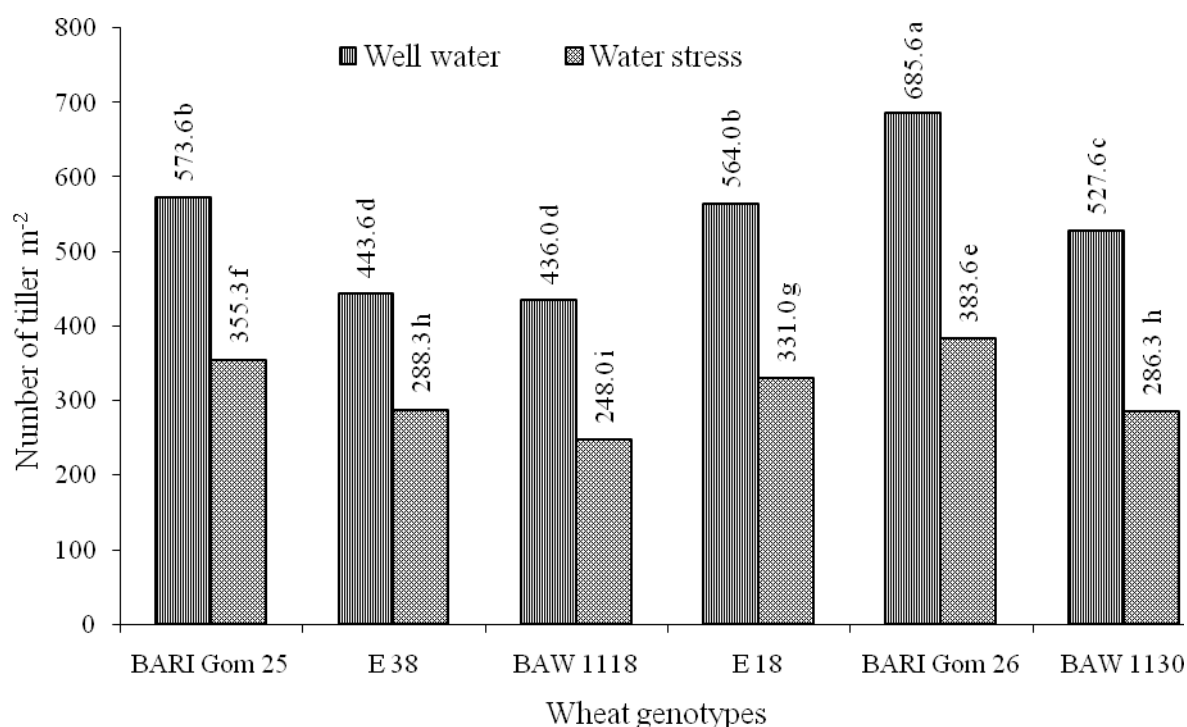


Fig.3.3.11. Number of tiller m^{-2} of different wheat genotypes at maximum tillering stage (45 DAS) influenced by water deficit stress

water stressed treatments as reported by Budiman and Nompo (2015) are in line in this study. The reduced number of tillers due to water stress might be because of died of some tillers as a result water shortage.

The reduction in the number of tillers due to water stress has also been reported by several researchers such as Bade *et al.* (1985) in Bermudagrass and Kleingrass, Velloso (1997) in Ryegrass. Agronomical characteristics such as tillering, number of fertile tillers in cereals are affected by water stress conditions (Blum 2005). Maralian *et al.* (2010) observed that tillering and heading stages were sensitive to water stress, and the productivity of wheat reduced more than 37% compared with control condition.

3.3.25 Phenological parameters

Water deficit stress may influence the phenology of the plant by pushing forward the flowering in wheat (Parchin *et al.* 2011). Water deficit diminishes all the phenological growth periods, dry matter production and final yield of durum wheat (Kiliç and Yağbasanlar 2010). The particular duration of plant growth is one of the most important factors for the phenological development of crops for yield adaptation in any environment (Motzo and Giunta 2007). The length of growing period and phenological development of crops can affect the yield either by consuming more resources or by decreasing the environmental tensions or by reducing the length of the periods (Attarbashi *et al.* 2002).

Days to heading

Days to heading was influenced significantly by the interaction effect of water regimes and wheat genotypes. Water deficit condition significantly reduced the aforementioned phenological trait compared to well water condition (Table 3.3.4). The number of days required attaining heading ranged from 67 to 74 under well water and the values were 63 to 70 under water deficit condition. The heading occurred 3 days earlier in E 38, 4 days earlier in BARI Gom 25 and BAW 1118, 5 days earlier in E 18 and BARI Gom 26 and 6 days earlier in

Table 3.3.4. Effect of water regimes on days required to attain heading, anthesis and physiological maturity of different wheat genotypes

Wheat genotypes	Water regimes	Days to heading		Days to anthesis		Days to physiological maturity	
		No. of days	Early (d) to ontrol	No. of days	Early (d) to control	No. of days	Early (d) to control
BARI Gom 25	Well water	69 cd	-	71 b	-	105 c	-
	Water stress	65 fg	4	68 d	3	103 d	2
E 38	Well water	74 a	-	75 a	-	107 a	-
	Water stress	71 b	3	74 a	1	106 b	1
BAW 1118	Well water	67 e	-	72 b	-	103 d	-
	Water stress	63 h	4	68 d	4	101 f	2
E 18	Well water	71 b	-	75 a	-	107 a	-
	Water stress	66 ef	5	71 b	4	104 c	3
BARI Gom 26	Well water	70 bc	-	72 b	-	105 c	-
	Water stress	65fg	5	68d	4	102 de	3
BAW 1130	Well water	70 bc	-	72 b	-	105 bc	-
	Water stress	64 g	6	67 d	5	102 ef	3
Level of significance		*		**		*	
CV (%)		1.48		0.83		0.44	

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

^{NS} indicates insignificant

BAW 1130 under water stress comparing with well water condition. Early heading has been known as a major drought escaping mechanism, particularly in terminal drought stresses as depicted by Allahverdiyev (2015) in durum and bread wheat. Plants allow finishing the life span earlier due to water deficit condition (Levitt 1980). This finding is in agreement with the results of Kiliç *et al.* (1999), Bayoumi *et al.* (2008), Sial *et al.* (2009), Kiliç and Yağbasanlar (2010), Khakwani *et al.* (2012a) who reported that drought reduced the number of days to heading.

Days to anthesis

In this research, wheat genotypes and water regimes interacted significantly to influence the number of days required to anthesis. Under well water and water deficit condition, days required to anthesis varied from 71 to 75 and from 67 to 74, respectively (Table 3.3.4). There was a minor difference in E 38 genotype in days to anthesis under water stress (74 days) and well water (75 days) conditions. Days to anthesis occurred 3 days earlier in BARI Gom 25, 4 days earlier in BAW 1118, E 18 and BARI Gom 26 under water stress condition. The genotype BAW 1130 showed very earlier anthesis (5 days before) under water stress as compared to well water condition which indicates its more susceptibility to water stress.

Days to physiological maturity

The number of days to physiological maturity was influenced by the combine effect of water regimes and wheat genotypes. To attain the physiological maturity the required days varied from 103 to 107 and from 102 to 106 under well water and water deficit condition, respectively (Table 3.3.4). The earlier physiological maturity was observed in the genotype E 18, BARI Gom 26 and BAW 1130 (3 days) which was followed by that in BAW 1118 and BARI Gom 26 (2 days), whereas only 1 day earlier for physiological maturity was observed in E 38. Many researchers showed the similar results and they postulated that drought reduced the number of days to maturity (Saleem *et al.* 2007, Kiliç and Yağbasanlar 2010) and grain filling period (Sial *et al.* 2009, Kiliç and Yağbasanlar 2010).

3.3.26. Yield contributing characteristics

Plant height

Optimum plant height has been considered as an important trait to avoid lodging. Height of plant was significantly influenced by the interaction effect of wheat genotypes and water regimes (Table 3.3.5). Under well water condition, the highest plant height (115.07 cm) was observed in genotype E 38, whilst the lowest height (95.39 cm) was recorded in E 18. Water deficit stress drastically reduced the plant height in all wheat genotypes. But the magnitude of reduction in plant height due to water deficit stress was dissimilar among the wheat genotypes. The utmost reduction (19.37%) was observed in BARI Gom 26 due to water stress followed by BAW 1130 (15.80%). Contrary, the least reduction (9.93%) due to water stress was recorded in BARI Gom 25 indicating lesser influence of water stress i.e. tolerant to drought condition followed by the genotypes E 18 (11.76%), E 38 (13.10%) and BAW 1118 (13.37%). The reduction of plant height due to water stress has been observed by Qadir *et al.* (1999) in four wheat genotypes. Water stress subjected through out the reproductive growth stages caused a substantial decrease in plant height for durum and bread wheat genotypes (Saleem 2003). Reduction in plant height in wheat due to water deficit stress was also recorded by Khakwani *et al.* (2012b), Alderfasi *et al.* (2001). Water stress reduces relative turgidity and increases protoplasm dehydration of cell, consequently, slow down of cell expansion and cell division resulting of decrease in plant height (El-Kholy and Gaballah 2005). Water stress declined cell enlargement, enhanced leaf senescence and in turn reduced plant height (Manivannan *et al.* 2007).

Spike length

The spike length is an important yield contributing trait of crop. Bogale *et al.* (2011) depicted that the ear length determines the number of kernel per ear which is influenced by the cultivars and water availability at various growth stages of durum wheat. Water regimes and wheat genotypes significantly influenced the spike length, although their interaction effect

Table 3.3.5. Effect of water deficit stress on plant height, spike length and spikelets spike⁻¹ of different wheat genotypes at harvest

Wheat genotypes	Water regimes	Plant height		Spike length		Spikelets spike ⁻¹	
		cm	Change to control(%)	cm	Change to control (%)	Number	Change to control (%)
BARI Gom 25	Well water	99.52 b		11.13		16.63	
	Water stress	89.64 d	-9.93	9.47	-15.00	13.76	-17.26
E 38	Well water	115.07a		9.58		17.9	
	Water stress	99.99 b	-13.10	8.32	-13.15	15.5	-13.41
BAW 1118	Well water	98.62 bc		9.74		16.3	
	Water stress	85.43 e	-13.37	8.75	-10.16	13.93	-14.54
E 18	Well water	95.39 c		10.75		18.47	
	Water stress	84.17 e	-11.76	9.13	-15.07	14.73	-20.25
BARI Gom 26	Well water	99.54 b		9.23		15.77	
	Water stress	80.26 f	-19.37	8.16	-11.59	13.2	-16.30
BAW 1130	Well water	101.69 b		11.25		16.8	
	Water stress	85.62 e	-15.80	9.44	-16.09	13.83	-17.68
Level of significance		**		NS		NS	
CV (%)		1.67		2.85		4.12	

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

^{NS} indicates insignificant

was non-significant (Table 3.3.5). The spike length reduced due to water stress in all wheat genotypes compared to well water condition. These results are in harmony with Baque (2003), Sial *et al.* (2009), Mirbahar *et al.* (2009) and Kiliç and Yağbasanlar (2010), Ihsan *et al.* (2016), Khan and Naqvi (2011).

Number of spikelets spike⁻¹

The number of spikelets spike⁻¹ was significantly influenced by the water regimes and the wheat genotypes but their interaction effect was insignificant (Table 3.3.5). The number of spikelets spike⁻¹ of wheat genotypes ranged from 15.77 to 18.47 at well water condition while the values were 13.20 to 15.50 at water stress condition. Water deficit stress decreased the number of spikelets spike⁻¹. The least reduction (13.41%) was noted in E 38, after that BAW 1118 (14.54%), while the highest reduction (20.25%) was examined in E 18, after ward BAW 1130 (17.68%), indicating their tolerance and suceptibility to drought stress, respectively. Dencic *et al.* (2000) and Shehzadi (1999) concluded that spikelets spike⁻¹ is more sensitive to drought stress in different cultivars of wheat. Khan and Naqvi (2011) have been noticed a significant decrease in number of spikelets spike⁻¹ in wheat genotypes under water deficit stress condition and anthesis stage is most sensible stage where water stress severely reduced the number of spikelets spike⁻¹.

Number of spikes m⁻²

The number of spikes m⁻² is an important parameter that partly determines the final grain yield. Water regimes and wheat genotypes interacted significantly to influence the number of spikes m⁻² (Table 3.3.6). Water deficit stress reduced the number of spikes m⁻² in wheat genotypes ranging from 185.0 to 237.3 under water stress and from 256.7 to 294.7 at well water condition. The degree of reduction in different genotypes was unlike. Water stress reduced the least (14.64%) in E 38 while the upper limit reduction was obtained in BAW11130 (28.68%) among the genotypes. Abayomi and Wright (1999) reported that

Table 3.3.6. Effect of water deficit stress on yield attributes of different wheat genotypes

Wheat genotypes	Water regimes	Spikes m ⁻²		Grains spike ⁻¹		1000-grain weight	
		Number	Change to control (%)	Number	Change to control (%)	gm	Change to control (%)
BARI Gom 25	Well water	289.3 ab	-	35.97 c	-	53.83 a	-
	Water stress	235.7 d	-18.53	28.20 d	-21.60	51.17 bc	-4.94
E 38	Well water	278.0 ab	-	49.70 a	-	34.48 g	-
	Water stress	237.3 d	-14.64	44.50 b	-10.46	33.19 g	-3.74
BAW 1118	Well water	294.7 a	-	43.60 b	-	40.99de	-
	Water stress	233.0 d	-20.94	34.47 c	-20.94	42.83de	4.49
E 18	Well water	285.0 ab	-	49.60 a	-	37.22 f	-
	Water stress	218.7 d	-23.26	37.73 c	-23.93	37.53 f	0.83
BARI Gom 26	Well water	256.7 c	-	46.17ab	-	43.21d	-
	Water stress	185.0 e	-27.93	34.47 c	-25.34	40.65 e	-5.92
BAW 1130	Well water	272.0 bc	-	38.40 c	-	52.40 ab	-
	Water stress	194.0 e	-28.68	28.40 d	-26.04	49.41 c	-5.71
Level of significance		**		**		**	
CV (%)		3.62		4.11		2.26	

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$

** indicates significant at 1% level of probability

limited soil water in wheat affects the number of spikes m^{-2} depending on the growth stage, where stress occurs, which negatively affects the grain yield. Mbave (2013) showed that the number of ears per metre square was significantly reduced by water stress imposed in the flowering stage. Passioura (2007) also found 37% reduction in spike m^{-2} when moisture stress was imposed during spike emergence and anthesis stage. Akram (2011) showed in his study that water deficit at different growth stages depressed the number of tillers initiation and surviving up to maturity, and in this manner reduced the number of spikelets or seeds per ear.

Number of grains spike⁻¹

The number of kernels ear⁻¹ or number of grains spike⁻¹ determines the sink capacity and weight of grain that contribute to the final yield (Qadir *et al.* 1999). Furthermore, the number of grains spike⁻¹ is also determined by soil water availability at various growth stages (Bogale and Tesfaye 2011). Grains spike⁻¹ is considered as the most important yield contributing trait. Grains spike⁻¹ was quite variable due to soil water status and genetic potentiality. Since, the number of grains spike⁻¹ is typical yield component and most sensitive to high temperature and/or drought, and it is, therefore, suggested as the most reliable selection criterion for drought tolerance (Shpiler and Blum 1991). In the present study, the number of grains spike⁻¹ significantly decreased through the interaction effects of wheat genotypes and water regimes (Table 3.3.6).

Under well water condition wheat genotype contained 34.8 to 49.7 grains spike⁻¹, whereas, the values were reduced and varied from 28.2 to 44.5 due to water deficit condition. But the magnitude of reduction in the number of grains spike⁻¹ due to water deficit stress was dissimilar in different wheat genotypes. However, the highest reduction (26.04%) was obtained in BAW 1130, followed by BARI Gom 26 (25.34%) be a sign of higher water stress susceptible (WSS) genotypes. Likewise, the lowest reduction (10.46%) was observed in E 38 afterward BAW 1118 (20.94%), BARI Gom 25 (21.60%) and E18 (23.93%) designating

them as water stress tolerance genotypes. Grain yield and yield contributors especially number of grains spike⁻¹ and 1000-grain weight were also important in determining the cultivar potential for drought resistance (Denčić *et al.* 2000). As both of these traits are related to reproductive stage and any decline in these traits can directly reduce final grain yield. Jatoi *et al.* (2011) found that the range of wheat seeds spike⁻¹ was 50-68 in non-stress condition, while the values were reduced to 32-50 in water stress conditions. Thus on average, water stress caused 31.09% decline in grains. Water stress at anthesis reduced pollination and thus fewer grains are formed spike⁻¹ which results in the reduction of grain yield (Elhafid *et al.* 1998, Akram 2011). Water stress imposed during later stages might additionally cause a reduction in the number of kernels ear⁻¹ and kernel weight (Denčić *et al.* 2000). According to Saleem (2003), drought stress reduced the number of grains spike⁻¹ and the grain yield, and genotypes with a higher number of grains ear⁻¹ produced greater yield (Iqbal *et al.* 1999). Tompkins *et al.* (1991) reported a significant suppressive effect of water stress on the number of grains spike⁻¹. Drought stress during the flowering stage disrupts flowering, photosynthesis and the transfer of stored substances into grains, which reduces the number and weight of grains (Shamsi and Kobraee 2011). The number of grains spike⁻¹ has been influenced by different irrigation in wheat cultivars (Khan *et al.* 2002, Khan *et al.* 2004), and the post-anthesis drought being the most sensitive stage for number of grains spike⁻¹ (Ashraf 1994, Akram 2011).

Thousand grain weight

In the present study, wheat genotypes and water regimes interacted significantly to decrease thousand grain weight (Table 3.3.6). Under well water condition, thousand grain weight varied from 34.48 to 53.83 g in different wheat genotypes. Due to water deficit stress, thousand grain weight was decreased in four wheat genotypes BARI Gom 25 (4.94%), E 38 (3.37%), BARI Gom 26 (5.92%) and BAW 1130 (5.71%), on the other hand, thousand grain weight was slightly increased in BAW 1118 (4.49%) and E18 (0.83%). These results are in

line with the findings of Majid *et al.* (2007), who reported that drought stresses affected the 1000-grain weight in different wheat varieties not in a definite pattern as reported. They also reported an increase in 1000-grain weight under pre-, post-anthesis and terminal drought stresses differentially of local hexaploid wheat.

Stress during anthesis, significantly decreased 1000-grain weight has been observed in all genotypes except Chakwal-86 that showed increase in 1000-grain weight. It may be suggested that this genotype had the ability to cope the stress. Reduction in 1000-grain weight due to water deficit has been studied by many workers (Dastfal and Ramazanpoor 2000). This reduction in 1000-grain weight could be attributed to a decrease in the supply of assimilates to the grains which led to curtailing the duration of grain filling phase (Rajiki 1982, Qadir *et al.* 1999). Drought stress reduced the number of grain/spike and grain yield (Saleem *et al.* 2007) while kernel weight is negatively influenced by high temperatures and drought during ripening (Nouri *et al.* 2011, Khan *et al.* 2005 and Qadir *et al.* 1999) who observed that 1000-grain weight of wheat was reduced mainly due to increasing water stress. The decrease in 1000-grain weight may be due to disturbed nutrient uptake efficiency and photosynthetic translocation within the plant (Ashraf *et al.* 1994) that produced shrivelled grains due to hastened maturity. This is possible due to the shortage of moisture which forces plant to complete its grain formation in relatively lesser time (Riaz and Chowdhry 2003). Under water stress, the decrease in seed set and grain growth in wheat has been reported by several workers (Saini *et al.* 1984, Ahmadi and Baker 1999 and Khan *et al.* 2012).

Grain yield

Grain yield is the ultimate result of all physiological and agronomical responses of cultivars to drought stress conditions. Drought had unusual effects on the grain yield depending on the developmental stage at which it occurs (Agboma *et al.* 1997). Saeidi *et al.* (2010) found that post-anthesis water deficiency stress reduced the grain yield. Yield is mainly a function of various components which can broadly be divided into the number of plants, dry matter

Table 3.3.7. Effect of water deficit stress on grain and biological yield of different wheat genotypes

Wheat genotypes	Water regimes	Grain yield		Biological yield	
		(t ha ⁻¹)	Change to control (%)	(t ha ⁻¹)	Change to control (%)
BARI Gom 25	Well water	3.74 bc	-	9.36 a	-
	Water stress	2.71 ef	-27.54	6.31 bc	-32.59
E 38	Well water	3.24 d	-	9.32 a	-
	Water stress	2.48 e	-23.69	6.99 b	-25.00
BAW 1118	Well water	3.86 bc	-	9.55 a	-
	Water stress	2.88 e	-25.39	6.77 bc	-29.11
E 18	Well water	3.64 c	-	9.41 a	-
	Water stress	2.41 f	-33.79	6.21 bc	-34.01
BARI Gom 26	Well water	4.38 a	-	10.06 a	-
	Water stress	2.63 ef	-39.95	6.21 bc	-38.27
BAW 1130	Well water	4.03 b	-	9.57 a	-
	Water stress	2.36 f	-41.44	6.04 c	-36.89
Level of significance		**		**	
CV (%)		4.61		4.39	

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$

** indicates significant at 1% level of probability

production, seed numbers, seed size and individual seed weight. The present study showed that water regimes significantly interacted with wheat genotypes to influence yield (Table 3.3.7). In normal condition, the grain yield of wheat genotype varied from 3.238 to 4.382 t ha⁻¹ but in water deficit stress, the grain yield decreased remarkably ranging from 2.356 to 2.875 t ha⁻¹ and the extent of reduction assorted with wheat genotypes. Nevertheless, the grain yield reduced to peak of 41.44% in BAW 1130 followed by 39.95% in BARI Gom 26 due to water stress indicating water stress susceptible genotypes while the grain yield decreased to least of 23.69% in E 38, followed by 25.39% in BAW 1118, 27.54% in BARI Gom 25 and 33.79% in E18 under water stress showing drought tolerance genotypes. These results are in agreement with Zafarnaderi *et al.* (2013), who showed that grain yield is strongly affected by water stress because of the reduction in number of spikes m⁻², number of grains spike⁻¹ and TGW under stress conditions. Ashraf (1994) reported that the productive spikes per plant contribute in increasing the yield under water deficit conditions. In the present study, the spikes m⁻², number of grains spike⁻¹, and 1000-grain weight, the major responsible factors for grain yield, were influenced by the water stress. In fact yield and yield components of the plant were reduced in drought condition even in tolerant genotypes.

The results of this study confirm to the findings of Karim *et al.* (2000) and Baque *et al.* (2006) who reported that water stress reduced grain yield by reducing productive tillers per plant, fertile spikelet per plant, number of grains per plant and individual grain weight.

According to Ali (2011), growth of wheat grain is reduced depending upon the degree of water deficit and the rate of stress development, thereby limiting final wheat grain yield. Drought stress at the grain-filling period dramatically reduces grain yield (Talebi *et al.* 2009). Akram (2011) claimed that the sensitivity of grain yield depends upon the severity of stress and the stage when it is applied. Water deficit imposed at different stages of plant growth separately showed a significant reduction in grain yield, possibly as a result of reducing the production of photo-assimilates (source limitation) for grain filling, reducing the sink power

to absorb photo-assimilates and reducing the duration of grain filling (Martiniello and Teixeira da Silva 2011).

Above ground biological yield

Plants produce maximum biomass under an adequate water supply, whereas moisture stress causes a marked decrease in plant biomass production (Ashraf 1994). Moisture stress is known to reduce biomass, tillering ability, grains/spike and grain size at any stage, but the extent of damage depends on the intensity and length of that stress. Ashraf (1994) and Ghazal *et al.* (1998) indicated that plant produces maximum biomass under adequate water supply, whereas moisture stress causes a marked decrease in plant biomass production. In the present study, above ground biological yield (BY) of different wheat genotypes was decreased significantly by the water regimes (Table 3.3.7). Under well water condition, the biological yield of wheat genotype was 9.324 to 10.062 t ha⁻¹ but the values decreased to 6.035 to 6.991 t ha⁻¹ due to water deficit stress. The highest reduction (38.27%) of BY was recorded in BARI Gom 26, next BAW 1130 (36.89%) due to water stress signifying them to susceptible genotypes, and the lowest reduction (25.00%) was observed in E 38 followed by BAW 1118 (29.11%), BARI Gom 25 (32.59%), and E18 (34.01%). The minimum reduction due to stress signifies tolerance genotypes to stress.

The results of the present experiment are also in line with the findings of Wang *et al.* (2004) who reported that skipping irrigation at different growth stages significantly reduced the biological yield in different wheat genotypes. Water stress experienced by a wheat crop during growth stages is known to have cumulative effects expressed as a reduction in total biomass as compared to well watered conditions (Mirbahar *et al.* 2009). Almeselmani *et al.* (2011a) observed that biomass yield decreased beyond 70% due to drought in wheat. The biological yield plant⁻¹ in wheat was reduced due to moisture stress by 39 to 48% (Mirbahar *et al.* 2009), 32.9% (Bayoumi *et al.* 2008). Biological yield per plant decreased under stressed environment is also mentioned by Chandler and Singh (2008) who reported that

grain yield and biological yield particularly showed maximum sensitivity to moisture stress and shoot water potentials of french bean (*Phaseolus vulgaris* L.).

3.3.27 Water stress susceptible index (SSI)

The water stress susceptibility index (SSI) is independent of yield potential and drought intensity, since larger values of SSI indicate greater water stress susceptibility (Bayoumi *et al.* 2008). The present investigation showed that the SSI based on grain yield was the lowest (0.72) in the wheat genotype E 38 followed by BAW 1118 (0.79), BARI Gom 25 (0.85), E 18 (1.04) and SSI was the highest in BAW 1130 (1.28) after that BARI Gom 26 (1.23) (Fig. 3.3.12). These results revealed that the genotype E 38 showed the lowest stress susceptibility i.e., the genotype showed greater stress tolerance and the genotype BAW 1130 showed the highest stress susceptibility index i.e., the genotypes demonstrated the lowest stress tolerance.

The SSI of different wheat genotypes based on above ground biological yield is presented in Fig. 3.3.13. The genotype E 38 showed the lowest SSI of 0.76 which was followed by BAW 1118 (0.89), BARI Gom 25 (0.99), E 18 (1.04), BAW 1130 (1.13), and BARI Gom 26 (1.17) (Fig. 3.3.13). Based on the SSI values, the tolerance of the genotypes can be ranked as E 38 > BAW 1118 > BARI Gom 25 > E 18 (1.04) > BAW 1130 > BARI Gom 26. Talebi (2011) reported that DSI (drought susceptibility index) values indicated the potential for screening durum wheat genotypes for drought response. Guttieri *et al.* (2001) using SSI criterion suggested that SSI more than 1 indicating above-average susceptibility, and SSI less than 1 indicated below-average susceptibility to drought stress.

Considering the results of experiment- III, it may be concluded that based on physiological traits such as, better grain growth duration, greater accumulation of flag leaf proline and soluble sugar, greater stability of flag leaf chlorophyll, better relative water content and cooler canopy under water deficit stress, E 38 was found to be more water stress tolerant, followed by BARI Gom 25, BAW 1118, E 18 and BARI Gom 26 and BAW 1130 were observed as susceptible genotypes.

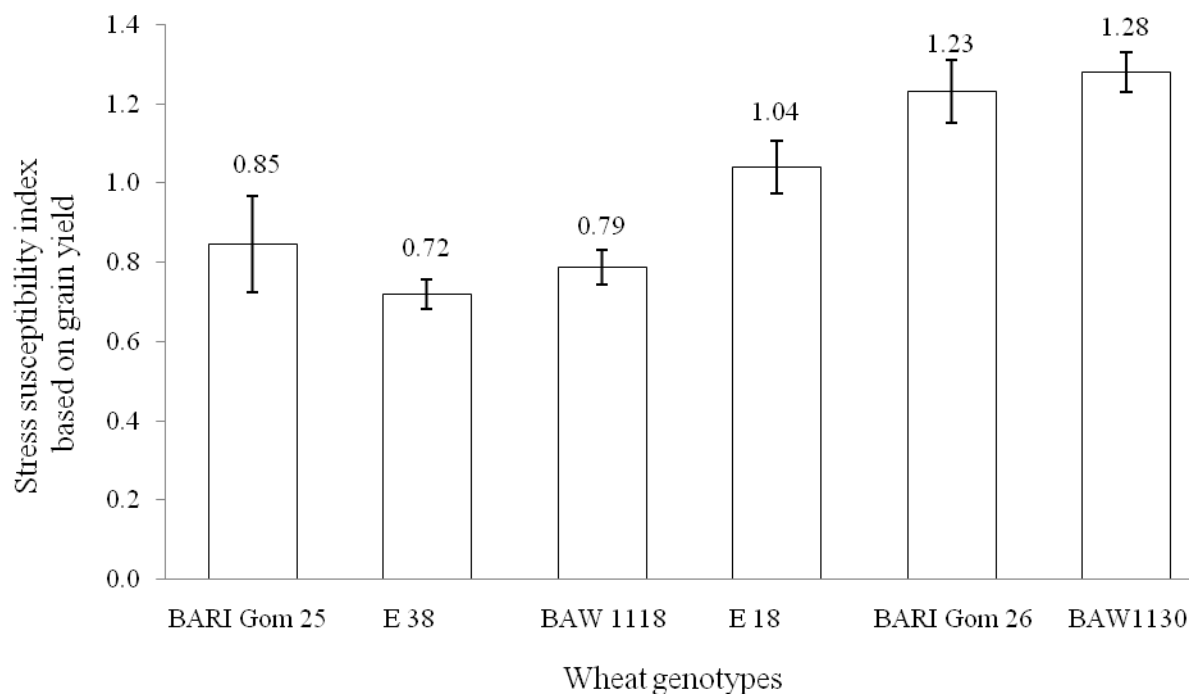


Fig. 3.3.12. Stress susceptibility index of different wheat genotypes based on grain yield

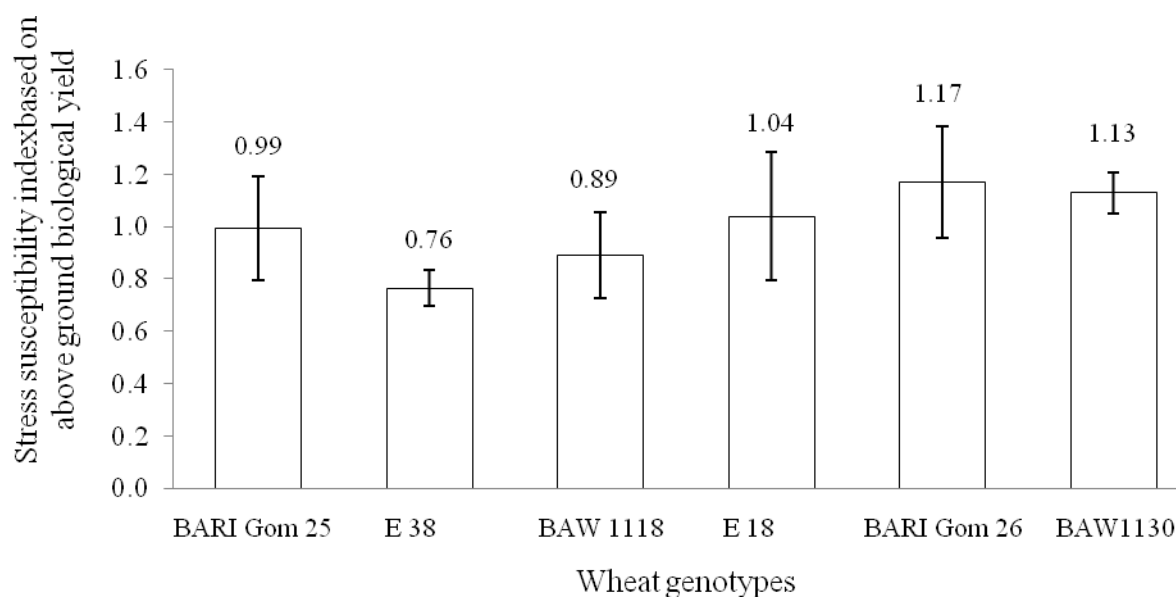


Fig. 3.3.13. Stress susceptibility index of different wheat genotypes based on above ground biological yield

Experiment IV: IMPROVEMENT OF DROUGHT TOLERANCE OF WHEAT BY INCREASING LEVEL OF POTASSIUM FERTILIZATION

INTRODUCTION

Drought is a common stress limiting crop growth and it may increase cellular membrane permeability, resulting in K outflow. Internal K starvation may disorder plant metabolism and limit plant growth (Wei *et al.* 2013). Potassium (K) is the most abundant cation in plants and has a strong positive relationship between K fertilizer and grain yield of wheat, maize, soybean (Pettigrew 2008). K plays essential roles in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance and resists drought stress (Marschner 2012). Application of potassium enhanced root growth and stem elongation, increased leaf water potential, osmotic potential, turgor potential, gas exchange parameters like photosynthetic rate etc. under drought stress. Most importantly, potassium is greatly helpful in the transportation of sugars prepared in leaves to fruit (Aslam *et al.* 2013). Status of mineral-nutrient in plants plays a critical role in increasing plant resistance to drought stress (Marschner 1995). For the survival of crop plants, K is to be valuable of the mineral nutrients in ameliorating the ill-effects of soil water stress (Umar 2006). The function of stomata is to control water loss from the plant via transpiration and the stomata cannot function properly and water losses from plant may reach damaging levels when K^+ is deficient (Gething 1990). Further, by reducing the transpiration and increasing the retention of water in plants K also decreases the loss of soil moisture (Umar and Moinuddin 2002). Potassium fertilization mitigates the adverse effects of moisture stress in plants by increasing translocation and maintaining water balance within plants (Greenwood and Karpinets 1997). Foliar fertilization of K on crops can complement and guarantee the availability of nutrients to crops for obtaining higher yields (Arif *et al.* 2006). Temporary water shortage in a particular crop plant can be strengthened by K application through acclimatization mechanisms. Its anti stress action may be manifested through the

increasing rate of root-system growth into humid parts of the soil profile in response to a decreasing water supply (Perna and Menzies 2010, Damm *et al.* 2013). Potassium supply in plant reduced transpiration rate and improved cell water status resulting alleviated the stress injury under water stress condition (Losch *et al.* 1992). Usefulness of K supply in water stressed plants are well known such as increased dry matter, permeability of plasma-lemma, water potential, photosynthetic rate, chlorophyll content, leaf area, stem width, decreased carotenoid contents and respiration rate (Akhtar *et al.* 1999, Farooq *et al.* 2009 and Taiz and Zeiger 2010). In fact, detrimental effects of water stress on growth and development can be minimized by K fertilization through its positive effect on stomatal regulation, osmotic adjustment, protein synthesis and photosynthesis (Asgharipour and Heidari 2011). Therefore, the present investigation was carried out to sustain desirable wheat yield under water deficit condition by increasing K supply.

MATERIALS AND METHODS

This chapter describes details of the methodology that were used in performing this piece of research. The components under description include location, soil, crop, treatment, experimental design, intercultural operations, data collection etc.

3.4.1 Location and duration

The experiment was conducted in an experimental field of the Wheat Research Center (WRC), Nashipur, Dinajpur, Bangladesh during November 2016 to April 2017. The experimental site is situated under the Dinajpur Sadar Upazila and located at 25°39' N latitude and 88°41' E longitude with an elevation of 37.58 meter above the sea level (FAO/UNDP 1988).

3.4.2 Soil and climate

The experimental field was a medium high land belonging to the non-calcareous dark gray flood plain soil under the Agro-Ecological Zone (AEZ) of Old Himalayan Piedmont Plain (AEZ 1) (FAO/UNDP 1988). The soil is sandy loam under the order Inceptisol. The experimental site is situated in the sub-tropical region characterized by heavy rainfall during the months from May to September and scanty rainfall in the rest of the year. Details of the soil characteristics of the experimental site is presented in Appendix 1 and Appendix 2, and details of the meteorological data in respect to temperature, rainfall and relative humidity during the growing period of the experimental site are presented in the Appendix 5.

3.4.3 Experimental design and layout

The experiment was conducted in a split plot design with three replications. The unit/sub plot size was 4 x 2 m. The distance between unit/sub plots was 0.5 m, main plot to main plot was 1 m and block to block distance was 2 m. Five potassium fertilization treatments in combination with water regimes were placed in the main plots as main plot treatments whereas two wheat genotypes were placed randomly in the sub plots as sub-plot treatments.

3.4.4 Experimental treatments

The treatments were-

A. Main plot treatments: Five potassium fertilizer treatments along with water regimes-

T₁: Recommended dose of K (50 kg K ha⁻¹) under well water condition

T₂: Recommended dose of K (50 kg K ha⁻¹) under water stress condition

T₃: 75 kg K ha⁻¹ under water stress condition

T₄: 100 kg K ha⁻¹ under water stress condition

T₅: Foliar application of K₂SO₄ (40, 55 and 80 DAS) with recommended dose of K (50 kg K ha⁻¹) under water stress condition

B. Sub-plot treatments: Two wheat genotypes- V₁: E 38, and V₂: BAW 1130

3.4.5 Land preparation

The land was ploughed by a power tiller and was levelled by harrowing and laddering carefully. The weeds and stubble were removed and main plots, sub-plots and blocks were prepared and irrigation channels were made around each block.

3.4.6 Fertilizer application and irrigation

Fertilizers were applied during final land preparation as WRC recommended doses (100-30-20-1.25-1 kg ha⁻¹ N, P, S, Zn and B) (WRC 2013) was applied in the form of urea, triple super phosphate (TSP), muriate of potash (MP), gypsum and boric acid, respectively. The cow dung was applied at the beginning of land preparation @ 5000 kg ha⁻¹. After land preparation, full dose of P, S, Zn, B and two third of N were incorporated thoroughly into the soil as basal dose in the well watered plot. The remaining amount of N was applied after the first irrigation at crown root initiation stage (CRI) i.e. 18 days after seedlings emergence. In case of water deficit stressed plot full dose of N, P, S, Zn, B were incorporated thoroughly into the soil as a basal dose. K fertilizer was applied according to treatments. For 1% K

fertilizers foliar application 2.23% K₂SO₄ with 1% *Tween 20* was sprayed three times at 40, 55 and 80 DAS.

3.4.7 Sowing of seed

Seeds of two wheat genotypes (E 38 and BAW 1130) were sown on 23 November 2016 in rows of 20 cm apart, at the rate of 120 kg ha⁻¹. Slight irrigation was given for uniform germination after sowing. To achieve excellent germination and protecting against fungal attack during the seedling stage, seeds were pre-treated with a fungicide Provax-200 WP (containing Carboxin and Thiram) an effective fungicide for seeds.

3.4.8 Irrigation

Six plots (well watered) were irrigated three times (at 20, 56 and 85 DAS) but the remaining plots (water stressed) were not irrigated throughout the growing period to maintain water deficit stress condition and the crop was protected from rainfall by rainout shelter.

3.4.9 Intercultural operations

After sowing, care was taken against birds up to 15 days. Intercultural operations were done when required and depending on treatments. Weeding was done 4-5 days after top dressings of urea to break the soil crust, to keep the plots free from weeds which ensure sufficient nutrition for individual plant.

3.4.10 Data collection

3.4.10.1 Leaf area index, leaf dry weight and total dry weight

The plants were uprooted from an area of one meter square from each plot (5 lines and each line had 1 meter length) and separated into leaf, stem and root at 60 DAS for measuring leaf area index, leaf dry weight and total dry weight. Then leaf area was calculated with an Automatic Leaf Area Meter (Model AAM-9, Hayashi Denko Co. Ltd., Tokyo, Japan). After separating the different parts of the plants (leaf, stem and root) individual component were oven (Model- E28# 03-54639, Binder, Germany) dried at 70°C for at least 72 hours and

weight were recorded with an electrical balance (Model- AND EK- 300). For total dry weight sum of leaf, stem and root dry weight were taken and the LAI of wheat at 60 DAS was calculated by using the following equation as described by Radford (1967).

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

3.4.10.2 Relative leaf water content

Relative flag leaf water content was determined at 65 and 75 DAS. Five flag leaves for each treatment combination collecting from the field was sealed immediately in plastic bags and quickly transferred to the laboratory. Fresh weight was taken within 2 hours after excision. Turgid weight was obtained after soaking leaves in distilled water in test tubes for about 16 to 18 hours at room temperature. Dry weight was obtained after oven drying the leaf samples for 72 h at 70°C. Relative leaf water content was calculated using the following formula (Barrs and Weatherly 1962).

$$\text{RLWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.4.10.3 Water retention capacity

Water retention capacity was determined at 65 DAS. For this purpose, the leaves were collected in tightly fastened polythene bags. Five flag leaves from each plot was collected at 9:00 am and there fresh weight (FW) was taken immediately. Then the leaves were kept at room temperature in a plastic tray. Fresh weight of the leaves was taken at 2 hours interval for 4 times. Finally, leaves was dried in an oven at 70°C for 72 hours and their dry weight (DW) was taken with the help of an electrical balance. The water retention capacity of leaves was calculated using the following formula according to Sangakkara *et al.* (1996):

$$\text{Water retention capacity (\%)} = \frac{\text{FW} - \text{DW}}{\text{FW}} \times 100$$

Here, FW = Fresh weight of leaf, and DW = Dry weight of leaf

3.4.10.4 Chemical analysis of plant sample

Determination of leaf N, P and K content

Preparation of plant samples

The representative leaf samples from each plot were dried in an oven at 60°C for 48 hours. The leaves were ground separately by a grinding machine (Model No. 1029-B, Yoshida Seisakusho Co. Ltd., Japan) to pass through a 20 mesh sieve. The prepared samples were then put into the paper bags and kept into the desiccators till being used. The ground samples were weighed and used for digestion.

Nitrogen: Total nitrogen content was estimated by Micro Kjeldahl method (Black 1965) using Selenium powder, $\text{CuSO}_4 \cdot \text{H}_2\text{O}$ and K_2SO_4 mixture (1:10:1000) as catalyst, following Salicylic- H_2SO_4 digestion.

Leaf nitrogen content was determined in regional laboratory of Soil Resource Development Institute (SRDI), Noakhali, Bangladesh.

Determination of leaf N

Digestion: Plant sample of 0.1g was taken in a 100 ml Kjeldahl flask. 0.5g of catalyst (K_2SO_4 : $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$: Selenium powder = 10:1:0.1) and 4 ml of 3% salicylicsulfuric acid were added in it and the flask was swirled until the acid and catalyst were mixed with the sample. Then the flask was heated continuously on a burner stand inside the fume hood. When the colour of the mixture had turned green, the mixture was boiled further for 30 minutes. The digest was cooled and 40 ml of distilled water was added in it. Then the solution was transferred in to 100 ml volumetric flask. After cooling the solution was diluted up to 100 ml with distilled water.

Distillation: Ten ml of plant digest from stock solution and 5 ml of 40% NaOH solution were poured in to the distillation chamber through funnel and the funnel was washed with small amount of distilled water. 5 ml of 4% boric acid indicator solution was taken in a 100 ml

conical flask and was placed under the condenser of the distillation apparatus to collect the distillate. When the distillate reached to a volume of about 50 ml the distillation was stopped.

Titration: The distillate was titrated against 0.02N H₂SO₄ with the help of microburette. A blank titration was carried out following the same procedure of digestion and distillation.

%N was calculated by the following formula-

$$\%N = 14.007 \times N \text{ of H}_2\text{SO}_4 \times f \times (T - B) \times a/c \times p/w$$

Where,

14.007 for 1N H₂SO₄ (1ml) $\equiv$ 14.007 mg of NH₄-N

N of H₂SO₄ used in titration = 0.02

f = correction factor = 1.02

T = Amount of 0.02N of H₂SO₄ (ml) required for sample titration

B = Amount of 0.02N of H₂SO₄ (ml) required for blank titration

a = Volume of the digest in volumetric flask (ml) = 100

c = Volume of the digest taken for distillation (ml) = 10

p = Conversion factor for percentage = 100

w = Dry weight of the plant sample taken for digestion in mg = 100

Determination of phosphorus and potassium

Leaf Phosphorus and Potassium content was determined in regional laboratory of Soil Resource Development Institute (SRDI), Noakhali, Bangladesh.

Digestion of plant samples with Nitric-Perchloric acid

Plant sample were wet-digested with nitric-perchloric acid for the determination of phosphorus and potassium. 0.5 g oven dried ground samples were taken in a digestion flask. 10 ml di-acid mixture (HNO₃:HClO₄ in the ratio 2:1) was added into the flask and the flask was allowed to stand for about sometimes and followed by heating. Heating was continued until the digest was clear and colorless. After cooling the content was transferred to a 100 ml volumetric flask and the volume was made up to the mark with distilled water and filtrate

them. A reagent blank was prepared in the similar manner. 20 ml of filtrate was transferred to a 100 ml volumetric flask using a pipette and volume with distilled water and mixed for determination of P and K.

Phosphorus: 5 ml of diluted filtrate, 30 ml of water, 10 ml of ammonium molybdate-ascorbic acid were taken into 50 ml volumetric flask and the volume was made up to mark and then phosphorus was estimated by spectrophotometer after 15 minutes and calculated using a standard curve (Petersen 2010).

Potassium: 10 ml of filtrate was transferred into 50 ml volumetric flask and the volume was made up to the mark with distilled water and then potassium was determined with flame photometer and calibrated using standard curve (Petersen 2010).

3.4.10.5 Plant height

Plant height was measured from the base of the plant to the tip of the spike excluding the awn at maturity. Ten plants sample from each treatment were taken (excluding the line from where grain yield was taken) and means were calculated.

3.4.10.6 Spike character

Ten spikes from the main shoot were collected randomly per plot (excluding the line from where grain yield was taken) to collect data on spike characters, number of spikelets per spike and number of grains spike⁻¹.

Spike length: Spike length (excluding awn) was measured manually using scale per plot and were recorded in cm and averaged.

Spikelets spike⁻¹: From that 10 spikes number of spikelets was counted and averaged.

Grains per spike: From that ten spikes number of filled and unfilled grains was counted and averaged.

3.4.10.7 Number of spikes m⁻²

The numbers of developed and underdeveloped spikes from 1m long five lines were counted from each plot (No. of spikes x 5 = spikes m⁻²). Counting should be done diagonally at physiological maturity to avoid damage of plants due to walking inside plot.

3.4.10.8 Thousand grain weight

From each plot thousand grains were taken randomly from (excluding the area from where grain yield was taken) dried sample and weighed by electrical balance in g on 12% moisture basis.

3.4.10.9 Grain and above ground biological yields

Yield sample was taken from a 2.5 × 1.2 m area (i.e., 6 middle rows) when 80% of the seeds became physiologically mature. The plants from six lines of 2.5 m length comprising 3.0 m² from each plot were harvested randomly through the soil surface for computation of grain yield and above ground biological yields. After harvesting the sample were sun dried and then weighed for biological yield. After threshing, cleaning and drying, the grain yields were recorded plot-wise and at the same time moisture percent also recorded by a moisture meter. Finally the grain and biological yields were converted into tons hectare⁻¹.

Data on grain yield (GY) was determined and adjusted to 12% moisture level by the following equation (Hellevang 1995).

$$Y (M_2) = \frac{(100-M_1)}{(100-M_2)} \times Y (M_1)$$

Where, Y (M₂) =Weight of grain at expected moisture percentage (generally 12% for wheat),

Y (M₁) = Weight of grain at actual moisture percentage,

M₁= Actual moisture percentage,

M₂= Expected moisture percentage.

3.4.10. 10 Soil moisture content

The soil samples were collected from desired depth from several places, in air tight containers. The samples were weighed and then they were dried in an oven at 105°C for about 24 hours or till constant weight. The samples were then taken out and weighed again and the loss in weight was the amount of water soil.

$$\text{Soil moisture content (\%)} = \frac{\text{Weight of moist sample} - \text{Weight of oven dry sample}}{\text{Weight of oven dry sample}} \times 100$$

3.4.11 Statistical analysis

The data were analyzed by partitioning the total variance with the help of computer by using MSTAT-C program. The treatment means were compared using Duncan's Multiple Range Test (DMRT) at $P \leq 5\%$ level.

RESULTS AND DISCUSSION

3.4.12 Soil moisture content

Moisture content of the soil at 0-15 cm depth of well watered and water stressed plots at different days after sowing is presented in Figure 3.4.1. Irrigation was applied at 18, 56 and 85 DAS in well watered plot. The moisture contents were recorded at 45, 60, 75, 90 and 105 DAS. In well watered plots after 45 DAS moisture per cent was increased sharply and it was the highest at 60 DAS then also declined sharply at 75 DAS. After 75 DAS, it was increase up to 90 DAS and then again decreased sharply up to 105 DAS. In water stressed plots moisture per cent was the highest at 45 DAS and after that it was decreased gradually with the progress of time and the lowest at 105 DAS. This figure revealed that well watered plots maintained higher soil moisture through out the study period than water stressed plot. This figure also showed the moisture content in the well watered plots increased with every stage of irrigation.

3.4.13 Leaf area index

Leaf area index (LAI), measured at 60 DAS, significantly reduced under water deficit condition, and the highest LAI was recorded under well watered conditions (Table 3.4.1). This reduction in leaf area induced by the drought stress can lead to reduce photosynthesis and thereby reduced the crops yield (Kramer 1983). Application of additional potassium remarkably increased the LAI of wheat genotypes. Under water deficit stress conditions, the highest LAI (4.29) was obtained from the application of additional 25 kg K ha⁻¹ with the recommended doses of fertilizers (RDF) (T₃) followed by application of additional 50 kg K ha⁻¹ with the RDF (T₄). Foliar application of K₂SO₄ with RDF produced the lowest LAI (3.72) under water stress condition (T₅). The results also showed that wheat genotype E-38 (V₁) produced higher LAI (4.38) than the genotype BAW-1130 (V₂). Imanparast *et al.* (2013) opined that leaf width, leaf area index of three wheat varieties (Azar2, Gascogen, and Sardari) significantly reduced under water stress condition but the application of potassium

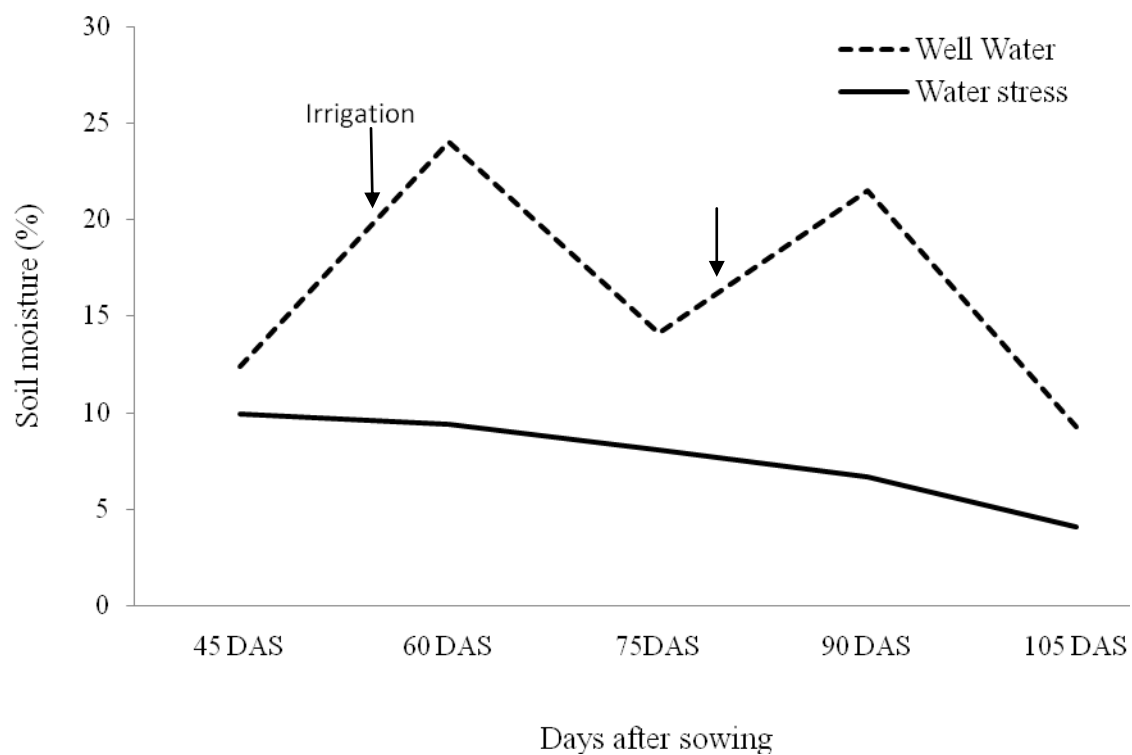


Fig. 3.4.1. Soil moisture content (0-15 cm depth) at different days after sowing as influenced by water regimes

Table 3.4.1 Effect of increasing level of potassium on the leaf area index, leaf dry weight and total dry weight of wheat under water deficit stress condition at 60 DAS

Treatments	Leaf area index	Leaf dry wt. (g)	Total dry wt. (g) at
Potassium fertilization treatment along with water regimes			
T ₁	4.90 a	8.84 a	27.60 a
T ₂	3.27 d	6.86 c	22.85 c
T ₃	4.29 b	8.21b	26.56 ab
T ₄	4.28 b	7.74 b	25.35 abc
T ₅	3.72 c	6.93 c	23.80 bc
CV (%)	5.37	4.14	6.42
Level of significance	**	**	*
Wheat genotypes			
E-38 (V ₁)	4.38 a	7.97 a	23.54 b
BAW-1130 (V ₂)	3.81 b	7.46 b	26.93 a
CV (%)	8.51	3.10	9.35
Level of significance	**	**	**
Wheat genotypes × Potassium fertilization treatment along with water regimes			
T ₁ × V ₁	5.25	8.65 ab	25.88
T ₁ × V ₂	4.56	9.02 a	29.33
T ₂ × V ₁	3.26	7.00 cd	20.46
T ₂ × V ₂	3.29	6.72 d	25.24
T ₃ × V ₁	4.52	9.02 a	25.52
T ₃ × V ₂	4.04	7.39 cd	27.18
T ₄ × V ₁	4.54	8.05 b	22.88
T ₄ × V ₂	4.02	7.43 c	28.25
T ₅ × V ₁	4.32	7.11 cd	22.96
T ₅ × V ₂	3.13	6.74 d	24.64
CV (%)	8.51	3.10	9.35
Level of significance	NS	**	NS

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$ within main and interaction effect

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

NS indicates insignificant

DAS indicates days after sowing

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

remarkably increased the values of those mentioned traits. Khan *et al.* (2001) also concluded that leaf numbers, rate of expansion, final leaf size and leaf area of maize variety decreased noticeably with increasing water stress. Yadav *et al.* (2005) reported that drought stress reduced the total leaf area of sorghum.

3.4.14 Leaf dry weight

The leaf dry weight (LDW) at 60 DAS was influenced extensively by potassium fertilization treatments along with water regimes and wheat genotypes as well as by their interaction effect (Table 3.4.1). The highest leaf dry weight (8.84 g) was obtained with the RDF under well water condition (T_1), and the lowest with the RDF under water stress condition (T_2). Potassium fertilization treatments noticeable increased the LDW (12.83 to 20%) under water deficit condition, and the highest LDW (8.21g) was obtained at 25 kg ha⁻¹ additional K with RDF (T_3) which was statistically identical with additional 50 kg K ha⁻¹ along with RDF (T_4). The improvement of LDW from foliar application of K₂SO₄ with RDF under water stress condition (T_5) was not remarkable. In case of the genotypical achievement due to the accomplishment of additional K under water stress, the wheat genotype E-38 (V_1) generated higher LDW (7.88) than the genotype BAW 1130 (V_2). Significant variations among the interaction effects of potassium fertilization and wheat genotypes under water stress were observed in this study, and the combined effect of $T_3 \times V_1$ produced the highest LDW (9.023 g) followed by the combination effect of $T_1 \times V_2$ and $T_1 \times V_1$, and the lowest LDW (6.17 g) obtained with the combination of $T_5 \times V_2$, which was statistically similar with the $T_5 \times V_1$, $T_2 \times V_2$ and then $T_2 \times V_1$. These results are in corroborated with findings of Baque *et al.* (2006) who found that water stress severely affected dry matter production in leaf, stem, spike and root, while high level of K improved the dry matter production in different plant parts. Imanparast *et al.* (2013) showed that growth traits like seedling and root dry weight significantly reduced under water stress condition, and application of potassium remarkably increased the values of those mentioned traits.

3.4.15 Total dry weight

Total dry weight (TDW) at 60 DAS was inclined considerably due to the effect of water deficit condition (T_2) comparing with well water condition (T_1), and the TDW deprived from 27.60 g to 22.85 g tabulated as 17.21% attributable to water deficit condition. Additional potassium fertilization from 25 to 50 kg ha⁻¹, and foliar feeding of K along with RDF progressively increased the TDW (4.16 to 11.86%) of water stressed wheat genotypes (Table 3.4.1). Among the potassium fertilization treatments, the highest TDW was recorded at the T_3 treatment, followed by the T_4 treatment under water deficit condition. Foliar application of K_2SO_4 under water stress condition (T_5) increased TDW of wheat plants but the increment was not remarkable judge against without additional K fertilization at the same condition (T_2). Concerning the performance of the genotypes, the higher TDW (26.93 g) was obtained from the genotype BAW 1130 (V_2) as compared to E-38 genotype. Similar results were also reported by Wei *et al.* (2013) who noticed that shoot and root biomass of wheat decreased due to drought stress while the exogenous application of K as K_2CO_3 increased the total biomass production on that condition. The total dry weight of wheat decreased with the increasing levels of water stress but total dry weight increased with the increasing levels of potassium (Baque *et al.* 2006). The role of potassium (K) in mitigating the adverse effects of drought stress on maize cultivars was assessed by Zhang *et al.* (2014) and reported that application of K increased dry matter across all growth stages and grain yield.

3.4.16 Relative water content

Relative water content (RWC) of flag leaf, measured at 60 and 75 DAS was significantly influenced by potassium fertilization treatments along with water regimes and wheat genotypes as well as by their interaction effects (Fig. 3.4.2). The results also showed that the RWC was reduced significantly due to water stress compared to well water condition, and additional soil or foliar application of K improved the RWC at the two measured growth stages although plants maintained higher RWC at early stages (65 DAS) than that of 10 days

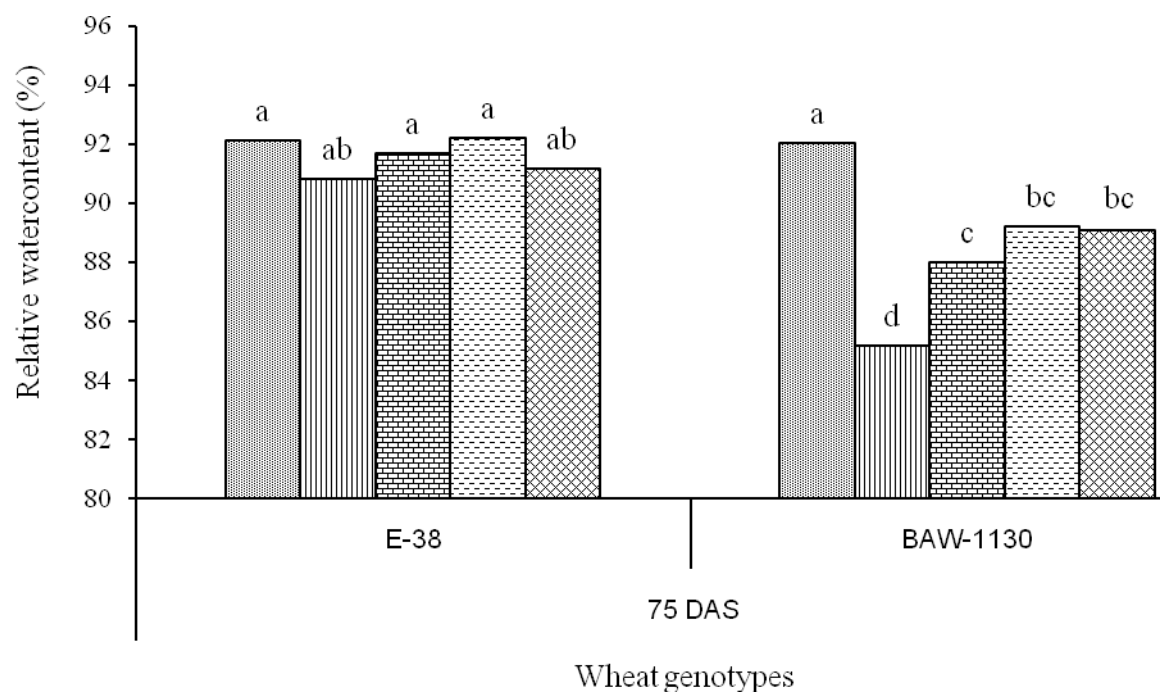
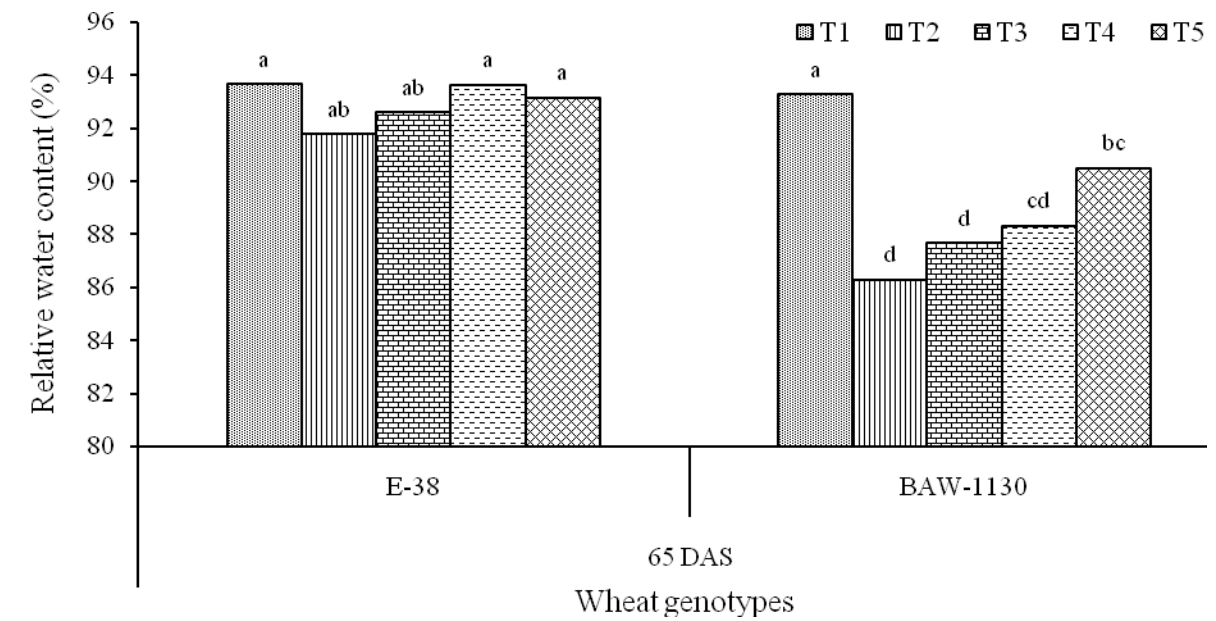


Fig. 3.4.2. Effect of increasing level of potassium content on relative leaf water content of wheat under water deficit stress condition at 65 and 75 DAS

DAS indicates days after sowing

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

later (75 DAS) in all the studied treatments. The wheat genotype E 38 (V_1) maintained superior RWC to the genotype BAW-1130 (V_2) and it did not show statistical difference as comparing to stress, non-stress and excess K fertilization treatments at 65 and 75 DAS indicating tolerant of E 38 genotype under water deficit condition. On the other hand, BAW 1130 genotype showed statistical differences under stress and excess K fertilization treatments at the two observation periods which designating it's exceedingly responsiveness to stress. Considering the combination effect, the highest RWC (93.67%) was obtained from the genotype E 38 (V_1) under well water condition of $T_1 \times V_1$, followed by the treatment combination of $T_4 \times V_1$ and $T_5 \times V_1$ and the lowest one (91.76%) was obtained from the treatment combination of $T_2 \times V_1$. Moreover, the wheat genotype BAW 1130 (V_2) showed the maximum RWC (93.27%) with the treatment combination of $T_1 \times V_2$, followed by $T_5 \times V_2$, $T_4 \times V_2$ and $T_3 \times V_2$, while the lowest one was (86.30%) obtained from the treatment combination of $T_2 \times V_2$.

The spraying potassium (as potassium iodide) in wheat enhances relative water content especially under moisture stress condition as reported by Lindhaur (1989) is supported this study. Application of potassium improves RWC of plants under normal as well as water stress conditions and the maintenance of plant water economy by K application in terms of a high RWC level under water stress condition could be ascribed to the supposed role of K in stomatal resistance, water use efficiency and lowered transpiration rate (Umar and Moinuddin 2002). Zhang *et al.* (2014) reported that K application increased relative water content, over and above nitrate reductase activity, and concentrations of potassium ion, free proline, soluble protein, and endogenous glycine betaine of potato. Umar (2006) showed that RWC was significantly lower in water-stressed plants than in plants grown under normal conditions, and application of K improved the RWC in crops with the maximum effect figuring at K_{120} in mustard and sorghum, and at K_{75} in groundnut. This is indicative of a positive role of potassium in hydration and organization of cell protoplasm, and thereby, in

maintenance of turgor and growth of the plant in water stress condition (Sinclair and Ludlow 1989, Khanna-Chopra *et al.* 1994). The RWC in leaf and leaf water potential of wheat reduced due to drought stress, which had significant effect on photosynthesis (Siddique *et al.* 2000). Erickson *et al.* (1991) reported that the RWC of peanut was reduced significantly by creating water stress, and more reduced RWC were recorded when crop faced deficit water at flower initiation stage. Water deficit lowered the leaf turgor, thus causing reduction in leaf expansion rate. This led to the reduced assimilatory surface of the crop which ultimately adversely affected yield and yield contributing factors. According to the earlier studies the adverse effect of drought stress on plant could be ameliorated by conserving water by increase in root penetration, partial closing of stomata, and reduction in transpiration (Alfredo and Setter 2000, Hoad *et al.* 2001). Besides, it has been found that accumulation of K can maintain the internal water balance, osmotic adjustment, turgor pressure and physiological processes (i.e. photosynthesis and stomatal opening) of plants which are subjected to water deficit (Serraj and Sinclair 2002). Shabbir *et al.* (2015) concluded that foliar K spraying improved physiological processes and nutrients uptake in wheat under water deficit conditions by maintaining better water relations, in wheat genotypes. K is an essential element in maintenance of osmotic potential and had a positive impact on stomata closure and water uptake which increases tolerance of plants to water stress (Epstein 1972, Cakmak 2005, De La Guardia and Benlloch 1980). Thalooth *et al.* (1990) reported that K application could improve the water content in the broad bean leaves and the plant showed more tolerance to drought stress.

3.4.17 Water retention capacity

The water retention capacity (WRC) of flag leaf at 65 DAS was appreciably influenced by potassium fertilization treatment along with water regimes. The highest WRC were found in the morning and it was reduced gradually with the advancement of time in both wheat genotypes (Fig. 3.4.3.). Both wheat genotypes (E 38 and BAW 1130) maintained higher

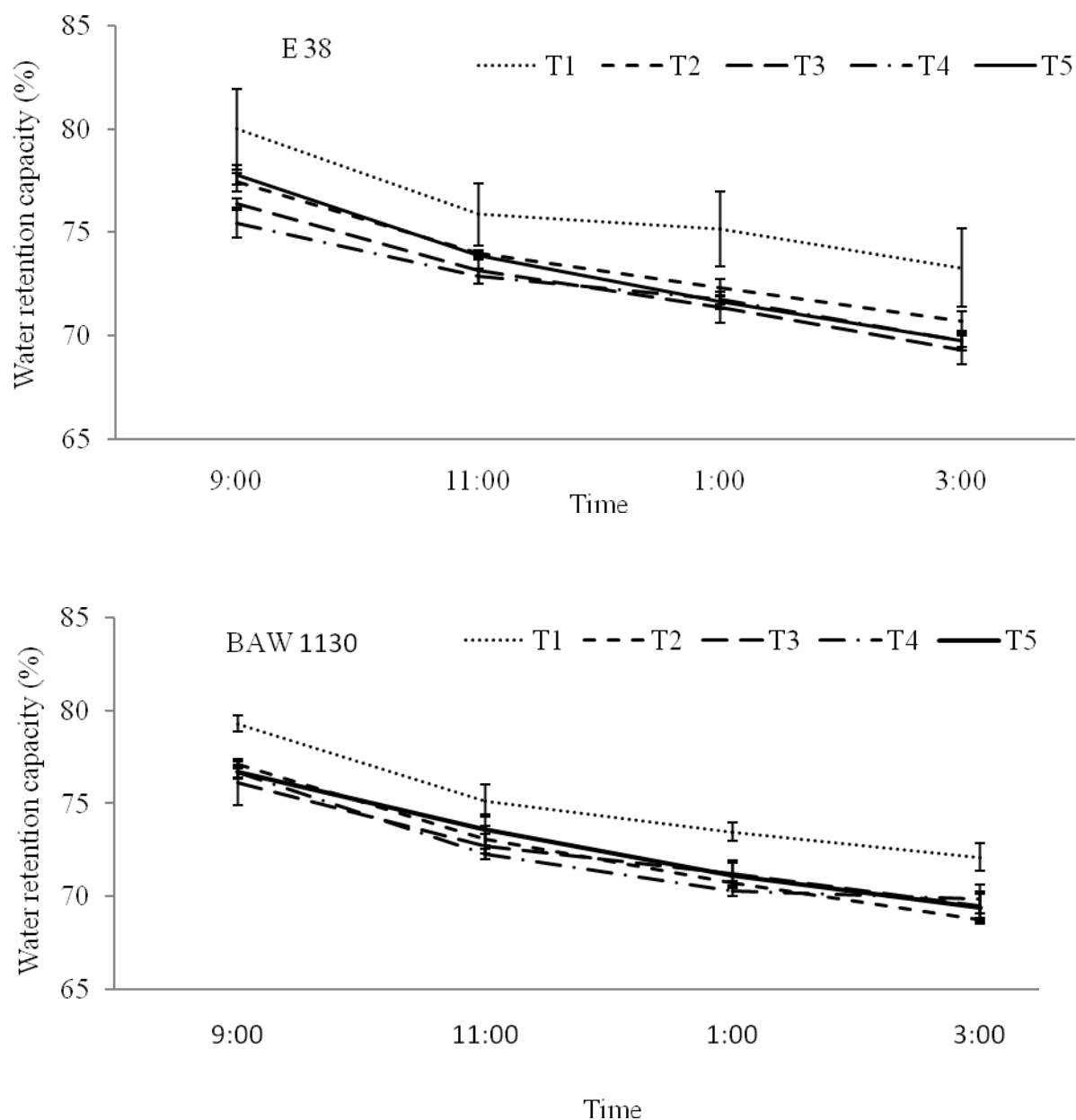


Fig.3.4.3. Effect of increasing level of potassium content on water retention capacity (%) (mean±SE) of wheat (E 38 and BAW 1130) under water deficit stress condition

DAS indicates days after sowing

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃=Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄=Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅=Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

capacity under well water condition compared to water stress condition but additional soil or foliar application of K (T_3 , T_4 and T_5) could improve the water retention capacity in the flag leaf under water stress condition. A higher WRC in plant leaves with increasing level of K application under water stress indicates the plant would absorb a greater amount of water to reach turgid weight (Sangakkara *et al.* 1996). Premachandra *et al.* (1993) noticed that application of potassium fertilizer under water stress condition reduced the leaf water potential, osmotic potential and increased osmotic adjustment of maize cultivars. This was mainly due to net increase in intercellular solutes as a result of high potassium fertilization.

3.4.18 N content in flag leaf

The N content in flag leaf was not influenced significantly at 65 DAS and at harvest by different Potassium fertilization treatment along with water regimes (Table 3.4.2). But the wheat genotype E 38(V_1) retained significantly higher amount of N in the flag leaf (2.05 and 2.164%) than BAW 1130 (V_2) at 65 DAS and at harvest, respectively. The results for interaction also revealed that the genotype E 38 with sufficient and insufficient water ($T_1 \times V_1$, and $T_2 \times V_1$) performed better for attaining N content than the genotype BAW 1130 at the same conditions ($T_1 \times V_2$, and $T_2 \times V_2$) on 65 and harvesting stage. On the contrary, the genotype BAW 1130 achieved higher amount of N with addition of K containing fertilizer under insufficient water condition ($T_3 \times V_2$, $T_5 \times V_2$) than the genotype E 38 (Table 3.4.2) with the same conditions ($T_3 \times V_1$, $T_5 \times V_1$) and same observation periods except in $T_4 \times V_2$ which achieved lower amount of N. These results do not support those of Patel and Singh (1998) and Baque *et al.* (2006) in wheat, Baruah *et al.* (1998) in rice who reported that water stress reduced the N uptake in plants. Elevated application of K under drought stress increased the uptake of N in wheat leaves (Baque *et al.* 2006). Samar Raza (2013) depicted that exogenous spray of K on plants under drought at grain filling stage increased the uptake of N by 10% and reduced the uptake of Na by 23%.

Table 3.4.2 Effect of increasing levels of potassium on leaf nitrogen content of wheat under water deficit stress condition

Treatments	Leaf nitrogen content (%)	
	At 65 DAS	At harvest
Potassium fertilization treatment along with water regimes		
T ₁	1.90	2.16
T ₂	2.29	2.54
T ₃	1.96	1.67
T ₄	1.79	2.36
T ₅	1.99	1.75
CV (%)	3.85	7.46
Level of significance	NS	NS
Wheat genotypes		
E38 (V ₁)	2.05 a	2.16 a
BAW1130 (V ₂)	1.92 b	2.03 b
CV (%)	4.62	5.82
Level of significance	**	**
Wheat genotypes × Potassium fertilization treatment along with water regimes		
T ₁ × V ₁	2.19	2.64
T ₁ × V ₂	1.60	1.68
T ₂ × V ₁	2.69	2.28
T ₂ × V ₂	1.90	2.81
T ₃ × V ₁	1.73	1.59
T ₃ × V ₂	2.19	1.76
T ₄ × V ₁	1.68	2.92
T ₄ × V ₂	1.90	1.81
T ₅ × V ₁	1.96	1.40
T ₅ × V ₂	2.01	2.10
CV (%)	4.62	5.82
Level of significance	NS	NS

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$ within main and interaction effect

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

^{NS} indicates insignificant

DAS indicates days after sowing

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

3.4.19 P content in flag leaf

The P content in the flag leaf at 65 DAS and at harvest was appreciably influenced by potassium fertilization along with water regimes and wheat genotypes as well as by their interaction effects (Table 3.4.3). Water stress significantly reduced the flag leaf P content from 305.5 and 262.1 g Kg⁻¹ to 238.8 and 197.2 g Kg⁻¹ at 65 DAS and at harvesting stage, respectively. Nonetheless, extra addition of K with RDF considerably increased the P content in the flag leaf under drought stress, and the values of P content were recorded utmost with the addition of extra 50 kg Kha⁻¹ (T₄) followed by the T₃ treatment at both growth stages. Between the two wheat genotypes, the P contents in the flag leaf (289.6 and 250.5 g Kg⁻¹) were higher than that of the genotype E 38(V₁) (265.5 and 182.6 g Kg⁻¹) at 65 and harvesting stages, respectively. Wheat genotype E 38 (V₁) combined with 50 kg additional K fertilizer (T₄) i.e. T₄ × V₁ significantly increased P content in leaf (303.3 and 258.2 g kg⁻¹) under drought stress which was statistically identical with the combined effect of T₃ × V₁ both at 65 and harvesting stages, respectively. Remarkably the least P content was observed in the genotype of BAW 1130 under stress condition (T₂ × V₂) at both the observation periods (Table 3.4.3).

However, the present study showed that drought stress reduced the uptake of P but the elevated K in soil and foliar increases the uptake of P in plants which is supported the findings of Barua *et al.* (1998) who concluded that water stress significantly reduced P contents in rice genotypes. Jin *et al.* (2006) found that drought stress decreased plant growth and yield, total P uptake and P translocation to seeds, but K fertilization mitigated the negative effects of drought stress on plant growth in two soybean cultivars. Faye *et al.* (2006) found that water stress affected the leaf water potential in two pearl millet cultivars, but K supply was able to improve the drought response of the more sensitive cultivar. High level of K improves the dry matter production in different plant parts and uptake of N, P and K is also enhanced with the increasing level of K under water stress conditions (Baque *et al.* 2006).

Table 3.4.3 Effect of increasing level of potassium on leaf phosphorus content of wheat under water deficit stress condition

Treatments	Leaf phosphorus content (g Kg ⁻¹)	
	At 65 DAS	At harvest
Potassium fertilization treatment along with water regimes		
T ₁	305.5 a	238.9 a
T ₂	262.1 c	197.2 d
T ₃	273.8 bc	217.9 bc
T ₄	278.2 b	225.5 ab
T ₅	268.2 bc	203.1 cd
CV (%)	2.51	3.92
Level of significance	**	**
Wheat genotypes		
E38 (V ₁)	289.6 a	250.5 a
BAW1130 (V ₂)	265.5 b	182.6 b
CV (%)	3.38	4.07
Level of significance	**	**
Wheat genotypes × Potassium fertilization treatment along with water regimes		
T ₁ × V ₁	310.6 a	262.7 a
T ₁ × V ₂	300.4 abc	215.1 c
T ₂ × V ₁	276.6 cde	236.8 b
T ₂ × V ₂	247.6 f	157.6 f
T ₃ × V ₁	284.6 bcd	257.9 a
T ₃ × V ₂	263.0 def	177.9 de
T ₄ × V ₁	303.3 ab	258.2 a
T ₄ × V ₂	253.2 ef	192.8 d
T ₅ × V ₁	272.9 def	236.7 b
T ₅ × V ₂	263.5 def	169.5 ef
CV (%)	3.38	4.07
Level of significance	*	*

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$ within main and interaction effect

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

^{NS} indicates insignificant

DAS indicates days after sowing

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

Water deficit has strong damaging effect on the plants and it reduced the uptake of P (Khondakar *et al.* 1983, Turner 1985, Kidambi *et al.* 1990, Alam 1994, Ashraf *et al.* 1998, Samar Raza, 2013). Foliar application of K ameliorated the adverse effect of drought in plants and improved the uptake of P by 36% and Ca by 18% under water deficit at grain filling stage as reported by Khondakar *et al.* (1983).

3.4.20. K content in flag leaf

The K content in the flag leaf measured at 65 DAS and harvesting stage was influenced significantly by potassium fertilization treatments along with water regimes and the interaction effect of potassium fertilization and wheat genotypes (Table 3.4.4). The K content in the flag leaf reduced significantly (2.04 and 1.91 g Kg⁻¹) due to lack of sufficient moisture at 65 DAS and harvesting stages. Nevertheless, the K content progressively increased with the additional K fertilizers and 50 kg additional K along with RDF performed superior results to other K fertilization treatments under stress condition at both the observation periods. Foliar fertilization of K₂SO₄ also enhanced K uptake in plants. No genotypical difference regarding K content was observed between the two studied genotypes at 65 DAS but major difference was recorded at the later stage of plant growth, and the genotype E 38 taken in higher K in plants. The interaction effect of potassium fertilization along with water regimes and wheat genotypes showed a remarkable performance concerning K uptake and the combined effect of T₄ × V₂ noticeable increased of K content followed by the treatment combination of T₃ × V₁ at 65 DAS under stress condition. On the other hand, plants uptake the highest amount of K with the treatment combination of T₄ × V₁, which was statistically similar to the treatment combinations of T₅ × V₁, and T₃ × V₁ under stress condition at the later stage of plant. Additional K under water deficit behaved almost the similar as regards to control condition (well water).

Table 3.4.4 Effect of increasing level of potassium (K) on leaf potassium content of wheat under water deficit stress condition

Treatments	Leaf potassium content (g Kg ⁻¹)	
	At 65 DAS	At harvest
Potassium fertilization treatment along with water regimes		
T ₁	2.34 a	2.16 a
T ₂	2.04 c	1.91 c
T ₃	2.16 b	2.00 b
T ₄	2.24 ab	2.08 ab
T ₅	2.16 b	2.09 a
CV (%)	2.42	2.21
Level of significance	**	**
Wheat genotypes		
E38 (V ₁)	2.20	2.10 a
BAW1130 (V ₂)	2.18	1.99 b
CV (%)	2.18	1.67
Level of significance	NS	**
Wheat genotypes × Potassium fertilization treatment along with water regimes		
T ₁ × V ₁	2.41 a	2.16 a
T ₁ × V ₂	2.27 b	2.17 a
T ₂ × V ₁	2.00 e	2.00 c
T ₂ × V ₂	2.08 d	1.82 e
T ₃ × V ₁	2.18 bc	2.10 ab
T ₃ × V ₂	2.13 cd	1.90 d
T ₄ × V ₁	2.21 bc	2.13 ab
T ₄ × V ₂	2.27 b	2.02 c
T ₅ × V ₁	2.17 c	2.12 ab
T ₅ × V ₂	2.15 cd	2.07 bc
CV (%)	2.18	1.67
Level of significance	*	**

DAS indicates days after sowing

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

reported in the previous studies that the uptake of N, P and K augmented with the increasing level of K under water stress conditions in wheat (Baque *et al.* 2006). The K⁺ contents in flag leaves increased in response additional K under drought stress in wheat at the different stages of crop growth as mentioned by Majid *et al.* (2007). When compared to control, water stress reduced K concentration in all wheat varieties but the tolerant ones were affected less (Yasin *et al.* 1993). Leaf K content decreased significantly on imposing water stress in the crops and addition of 120 kg Kha⁻¹ increased leaf K content of 51, 43.3 and 33.3% over control in mustard, sorghum and groundnut, respectively (Umar 2006). Cakmak (2005) has reported several examples emphasizing the role of potassium in alleviating the adverse effects of drought on crop production.

Exogenous application of K maintained the turgor pressure and internal water balance of the leaves, and thereby, reduced the adverse effect of drought by reducing the excessive uptake of Na by the plant under drought and spraying of K on plants under drought at grain filling stage was most effective which reduced the uptake of Na by 23% and increased the uptake of K by 24% (Samar Raza 2013). The opposite result from this study was reported by Khondakar *et al.* (1983) who found that wheat plants uptake higher K at tillering stage under water stress condition.

3.4.21 Plant height

Water deficit stress significantly reduced the plant height (7.49%) of wheat genotypes as compared to well water condition (Table 3.4.5). Application of additional K with RDF gradually increased the plant height under water stress condition but the increment was statistically ignorable. However, under water stress condition, the highest plant height (101.49 cm) was observed with 50 kg ha⁻¹ additional K fertilization (T₃), followed by the treatment of T₄ (100.37 cm), and T₅ (99.65 cm). These results are in agreement with Jamal *et al.* (1996), Siddique *et al.* (1999), and Khan *et al.* (2001) who found that plant height of

Table 3.4.5 Effect of increasing level of potassium on plant height and spike length of wheat under water deficit stress condition

Treatments	Plant height (cm)	Spike length (cm)
Potassium fertilization treatment along with water regimes		
T ₁	107.42 a	9.73 a
T ₂	99.37 b	8.24 c
T ₃	100.37 b	9.05 ab
T ₄	101.49 b	9.04 ab
T ₅	99.65 b	8.78 bc
CV (%)	3.01	4.11
Level of significance	**	**
Wheat genotypes		
E38 (V ₁)	107.06 a	8.12 b
BAW1130 (V ₂)	96.21 b	9.83 a
CV (%)	3.2	4.44
Level of significance	**	**
Wheat genotypes × Potassium fertilization treatment along with water regimes		
T ₁ × V ₁	112.07	8.76
T ₁ × V ₂	102.76	10.69
T ₂ × V ₁	104.73	7.46
T ₂ × V ₂	94.00	9.02
T ₃ × V ₁	107.96	8.17
T ₃ × V ₂	94.77	9.93
T ₄ × V ₁	105.69	8.14
T ₄ × V ₂	95.04	10.01
T ₅ × V ₁	104.83	8.07
T ₅ × V ₂	94.46	9.49
CV (%)	3.2	4.44
Level of significance	NS	NS

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$ within main and interaction effect

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

^{NS} indicates insignificant

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

wheat was reduced under moisture deficit condition. It might be due to dehydration of protoplasm, decrease in relative turgidity associated with turgor loss and decreased cell expansion and cell division (Hussain *et al.* 2008). Zhao *et al.* (2006) reported that drought stress reduced plant height due to hormonal imbalance (cytokinin, abscisic acid) which affected growth due to changes in cell wall extensibility. Usherwood (1985) reported that external application of K increased plant height under water stress condition by maintaining stomatal movement, net photosynthesis and the efficiency of CO₂ assimilation. Plant height of maize increased with the application of K as compared to control (Cheema *et al.* 1999). Aown *et al.* (2012) showed that the plant height of wheat adversely affected under water limited environment, and foliar application of K at the three critical growth stages improved the plant height, growth and drought tolerance of plants. EL-Abady *et al.* (2009) also found that the reduction of yield and growth i.e. plant height due to water stress during grain filling might have been due to the inhibition in photosynthesis efficiency under insufficient water conditions (Siddique *et al.* 1999). Similar results have been reported by Gupta *et al.* (2001) and hypothesized plant height in wheat increased with the application of increasing level of K. The wheat genotype E 38 (V₁) produced the taller plant (107.06 cm) than the plant height (96.21 cm) of the genotype BAW 1130 (V₂) with K fertilization treatments under water stress, and the earlier genotype increased 11.28% plant height than later one. There was no significant effect on the plant height among the interaction of the treatments. However, the highest plant height (107.96 cm) was with T₃ × V₁ followed by T₄ × V₁, and T₅ × V₁ under water stress, and the V₁ always produced maximum plant height with additional K fertilizer under water stress condition.

3.4.22 Spike length

The spike length at harvest was influenced notably by potassium fertilization treatment along with water regimes and wheat genotypes but their interaction effects on the spike length were insignificant (Table 3.4.5.). The highest spike length (9.73 cm) was obtained under well

watered condition (T_1) and the lowest under water stress condition (T_2). However, additional K fertilization increased spike length remarkably over without additional K under water stress, and in this condition, the highest spike length was observed with 25 kg additional K fertilization (T_3) followed by the treatment of T_4 (50 kg K ha⁻¹) and T_5 (foliar spraying of K₂SO₄).

These results are in agreement with the findings of EL-Abady *et al.* (2009) who reported that intensive water stress during grain filling reduced growth and provided the lowest values of spike length, but the spraying of wheat plants with 3.0% K₂O produced the highest values of growth and spike length followed by 1.5% K₂O spraying. These results are also in line with those stated by Abou El-Defan *et al.* (1999) and El-Sabbagh *et al.* (2002). Aown *et al.* (2012) showed that the spike length was adversely affected under water limited environment, and foliar application of K increased the spike length of wheat at all three critical growth stages which possibly improved the drought tolerance of plants. Contrasting the wheat genotypes, the genotype BAW 1130 (V_2) produced longer spike length (9.83 cm) than the spike length (8.12 cm) of the E 38 genotype (V_1), and the genotype BAW 1130 increased 21.06% spike length. The interaction effects among the treatments were insignificant. However, the highest spike length (10.01 cm) was recorded in the treatment combination of $T_4 \times V_2$ followed by $T_3 \times V_2$ (9.93 cm) under water deficit condition. Interestingly the genotype BAW 1130 (V_2) performed better regarding spike length than the genotype E 38 (V_1) in all treatment combinations under stress and non-stress conditions (Table 3.4.5).

3.4.23 Number of spikes m⁻²

The number of spikes m⁻² was significantly persuaded by potassium fertilization treatment along with water regimes and wheat genotypes, in addition to their effects of interaction (Table 3.4.6). The highest number of spikes m⁻² (274) was obtained at well water condition (T_1) and the lowest number of spikes m⁻² (254) was found from without addition of extra K with RDF under water stress condition (T_2). Furthermore, addition of K containing fertilizers

Table 3.4.6 Effect of increasing level of potassium on the spikes m^{-2} , spikelets spike^{-1} , grains spike^{-1} and 1000-grain weight (g) of wheat under water deficit stress condition

Treatment	Spikes m^{-2}	Spikelets spike^{-1}	Grains spike^{-1}	1000-grain weight (g)
Potassium fertilization treatment along with water regimes				
T ₁	274 a	17.5 a	39.8 a	41.87
T ₂	254 c	15.9 b	34.8 b	41.21
T ₃	271 ab	16.5 b	37.0 ab	42.36
T ₄	267 abc	16.4 b	36.4 b	42.11
T ₅	260 bc	16.1 b	35.8 b	40.86
CV (%)	3.42	2.57	6.1	2.24
Level of significance	*	**	*	NS
Wheat genotypes				
E-38 (V ₁)	297 a	16.7	41.9 a	33.41 b
BAW-1130 (V ₂)	233 b	16.3	31.6 b	49.95 a
CV (%)	3.61	4.28	5.59	2.26
Level of significance	**	NS	**	**
Wheat genotypes × Potassium fertilization treatment along with water regimes				
T ₁ × V ₁	305	17.5	45.5	33.52
T ₁ × V ₂	243	17.5	34.1	50.22
T ₂ × V ₁	286	15.7	39.7	32.76
T ₂ × V ₂	222	16.1	29.9	49.66
T ₃ × V ₁	304	16.8	41.7	33.59
T ₃ × V ₂	238	16.2	32.2	51.13
T ₄ × V ₁	299	17.0	41.2	34.43
T ₄ × V ₂	233	15.8	31.6	49.79
T ₅ × V ₁	290	16.4	41.2	32.76
T ₅ × V ₂	228	15.8	30.3	48.95
CV (%)	3.61	4.28	5.59	2.26
Level of significance	NS	NS	NS	NS

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$ within main and interaction effect

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

^{NS} indicates insignificant

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition

as soil and foliar significantly increased the number of spikes m^{-2} , and 25 kg additional K with RDF (T_3) produced the highest number of spikes m^{-2} under water stress condition followed by the application of 50 kg K ha^{-1} with RDF (T_4) and foliar feeding of K_2SO_4 (T_5) under the same condition. In case of varietal performance, the wheat genotype E 38 (V_1) produced greater number of spikes m^{-2} (297) than BAW 1130 (V_2). The results of this study are in agreement with findings of Baque *et al.* (2006) who found that the number of effective tillers per plant was decreased with the increasing levels of water stress, and application of K amplified the number of effective tillers per plant under water stress.

EL-Abady *et al.* (2009) noted that water stress reduced the number of spikes m^{-2} but foliar application of potassium significantly increased number of spikes m^{-2} . Additional application of soil and foliar K in both the genotypes improved the number of spikes m^{-2} under water stressed condition. The increase of spikes m^{-2} may be ascribed to the role of foliar spray with potassium on increasing photosynthetic activity which accounts much for high translocation of photo-assimilates from leaves to the grains. Similar findings were stated by Sarkar and Bandyopadhyay (1991), Abou El-Defan *et al.* (1999), El-Sabbagh *et al.* (2002) and El-Ashry and El-Kholy (2005). Again, EL-Abady *et al.* (2009) opined that the water stress during grain filling in wheat declined the yields of grain and straw, may be due to the reduction in rate and duration of filling processes and causing small grain size consequently reducing yield components like number of spikes m^{-2} , number and weight of grains spike^{-1} and 1000-grain weight. Similar results were also detected by Pierre *et al.* (2008) in wheat.

3.4.24 Number of spikelets spike^{-1}

Drought stress remarkably reduced the number of spikelets spike^{-1} as compared to well watered condition at harvest but with the addition of K containing fertilizers significantly increased the aforesaid trait. Conversely, no notable differences were observed between the genotypes and interactions among the treatment combinations regarding the number of spikelets spike^{-1} (Table 3.4.6.). The highest number of spikelets spike^{-1} (17.5) was obtained

from without adding extra K containing fertilizers along with RDF under well water condition (T_1), while the lowest one (15.9) was without K containing fertilizers under water stress condition (T_2). The results also revealed that the number of spikelets spike⁻¹ increased gradually with the increment of potassic fertilizers under water stress condition. This statement is supported by Taiz and Zeiger (1991) in their experiment in plants who reported that the reduced number of spikelets per ear may be due to limited photosynthetic activity before spike emergence, because spikelets per spike are determined before spike emergence. Aown *et al.* (2012) postulated that the number of spikelets per spike was adversely affected under water limited environment but the foliar application of K improved the spikelets per spike of wheat plant.

The intensive water stress during grain filling reduced the number of spikelets spike⁻¹ but spraying of K₂O (1.5 and 3.0%) improved this yield contributing trait over control treatment (without foliar application of potassium) in the consecutive two years (EL-Abady *et al.* 2009). The results are also corroborated with the findings of Abou El-Defan *et al.* (1999) and El-Sabbagh *et al.* (2002) in wheat crop.

3.4.25 Number of grains spike⁻¹

The number of grains spike⁻¹ was influenced significantly by water stress condition, and the well water treatment, wheat plant produced the highest number of grains spike⁻¹. Application of potassium containing fertilizer progressively increased the number of grains spike⁻¹ (Table 3.4.6.). The highest number of grains spike⁻¹ (39.8) was obtained under well water condition (T_1) and the lowest one (34.8) was observed under water stress condition (T_2). Under water stress condition, K fertilization augmented the number of grains spike⁻¹, and addition of 25 kg extra K as muriate of potash with RDF produced the highest value of this trait (36.97) followed by the application of 50 kg K ha⁻¹ as the same source with RDF. The results also showed that the number of grains spike⁻¹ was reduced significantly due to water stress compared to well water condition. Richards *et al.* (2001) recommended the similar results in

their study previously and reported that the numbers of grains per spike were decreased under water stress. In case of genotypic evaluation, elevated number of grains spike⁻¹ (41.88) observed in the genotype E 38 (V₁) than the genotype BAW 1130 (V₂) of 31.61. The genotype E 38 produced 32.49% more grains spike⁻¹ as compared to BAW 1130.

The decrease in number of grains spike⁻¹ under water stress condition may be due to reduced root growth about the time of spike formation that resulted in reduced nutrient uptake. Water stress significantly reduced the growth and development of plants but K supplement maintained the increase in grain numbers per row in maize (Rasheed *et al.* 2004, Oktem and Oktem 2005), and number of grains spike⁻¹ in wheat (Aown *et al.* 2012). Foliar application of K significantly increased number and weight of grains spike⁻¹ of wheat (Sarkar and Bandyopadhyay 1991, Abou El-Defan *et al.* 1999, and El-Sabbagh *et al.* 2002). EL-Abady *et al.* (2009) postulated that intensive water stress during grain filling (withholding last two irrigations) reduced number of grains spike⁻¹, while spraying K in wheat plants produced the highest values of number of grains spike⁻¹ and the lowest value was found from without spraying of K. Similar results were also stated by Abou El-Defan *et al.* (1999) and El-Sabbagh *et al.* (2002).

3.4.26 Thousand grain weight

Thousand grain weight (TGW) was insignificant among the treatments of water stress, and K fertilization as well as their treatment combinations with water stress. The significant variation regarding TGW was recorded between the wheat genotypes at harvest (Table 3.4.6). The wheat genotype BAW 1130 generated higher TGW (49.95 g) than the genotype E 38 (V₁) of 33.41g. The decreased TGW under drought at flowering stage was due to less efficient and disturbed nutrient uptake and limited photosynthetic translation within the plant which hastened maturity and producing shrivelled kernels (Plaut *et al.* 2004). Due to water stress at heading reduced weight of TGW was reported by Royo *et al.* (2000), and EL-Abady

et al. (2009). Hussain *et al.* (2007) and Rasool *et al.* (1987) reported significant increase in grains weight of maize with increase in K levels. EL-Abady *et al.* (2009) also showed the increment of TGW under K levels in wheat. A higher TGW was achieved in trials with artificially imposed drought when fertilized with K (Baque *et al.* 2006, Yang and Zhang 2006, Grzebisz *et al.* 2009). This hypothesis is supported by Cakmak (2005) who reported that high K accumulation in the leaves enables a plant to extend its capability to produce and transport assimilates from the leaves to the grain.

3.4.27 Grain yield

The grain yield was influenced significantly by potassium fertilization treatments but the variation of wheat genotypes as well as the interaction effect of potassium fertilization treatments and wheat genotypes on grain yield was insignificant (Table 3.4.7). Among the treatments the highest grain yield (3.06 t ha^{-1}) was obtained under well water condition (T_1) and the lowest one (2.31 t ha^{-1}) was obtained from water stress condition (T_2). The results also showed that the grain yield was reduced considerably (24.51%) due to water stress compared to well water condition, and additional soil or foliar application of K improve the grain yield. However, addition of K containing fertilizers increased the grain yield extensively (6 to 18%), and the highest grain yield was recorded at the treatment of T_3 followed by the T_4 and T_5 . Foliar application of K significantly increased the number of spikes m^{-2} , number and weight of grains spike⁻¹, 1000-grain weight, grain and straw yields of wheat as reported by Sarkar and Bandyopadhyay (1991), Abou El-Defan *et al.* (1999), El-Sabbagh *et al.* (2002), EL-Abady *et al.* (2009). It is reported by Fusheng (2006) that the seeds from potassium deficient plants are small, shrivelled, more susceptible to diseases, and suitable amount of K application can be improved seed quality. Umar (2006) revealed that seed yield, biomass and harvest index in mustard, sorghum and groundnut decreased under water stress conditions in comparison to well watered condition and this detrimental effect of water stress could be ameliorated by K application. He also noted that K_{120} fertilization in

Table 3.4.7 Effect of increasing level of potassium on grain and biological yield of wheat under water deficit stress condition

Treatments	Grain yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)
Potassium fertilization treatment along with water regimes		
T ₁	3.06 a	8.95 a
T ₂	2.31 d	6.55 c
T ₃	2.73 b	7.42 b
T ₄	2.66 bc	7.30 b
T ₅	2.44 cd	6.96 bc
CV (%)	4.43	4.57
Level of significance	**	**
Wheat genotypes		
E-38 (V ₁)	2.58	7.41
BAW-1130 (V ₂)	2.69	7.60
CV (%)	5.99	4.43
Level of significance	NS	NS
Wheat genotypes × Potassium fertilization treatment along with water regimes		
T ₁ × V ₁	3.13	9.16
T ₁ × V ₂	2.99	8.74
T ₂ × V ₁	2.27	6.62
T ₂ × V ₂	2.35	6.48
T ₃ × V ₁	2.59	7.31
T ₃ × V ₂	2.87	7.52
T ₄ × V ₁	2.55	7.12
T ₄ × V ₂	2.76	7.48
T ₅ × V ₁	2.37	6.86
T ₅ × V ₂	2.50	7.07
CV (%)	5.99	4.43
Level of significance	NS	NS

In a column, values followed by similar letter(s) did not differ significantly by DMRT at $P \leq 5\%$ within main and interaction effect

* indicates significant at 5% level of probability

** indicates significant at 1% level of probability

^{NS} indicates insignificant

T₁= Recommended potassium fertilization (50 kg K ha⁻¹) under well water condition

T₂= Recommended potassium fertilization (50 kg K ha⁻¹) under water deficit stress condition

T₃= Application of 75 kg K ha⁻¹ under water deficit stress condition

T₄= Application of 100 kg K ha⁻¹ under water deficit stress condition

T₅= Foliar application of K₂SO₄ with recommended potassium fertilization (50 kg K ha⁻¹) under water stress condition.

mustard and sorghum field under water stress conditions increased 70.45 and 358.3% more yield over the K_0 , respectively. The findings in this experiment are furthermore in agreement with Wyrwa *et al.* (1998) who showed that drought caused reduction in grain yield of *Triticale* only 16% when an adequate K was supplied but grain yield reduced by 54% at K deficit condition under water stress. Rama Rao (1983) also reported that the response of pearl millet and sorghum to K application in moisture stress conditions simulated in a similar way with this study. Seed yield of mustard was improved by K application in moisture stress conditions as reported by Umar and Bansal (1995). The increase in seed yield with K application under water stress conditions is presumably due to the improved water status of K treated plants as evident by a comparatively higher RWC that could improve various physiological processes. In fact, K application is known to improve such physiological characteristics as stomatal resistance, RWC, nitrate reductase activity (NRA), chlorophyll and proline contents which might improve the overall plant water status and metabolism (Beringer 1982, Umar *et al.* 1990). El-Hadi *et al.* (1997) found remarkable yield boosting for a wide range of annual crops by applying K when water supply was restricted. The improvement of wheat grain yield under water stress condition with additional application of K was contributed by improvement in spikes m^{-2} , grain spike $^{-1}$ and 1000-grain weight with the same treatment combinations (Mohammadi *et al.* 2013). Drought stress either at vegetative or flowering stage considerably decreased grain yield and yield components in wheat (Gupta *et al.* 2001, Nasri 2005, Anjum *et al.* 2011b). This decrease was due to reduced production of photosynthates under water deficit conditions (Anjum *et al.* 2003, Wahid and Rasul 2005). The increase in number of grains per ear by exogenous application of K was due to increase in number of spikelet in wheat where photosynthesis and root respiration increased grain yield under drought (Liu and Li 2005). It was indicated by many investigators that potassium played a key role in the osmotic adjustment (stomatal opening) of plants under water stress, and yield may be improved due to foliar potassium application to plants (Foyer *et al.* 2002). Most of the yield contributing characters as well as grain yield was reduced

substantially (Baque *et al.* 2006). Yield and yield contributing characters of wheat were also improved due to high level of K application.

3.4.28 Above ground biological yield

The above ground biological yield (BY) at harvest was influenced significantly by K fertilization treatment but the wheat genotypic effect and interaction effects of K fertilization treatment and wheat genotypes regarding the BY was insignificant (Table 3.4.7.). The highest above ground BY (8.95 t ha^{-1}) was recorded from the T_1 treatment (well water condition) and the lowest one (6.55 t ha^{-1}) was obtained from at water stress condition (T_2). The above ground BY was reduced significantly (6 to 13%) due to water stress compared to well water condition. However, application of $25 \text{ kg additional K ha}^{-1}$ with RDF under water stress condition increased the BY and the highest BY (7.42 t ha^{-1}) was observed at the T_3 treatment under water stress condition, followed by treatment of T_4 and T_5 at same stress condition. The improvement in above ground biological yield under water stress condition with additional foliar application of K was contributed partly by the improvement in grain yield. The decrease in above ground BY was due to reduced production of photosynthates under water deficit conditions (Anjum *et al.* 2003, Wahid and Rasul 2005). Potassium feeding was responsible for higher grain and BY in maize plants under conventional-furrow irrigation (Maqsood *et al.* 2013). Umar (2006) revealed that the effect of K application on the plant biomass was most prominent at K_{120} with a variation of 66.3 and 197.2% over K_0 under water stress conditions in mustard and sorghum, respectively. Amanullah (2016) reported that biomass yield increased due to K foliar feeding and the highest wheat biomass yield (8882 kg ha^{-1}) was obtained with 3% K as foliar and the lowest biomass yield (8422 kg ha^{-1}) was obtained with foliar 1% K.

Considering the results of experiment- IV, it may be concluded that extra application of potassium fertilizer improved the grain yield of wheat under water deficit stress but soil application of extra K^+ was more effective than foliar application.

CHAPTER IV

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary

Drought stress is currently the leading threat on world's food supply, limiting crop yield, even at the present climatic conditions. Hence, there is a need for selection of such wheat genotypes which could grown-up and produce better yield with limited supply of water as well as to develop suitable management strategies under water deficit condition. In the view of above considerations, the present attempt was made to find out drought tolerant varieties/lines of wheat for drought prone areas of Bangladesh, and to build up agronomic management for increasing drought tolerance.

In the first experiment, 30 wheat genotypes were used for screening under PEG induced three water potentials of 0, -2 and -4 bars. The rate of germination (RG) among the genotypes varied significantly with the different water potential levels, and the RG decreased with the advancement of stress. However, the highest and the lowest RG of 92.33 and 61.19% were recorded under water stress conditions of -2 and -4 bars, respectively. The stress tolerance index (STI) based on RG under water deficit stress was measured, and the wheat genotypes Shatabdi, BARI Gom 25, E 2, E 18, E 30, E 34, E 38, BAW 1118, BAW 1151 and BAW 1161 provided STI value of > 0.900 in severe water deficit stress, while wheat genotypes BARI Gom 26, BARI Gom 27, BARI Gom 28, E 28, E 42, BAW 1130, BAW 1140, BAW 1143 and BAW 1168 showed STI of < 0.800 . The genotypes showed the maximum STI values indicated most water stress tolerant, and the minimum STI values indicated water stress susceptible.

Co-efficient of germination (COG) was significantly decreased with increasing water potential levels. The STI regarding COG was calculated under water potential stresses (-2 & -4 bars), and the STI values varied among the genotypes. Wheat genotypes Sourav, BARI

Gom 25, E 2, E 18, E 23, E 29, E 34, E 38, BAW 1118, BAW 1135, BAW 1151, BAW 1157, BAW 1161, BAW 1163, BAW 1170 and BAW 1171 provided STI values > 0.980 , in contrary, genotypes BARI Gom 26, BARI Gom 27, E 24, E 28, E 42, BAW 1130, BAW 1140 and BAW 1168 produced STI values < 0.970 under higher water potential. The STI genotypes producing higher STI can be treated as higher water stress tolerant, while lower STI value generating genotypes can be designated as water stress susceptible.

Germination vigour index (GVI) varied significantly among the genotypes with the water potentials levels. At higher water stress (-4 bars), higher STI values (>0.920) were observed in BARI Gom 25, E 18, E 23, E 34, E 38, BAW 1118, BAW 1161 and BAW 1170 whereas, very lower STI values (< 0.800) were obtained in the Shatabdi, BARI Gom 26, BARI Gom 27, E 3, E 24, E 28, E 42, BAW 1130, BAW 1140 and BAW 1168 genotypes. The maximum and minimum STI value providing genotypes indicating their higher tolerant and susceptible genotypes to water deficit stresses, respectively. The STI based on the shoot length were measured under moderate and severe water stress. Under higher water stress the genotypes Shatabdi, BARI Gom 25, E 18, E 38, BAW 1118, BARI Gom 27, E 24, E 34, BAW 1143 and BAW 1170 showed higher STI values (>0.550) indicating tolerant genotypes and the genotypes Sourav, BARI Gom 26, BARI Gom 28, E 2, E 3, E 28, E 29, BAW 1130, BAW 1151, and BAW 1168 demonstrated lower STI values (< 0.450) designating susceptible genotypes. The shoot weight (g) was reduced with the increment of water deficit stress. Wheat genotypes Shatabdi, BARI Gom 25, E 18, E 34, E 38 and BAW 1118 provided > 0.700 STI, while genotypes BARI Gom 26, E 2, E 23, E 29, BAW 1130, BAW 1140, BAW 1151, BAW 1157 and BAW 1161 afford STI < 0.550 . The genotypes showing higher and lower STI values denoted water stress tolerant and susceptible genotypes, respectively.

From the first experiment, it is already identified the most drought tolerant and susceptible genotypes based on the germination and seedling growth properties. For more confirmation

of the tolerant and susceptible genotypes, a field experiment was conducted in 2014-15 cropping season. The experiment consisted of two factors namely Factor A: Thirty wheat genotypes, and Factor B: Three water regimes viz. i) well watered condition i.e. three irrigations at crown root initiation (CRI), anthesis, and grain filling stages, ii) one irrigation i.e. one irrigation at CRI stage and then stopped as well as protected the crop from rainfall by rainout shelter, and iii) no irrigation i.e. crop grown without irrigation and protected the crop from rainfall by rainout shelter. Water stress significantly influenced the spike length of the wheat genotypes, and the spike length reduced due to water stress conditions. The relative value based on the spike length under water potentials, the genotypes Shatabdi, BARI Gom 25, E 18, E 28, E 34, E 38, E 42, BAW 1118, and BAW 1130 showed relative values greater than 0.960 indicating in their drought tolerant, whereas the genotypes BARI Gom 26, E 24, BAW 1135, BAW 1140, BAW 1143, BAW 1151 and BAW 1161 showed lesser than 0.920 relative value in showing their drought susceptibility. The number of spikelets spike⁻¹ was reduced by the water stress conditions and the genotypes Shatabdi, BARI Gom 25, BARI Gom 27, E 28, E 30, E 34, E 42, BAW 1130 and BAW 1170 can be treated as tolerant genotypes due to showing their higher relative values (> 0.920). On the other hand, the genotypes Sourav, BARI Gom 26, BAW 1140, BAW 1143, BAW 1161 and BAW 1168 can be considered as susceptible by counting their less relative values (< 0.880). The number of grains per spike gradually decreased with increasing water deficit stress. The higher relative values (> 0.930) were recorded in the wheat genotypes of Sourav, Shatabdi, BARI Gom 25, BARI Gom 27, BARI Gom 28, E 24, E 34, E 38, E 42, BAW 1168 and BAW 1170, whereas the lower relative values (< 0.880) were obtained in the genotypes of BARI Gom 26, E 3, E 29, BAW 1118, BAW 1130, BAW 1138, BAW 1140, BAW 1143, BAW 1157, and BAW 1161 under severe water stress. The higher and lower relative value generating genotypes can be treated as tolerant and susceptible genotypes.

Water regimes significantly influenced the grain yield of wheat genotypes and the grain yield decreased with increase water stressed conditions in soil. The reduced number of effective tillers plant⁻¹, length of spike, number of grains spike⁻¹ and 1000-grain weight are the main reasons for reducing the grain yield of wheat. In no irrigated condition, higher relative values (>0.680) were recorded in the wheat genotypes of BARI Gom 25, E 3, E 18, E 24, E 28, E 34, E 38, BAW 1118, BAW 1170 and BAW 1171, which can be delighted as drought tolerant genotypes and among the highest relative value was in BARI Gom 25 followed by E 18, E 38, BAW 1118, BAW 1170, E 24, E 28, E 3, BAW 1171 and E 34. On the other hand, lower relative values (<0.600) were obtained in the genotypes of BARI Gom 26, BARI Gom 27, BARI Gom 28, E 23, BAW 1130, BAW 1138, BAW 1140, BAW 1143 and BAW 1157, and these genotypes can be treated as drought susceptible and the lowest relative value was in BARI Gom 26 followed by BAW 1130, BAW 1140, BARI Gom 27, BAW 1143, BARI Gom 28, BAW 1138, BAW 1157, E 23 and Sourav. It was observed that the genotypes which possessed the higher relative performance (RP) value based on the yield traits and yield is affected less by water deficit stress, and can be treated as drought tolerant genotypes. Contrary, the genotypes provided less RP values can be designated as stress susceptible genotypes.

Development of crop plants with stress tolerance, however, requires knowledge of the physiological mechanisms and genetic controls at different growth stages, considered a promising approach to select drought tolerant genotypes. The present attempt was made to find out drought tolerant variety of wheat considering physiological parameters. The experiment was laid out in a split-plot design with three replications. The treatments were: Two water regimes plot namely, i) well water condition: Three irrigations were applied at a) crown root initiation (CRI), b) anthesis, and c) grain filling stages, and ii) water deficit stress: No irrigation was applied and the crop was protected from rainfall by rainout shelter. Six wheat genotypes (BARI Gom 25, E 38, BAW 1118, E 18, BARI Gom 26, and BAW 1130)

including four tolerant and two susceptible selected based on STI and RP of seedling dry weight, yield traits, yield and clustering analysis from the 1st and 2nd experiment. Irrigation was arranged in main plots and wheat genotypes were placed in sub-plots. Different growth and physiological traits were measured during experimentation.

Chlorophyll (Chl) is one of the major components of chloroplasts for photosynthesis. In this study, water regimes significantly influenced the flag leaf Chl content of wheat genotypes. The Chl content was increased due to water deficit stress in all the wheat genotypes at 8 DAA but it decreased at 24 DAA. However, the highest (15.09%) and the lowest reduction (6.05%) were found in BAW 1130 and E 38 under water stress condition, respectively. The two sensitive genotypes BAW 1130 and BARI Gom 26 were found to affect more than the tolerant genotypes (BARI Gom 25, E 38, BAW 1118 and E 18) regarding Chl degradation in the present study.

Proline content of leaf and kernel was significantly influenced by water regimes. The genotype E 38 provided the maximum increment of proline content (113.74%), while the minimum reduction (11.66%) was found in BAW 1130 under water stress conditions. Accumulation of proline under stress in many plant species has been correlated with stress tolerance, and its concentration has been known to be usually higher in stress tolerant than in stress sensitive plants. Soluble sugar content in both wheat leaf and kernel remarkably was influenced by the drought stress. Under all well water and stress conditions, the maximum increment (23.88%) and minimum reduction (13.93%) of soluble sugar content in leaf was found in E 38 and BAW 1130, respectively. In case of kernel, BAW 1130 and BAW 1118 showed the maximum (32.81%) and minimum reduction (14.61%) of soluble sugar content, respectively. Starch level progressively increased with providing the water stress in the endosperm of wheat. The starch content in the kernel significantly varied from 37.77 to 59.90 mg g⁻¹ DW and 49.01 to 63.98 mg g⁻¹ DW in both well water and water deficit conditions,

respectively. The highest increment was recorded in the genotype of E 18 (42.60%) followed by BAW 1130 (30.73%), E 38(20.91%), BARI Gom 26 (6.06%) and BARI Gom 25 (2.08%), whereas the decline of starch content was observed only in the genotype of BAW 1118 (28.53%). Relative water content (RWC) in wheat plants is an important indicator of water contents under water deficit conditions. The genotype BAW 1118 showed the maximum RWC (95.33), while the minimum (85.33) was obtained in the BAW 1130 genotype among all of the treatment combinations. The genotype E 38 provided the lowest reduction of RWC (0.72%) due to water stress be evidence for most tolerant genotype, followed by BARI Gom 25 (4.36%), BAW 1118 (5.94%), and E 18 (6.19%) among all the genotypes. The genotype BAW 1130 showed the highest reduction in RWC (8.90%) designating most susceptible genotype followed by BARI Gom 26 (8.10%) due to water deficit stress. Water stress tolerance genotypes (BARI Gom 25, E 38, BAW 1118 and E 18) showed higher RWC as compared susceptible genotypes (BARI Gom 26 and BAW 1130) in both conditions. The degree of reduction of WRC was found more in susceptible genotypes than that in tolerance genotypes.

Canopy temperature depression (CTD) is a superior indicator of a genotype for physiological suitability to drought tolerance, and higher values of CTD are a sign of drought tolerance. However, the highest reduction (77.02%) was recorded in the genotype BAW 1130 indicating its stress susceptible followed by the genotype BARI Gom 26 (48.74%), whereas the lowest reduction (25.52%) was observed in the wheat genotype of E 38, specifying it most drought tolerant followed by the genotype of BAW 1118 (28.23%), and BARI Gom 25 (29.00%). The highest reduction (84.63%) was opined in BAW 1130 indicating most drought sensitive followed by BARI Gom 26 (54.01%), and the lowest was in E 38 (30.31%), signifying the most forbearing genotype go behind to BAW 1118 (31.58%), and BARI Gom 25 (33.33%).

The cell membrane stability (CMS) was measured as the percentage of injury of leaf tissues at anthesis under variable water regimes. The highest injury was obtained in the genotype BARI Gom 26 (68%) and the lowest injury was in the genotype E 38 (22%). Percentage injury was lower i.e. the CMS was higher in the genotypes indicated that these genotypes were more tolerant to water deficit stress. Water deficit stress influenced the phenology of wheat genotypes. The heading was occurred 6, 5, and 5 days earlier in BAW 1130, BARI Gom 26, and E 38 genotypes under water stress, respectively. Furthermore, the genotype E 38 showed only 3 days earlier heading due to water stress and rest of the genotypes showed 4 days earlier heading with the same condition. Days to anthesis was occurred 4 days earlier in BAW 1118, E 18 and BARI Gom 26 genotypes and the genotype BAW 1130 showed very earlier anthesis (5 days before) under water stress which indicates more susceptible to water stress. The earlier physiological maturity was observed in the genotype E 18, BARI Gom 26 and BAW 1130 (3 days) which was followed by that in BAW 1118 and BARI Gom 26 (2 days), whereas only 1 day earlier for physiological maturity was observed in E 38.

Grain yield is the ultimate result of all physiological and agronomical responses of cultivars and water regimes significantly decreased the grain yield of wheat genotypes. Nevertheless, the grain yield reduced to peak of 41.44% in BAW 1130 followed by 39.95% in BARI Gom 26 due to water stress indicating water stress susceptible genotypes, while, the grain yield decreased to least of 23.69% in E 38, followed by 25.39% in BAW 1118, 27.54% in BARI Gom 25, and 33.79% in E18 under water stress showing drought tolerance genotypes. The lowest stress susceptibility index (SSI) based on grain yield (0.72) was obtained in the wheat genotype E 38 followed by BAW 1118 (0.79), BARI Gom 25 (0.85), E 18 (1.04), and the highest SSI from BAW 1130 (1.28) then BARI Gom 26 (1.23). These results revealed that the genotype E 38 showed greater stress tolerance, and the genotype BAW 1130 showed the lowest stress tolerance.

The response of a plant to environmental stress is determined by its nutritional status. Nutrient management could be more feasible and economical method to induce drought tolerance in crops. Potassium (K) fertilization mitigates the adverse effects of moisture stress in plants by increasing translocation and maintaining water balance within plants. Hence, it is imperative to know the response of K of those genotypes under stress conditions. It is already identified the most tolerant (E 38) and susceptible genotypes (BAW 1130) of wheat in the previous studies. This study was, therefore, designed to investigate the role of potassium as soil and foliage application on wheat drought tolerance in rainfed conditions and to confirm that adequate K management can be used as an important tool to alleviate the negative effects of water deficit on plant growth, yield components, and yield. To study the effect of potassium fertilizer on wheat under water stress conditions, an experiment was conducted in 2016-17 in WRC, Dinajpur. Tolerant (V_1 : E 38), and susceptible (V_2 : BAW 1130) wheat genotypes were grown under five levels of potassium fertilizers with two water regimes viz. T_1 : Recommended dose of K (50 kg K ha^{-1}) under well water condition, T_2 : Recommended dose of K (50 kg K ha^{-1}) under water stress condition, T_3 : 75 kg K ha^{-1} under water stress condition, T_4 : 100 kg K ha^{-1} under water stress condition, T_5 : Foliar application of K_2SO_4 with recommended dose of K (50 kg K ha^{-1}) under water stress condition. Crop growth, physiology, water relation, and nutritional status were measured.

The leaf area index (LAI) significantly reduced under water deficit condition, and application of additional potassium remarkably increased the LAI of wheat genotypes. Under water deficit stress conditions, the highest LAI (4.29) was obtained from T_3 followed by T_4 . The T_5 treatment produced the lowest LAI (3.72) under water stress condition. Total dry weight (TDW) inclined considerably due to the effect of water deficit condition, and the TDW deprived from 27.60 g to 22.85g tabulated as 17.21% attributable to water deficit condition. Additional potassium fertilization from 0 to 50 kg, and K as foliar progressively increased the TDW (4.16 to 11.86%) of water stressed wheat genotypes. Concerning the performance of

the genotypes, the higher TDW (26.93g) was obtained from the genotype BAW 1130 (V_2) as compared to E 38 genotype. The relative water content (RWC) was reduced significantly due to water stress, and additional soil or foliar application of K improved the RWC. The wheat genotype E 38 maintained superior RWC to the genotype BAW 1130, indicating tolerant of E 38 genotype under water deficit condition.

The genotype E 38 (V_1) retained significantly higher amount of N in the flag leaf (2.05 and 2.164%) than BAW1130 (V_2) at 65 DAS and at harvest, respectively. On the contrary, the genotype BAW 1130 achieved higher amount of N with addition of K containing fertilizer under drought stress than the genotype E 38. Water stress significantly reduced the flag leaf P content from 305.5 to 262.1 g Kg⁻¹ and 238.8 to 197.2 g Kg⁻¹ at 65 DAS and at harvesting stage, respectively. Nonetheless, extra addition of K considerably increased the P content in the flag leaf under drought stress. Between the two wheat genotypes, the P contents (289.6 and 250.5 g Kg⁻¹) were higher in E 38 than that of the genotype BAW 1130 (265.5 and 182.6 g Kg⁻¹) at 65 DAS and harvesting stages, respectively. The K content in the flag leaf reduced (2.04 and 1.91 g Kg⁻¹) significantly due to lack of sufficient moisture at 65 DAS and harvesting stages. Nevertheless, the K content progressively increased with the increasing additional K fertilizers, and T_2 performed superior results to other K fertilization treatments under stress condition. Foliar fertilization also enhanced K uptake in plants and the genotype E 38 taken in higher K in plants.

The spike length was influenced notably by the water stress, and additional K fertilization increased spike length remarkably and the highest spike length was observed at T_3 followed by the treatment of T_4 and T_5 . The V_2 produced longer spike length (9.83 cm) than that of (8.12 cm) V_1 , i.e. the V_2 increased 21.06% spike length. Drought stress remarkably reduced the number of spikelets spike⁻¹ as compared to well watered condition at harvest, but with the addition of K containing fertilizers significantly increased the aforesaid trait. The highest

number of spikelets spike⁻¹ (17.5) was obtained at T₁, while the lowest one (15.9) was at T₂. The number of grains spike⁻¹ was influenced significantly by water stress condition. Application of K progressively increased the number of grains spike⁻¹. The highest number of grains spike⁻¹ (39.8) was obtained at T₁ and the lowest one (34.8) was observed under T₂. The grain yield was reduced considerably (24.51%) due to water stress compared to well water condition and additional soil or foliar application of K improve the grain yield. However, addition of K containing fertilizers increased the grain yield extensively (6 to 18%) and the highest grain yield was recorded at the treatment of T₃ followed by the T₄ and T₅. The increase in seed yield with K application under water stress conditions is presumably due to the improved water status of K-treated plants as evident by a comparatively higher RWC that could improve various physiological processes. The improvement of wheat grain yield under water stress condition with additional application of K was contributed by improvement in spikes m⁻², grain spike⁻¹ and 1000-grain weight with the same treatment combinations. Yield and yield contributing characters of wheat were also improved due to high level of K application.

Conclusion

In consideration of the results, it can be concluded that

- ❖ Water deficit stress delayed germination and reduced seedling growth traits and based on germination and seedling growth traits E 3, BAW 1135, E 30, E 34, BAW 1138, Shatabdi, E 18, BAW 1118, E 38 and BARI Gom 25 genotypes were found as more tolerant, while, BAW 1151, E 42, BAW 1170, E 29, BAW 1161, E 2, BAW 1157, E 23, BAW 1130 and BARI Gom 26 were found as more sensitive genotypes.
- ❖ Water deficit stress reduced the yield traits and consequently reduced the yield of all genotypes but the reduction was lower in wheat genotypes-BARI Gom 25, E 38, BAW 1118 and E 18, while higher reduction was recorded in BARI Gom 26 and BAW 1130.

- ❖ Based on physiological traits such as, better grain growth duration, greater accumulation of flag leaf proline and soluble sugar, greater stability of flag leaf chlorophyll, better relative water content and cooler canopy under water deficit stress, E 38 was found to be more water stress tolerant, followed by BARI Gom 25, BAW 1118, E 18 and BARI Gom 26 and BAW 1130 were observed as susceptible genotypes.
- ❖ Extra application of potassium fertilizer improved the grain yield of wheat under water deficit stress but soil application of extra K^+ was more effective than foliar application.

Recommendations

- Drought tolerance of wheat genotypes based on germination and early seedling growth characteristics is not strong enough to be exploited as screening tool. The physiological tolerance along with agronomic traits should be considered.
- Diverse potassium management strategies should be tested for improving grain yield of wheat under water deficit condition before specific recommendation.
- Field trial in drought prone area should be suggested.

CHAPTER V

REFERENCES

- Abayomi Y. A. and D. Wright. 1999. Effects of water stress on growth and yield of spring wheat (*Triticum aestivum* L.) cultivars. Trop. Agric. 76: 120-125.
- Abou El-Defan T. A., H. M. A. El-Kholi, M. G. M. Rifaat and A. E. Abd Allah. 1999. Effect of soil and foliar application of potassium on yield and mineral content of wheat grains grown in sandy soils. Egyptian J. Agric. Res. 77(2): 513-522.
- Adejare F. B. and C. E. Umebese. 2007. Stomatal resistance to low leaf water potential at different growth stages affects plant biomass in *Glycine max* L. American J. Agril. Biol. Sci. 2: 136-141.
- Agboma P. C., M. J. K. Jones, P. H. Rita and E. Pehu. 1997. Exogenous glycinebetaine enhances grain yield of maize, sorghum and wheat grown under two supplementary watering regimes. J. Agron. Crop Sci. 178: 29-37.
- Aggarwal P. K. and S. K. Sinha. 1987. Response of droughted wheat to mid-season water application, recovery in leaf area and its effect on grain yield. Aust. J. Agric. Res. 14: 227-237.
- Ahmad J. 2002. Effect of varying irrigation frequencies on phonology, growth and yield of three wheat varieties. M.Sc. Thesis, Dept. Agron., Univ. Agri., Faisalabad, Pakistan. pp. 32-35.
- Ahmad M., G. Shabbir, N. M. Minhas and M. K. N. Shah. 2013. Identification of drought tolerant wheat genotypes based on seedling traits. Sarhad J. Agric. 29(1): 21-27.
- Ahmadi A. and D. A. Baker. 2001. The effect of water stress on the activities of key regulatory enzymes of the sucrose to starch pathway in wheat. Plant Growth Regul. 35: 81-91.
- Ahmadi A. and D. Baker. 1999. Effects of abscisic acid (ABA) on grain filling processes in wheat. Plant Growth Regul. 28(3): 187-97.
- Ahmadizadeh M. 2013. Physiological and agro-morphological response to drought stress. Middle-East J. Sci. Res. 13: 998-1009.

- Ahmadizadeh M., A. Nori, H. Shahbazi and M. Habibpour. 2011. Effects of drought stress on some agronomic and morphological traits of durum wheat (*Triticum durum* Desf.) landraces under greenhouse condition. *Afr. J. Biotechnol.* 10: 14097-14107.
- Akhtar M., S. Ahmad, S. Mohsin and T. Mehmood. 1999. Interactive effect of Phosphorous and Potassium nutrition on the growth and yield of hybrid maize. *Pak. J. Biol. Sci.* 2: 240-241.
- Akhter M. M., A. EL Sabagh, M. N. Alam, M. K. Hasan, E. Hafez, C. Barutçular and M. S. Islam. 2017. Determination of seed rate of wheat (*Triticum aestivum* L.) varieties with varying seed size. *Sci. J. Crop Sci.* 6(3): 161-167.
- Akladios S. A. 2012. Influence of different soaking times with selenium on growth, metabolic activities of wheat seedlings under low temperature stress. *Afr. J. Biotech.* 11(82): 14792-14804.
- Akram H. M. and M. S. Iqbal 2004. Drought tolerance studies of wheat genotypes. *Pak. J. Biol. Sci.* 7(1): 90-92.
- Akram H. M., A. Sattar, A. Ali and M. Nadeem. 2012. Agro-physiological performance of wheat genotypes under normal moisture and drought conditions. *Iranian J. Plant Physiol.* 2(2): 361-369.
- Akram M. 2011. Growth and yield components of wheat under water stress of different growth stages. *Bangladesh J. Agril. Res.* 36(3): 455-468.
- Alam S. M. 1994. Nutrient by plants under stress conditions. In: Pessarakli M. (ed). *Handbook of Plant and Crop Stress*. MarcelDekker, New York, USA. pp. 227-246.
- Alderfasi A. A. 2001. Evaluation of certain traits associated with drought resistance in wheat under field conditions. *Annals Agric. Sci., Ain Shams Univ., Cairo.* 46(1): 71-83.
- Alfredo A. C. A. and T. L. Setter. 2000. Response of cassava to water deficit: Leaf area growth and abscisic acid. *Crop. Sci.* 40: 131-137.
- Ali M. A. 2011. Pedigree selection for grain yield in spring wheat (*Triticum aestivum* L.) under drought stress conditions. *Asian J. Crop Sci.* 3: 158-168.

- Ali M. A., S. Niaz, A. Abbas, W. Sabir and K. Jabran. 2009. Genetic diversity and assessment of drought tolerant sorghum landraces based on morph-physiological traits at different growth stages. *Plant Omics*. 2: 214-227.
- Ali M., C. R. Jensen, V. O. Mogensen, M. N. Andersen and I. E. Hensen. 1999. Root signaling and osmotic adjustment during intermittent soil drying sustain grain yield of field grown wheat. *Field Crops Res*. 62: 35-52.
- Allahverdiyev T. 2015. Effect of drought stress on some physiological traits of durum (*Triticum durum* Desf.) and bread (*Triticum aestivum* L.) wheat genotypes. *J. Stress Physiol. Biochem*. 11(1): 29-38.
- Almaghrabi O. A. 2012. Impact of drought stress on germination and seedling growth parameters of some wheat cultivars. *Life Sci. J*. 9(1): 590-598.
- Almeselmani M., F. Abdullah, F. Hareri, M. Naesan, M. A. Ammar, O. Z. Kanbar, and A. Saud. 2011a. Effect of drought on different physiological characters and yield component in different Syrian durum wheat varieties. *J. Agric. Sci*. 3: 127-133.
- Almeselmani M., J. A. Teixeira da Silva and P. Deshmukh. 2011b. Stability of different physiological characters, yield and yield components under high temperature stress in tolerant and susceptible wheat genotypes. *Fruit, Vegetable Cereal Sci. Biotech*. 5(special issue 2): 86-92.
- Almeselmani M., A. Saud, K. Al-Zubi, F. Abdullah, F. Hareri, M. Nassan, M. A. Ammar and O. Kanbar. 2012a. Physiological performance of different durum wheat varieties grown under rainfed condition. *Global J. Sci. Frontier Res*. 12: 55-63.
- Almeselmani M., A. A. Saud, K. Al-zubi, F. Hareri, M. Al-nassan, M. A. Ammar, O. Z. Kanbar, H. Al-Naseef, A. Al-nator, A. Al-gazawy, H. A. Al-sael. 2012b. Physiological attributes associated to water deficit tolerance of Syrian durum wheat varieties. *Exp. Agri. Hort*. 45: 21-41.
- Almeselmani M., A. Saud, F. Hareri, M. Nassan, M. A. Ammar, O. Kanbar and H. Al-Naseef. 2013. Physiological traits associated with yield improvement under rainfed condition in new wheat varieties. *Jordan J. Agril. Sci*. 9: 12-22.

- Almeselmani M., A. Al-Rzak Saud, K. Al-Zubi, S. Al-Ghazali, F. Hareri, M. Al-Nassan, M. A. Ammar, O. Z. Kanbar, H. Al-Naseef, A. Al-Nator, A. Al-Gazawy and J. A. Teixeira da Silva. 2015. Evaluation of physiological traits, yield and yield components at two growth stages in 10 durum wheat lines grown under rainfed conditions in Southern Syria. *Cercetări Agronomice în Moldova*. XLVIII (2): 29-49.
- Al-Tabbal J. A. and O. M. Kafawin. 2005. Effect of water deficit and plant growth regulators on leaf chlorophyll, proline and total soluble sugars content of durum wheat cultivar (*Triticum turgidum* L. vat. durum). *Dirasat, Agril. Sci.* 32(2): 195-204.
- Amanullah A., I. Irfanullah and Z. Hidayat. 2016. Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. www.nature.com/scientific report/, pp. 1-12.
- Anjum, F., M. Yaseen, E. Rasul, A. Wahid and S. Anjum. 2003. Water stress in barley. I. Effect on chemical composition and chlorophyll contents. *Pakistan J. Agric. Sci.* 40: 45-9.
- Anjum S. A., L. C. Wang, M. Farooq, M. Hussain, L. L. Xue and C. M. Zou. 2011a. Brassinolide application improves the drought tolerance in maize through modulation of enzymatic antioxidants and leaf gas exchange. *J. Agron. Crop Sci.* 197(3):177-185
- Anjum S. A., X. Xie, L. Wang, M. F. Saleem, C. Man and W. Lei. 2011b. Morphological, physiological and biochemical responses of plants to drought stress. *Afr. J. Agril. Res.* 6(9): 2026-2032.
- Aown M., S. Raza, M. F. Saleem, S. A. Anjum, T. Khaliq and M. A. Wahid. 2012. Foliar application of potassium under water deficit conditions improved the growth and yield of wheat (*Triticumaestivum*L.). *J. Anim. Plant Sci.* 22(2): 431-437.
- Araus J. L., G. Slafer, M. P. Reynolds and Royo. 2002. Plant breeding and drought in C³ cereals. What should we bread for? *Ann. Bot. C.* 89: 925-940.
- Arif M., M. A. Khan, H. Akbar and S. Ali. 2006. Prospects of wheat as a dual purpose crop and its impact on weeds. *Pak. J. Weed Sci. Res.* 12(1-2): 13-17.
- Arnon I. 1972. Crop Production in Dry Regions. Polunin, N. (Ed.). Vol. 1, Leornard Hill Book, London, UK. pp. 203-211.

- Asana, R. D. and R. F. Williams. 1965. The effect of temperature stress on grain development in wheat. *Aust. J. Agric. Res.* 16: 1-3.
- Asgharipour M. R. and M. Heidari. 2011. Effect of potassium supply on drought resistance in sorghum: plant growth and macronutrient content. *Pak. J. Agri. Sci.* 4893: 197-204.
- Ashraf M. 1994. Breeding for salinity tolerance in plants. *Crit. Rev. Plant Sci.* 13: 17-42.
- Ashraf M. and M. R. Foolad. 2007. Roles of glycinebetaine and proline in improving plant abiotic stress tolerance. *Environ. Exp. Bot.* 59: 206-216.
- Ashraf M., H. Bokhari and S. N. Cristiti. 1992. Variation in osmotic adjustment of lentil (*Lens culinnaris* Medic.) in response to drought. *Acta Bot. Neerlandica.* 41: 51-62.
- Ashraf M. Y. 1998. Yield and yield components response of wheat (*Triticum aestivum* L.) genotypes under different soil water deficit conditions. *Acta Agron. Hung.* 46: 45-51.
- Ashraf M. Y. and G. Sarwar. 2002. Salt tolerance potential in source members of Brassicaceae: Physiological studies on water relations and minerals contents. In: *Prospects for Saline Agriculture*. Ahmad R. and A. Malik (Eds.). Kluwer Acad. Pub., The Netherlands. pp. 237-245.
- Ashraf M. Y., A. R. Azmi, A. H. Khan and S. A. Ala. 1994. Effect of water stress on total phenols, Peroxidase activity and chlorophyll content in wheat. *Acta. Physiologiae Plant.* 16(3): 185-191.
- Ashraf M. Y., M. H. Naqvi and A. H. Khan. 1996. Evaluation of four screening techniques for drought tolerance in wheat (*Triticumaestivum* L.). *Acta Agron. Hungarica*, 44(3): 213-220.
- Ashraf M. Y., S. A. Ali and A. S. Bhatti. 1998. Nutritional imbalance in wheat genotypes grown at soil water stress. *Acta Physiol. Plant.* 20: 307-310.
- Asif M. and A. Kamran. 2011. Plant breeding for water-limited environments. *Crop Sci.* 51: 2911.

- Aslam M., M. S. I. Zamir, I. Afzal, M. Yaseen, M. Mubeen and A. Shoaib. 2013. Drought stress, its effect on maize production and development of drought tolerance through potassium application. *Cercetări Agronomice în Moldova*. XLVI(2): 99-114.
- Attarbashi M. R., S. Galeshi, A. Soltani and E. Zeinali. 2002. Relation of phenology and physiology traits with grain yield in wheat under raunfed conditions. *Iranian J. Agric. Sci.* 33(1): 21-28.
- Ayeneh A., M. van Ginkel, M. P. Reynolds and K. Ammar. 2002. Comparison of leaf, spike, peduncle, and canopy temperature depression in wheat under heat stress. *Field Crops Res.* 79: 173-184.
- Bade D. H., B. E. Condrad and E. C. Holt. 1985. Temperature and water stress effect on growth of tropical grasses. *J. Range Manage.* 38(4): 321-324.
- Baisak R., D. Rana, P.B.B. Acharya and M. Kar. 1994. Alteration in the activities of active oxygen scavenging enzymes of wheat leaves subjected to water stress. *Plant Cell Physiol.* 35: 489-495.
- Bajji M., J. M. Kinet and S. Lutts. 2002. The use of the electrolyte leakage method for assessing cell membrane stability as a water stress tolerance test in durum wheat. *Plant Growth Regul.* 36: 61-70.
- Balkaya A., R. Yanmaz and A. A. H. Kar. 2005. Morphological characterization of white head cabbage (*B. oleracea* var. capitata subvar. Alba) genotypes in Turkey. *New Zealand J. Crop Hort. Sci.* 33: 333-341.
- Balota M., M. William, A. Payne, S. R. Evett and M. D. Lazar. 2007. Canopy temperature depression sampling to assess grain yield and genotypic differentiation in winter wheat. *Crop Sci.* 47: 1518-1529.
- Baque M. A., M. A. Karim, A. Hamid and H. Tetsushi. 2006. Effects of fertilizer potassium on growth, yield and nutrient uptake of wheat (*Triticum aestivum* L.) under water stress conditions. *South Pacific Studies.* 27(1): 25-35.

- Baque M. A. 2003. Potassium induced changes in the physiology of wheat plants (*Triticum aestivum* L.) under water stress conditions. M.S. Thesis, Dept. of Agron., BSMRAU, Gazipur-1706, Bangladesh.
- Barrs H. D. and P. E. Weatherley. 1962. A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Aust. J. Biol. Sci.* 24: 519-570.
- Barua K. K., S. S. Bhuyan, P. T. J. Ghosh and A. K. Pathak. 1998. Response of rice (*Oryza sativa* L.) genotypes to moisture stress imposed at seedling stage. *Indian J. Plant Physiol.* 3: 181-184.
- Barutcular C., M. Yilderim, M. Koc, C. Akinci, I. Toptas, O. Albayrak, A. Tanrikulu, and A. El Sabagh. 2016. Evaluation of spad chlorophyll in spring wheat genotypes under different environments. *Fresenius Environ. Bull.* 25(4): 1258-1266.
- Baser I., S. Sehirali, H. Orta, T. Erdem, Y. Erdem and O. Yorgancilar. 2004. Effect of different water stresses on the yield and yield components of winter wheat. *Cereal Res. Commun.* 32(2): 217-223.
- Bates L. S. 1973. Rapid determination of free proline for water-stress studies. *Plant Soil.* 39:205-207.
- Bayoumi T. Y., M. H. Eid and E. M. Metwali. 2008. Application of physiological and biochemical indices as a screening technique for drought tolerance in wheat genotypes. *Afr. J. Biotech.* 7: 2341-2352.
- Bazzaz M. M., A. A. Mahmud and M. S. A. Khan. 2014. Effects of water stress on morpho-phenological changes in wheat genotypes. *Global J. Sci. Frontier Res.: D Agric. Vete.* 4(10): 1-9.
- Bazzaz M. M., Q. A. Khaliq, M. A. Karim, A. Al-Mahmud and M. S. A. Khan. 2015. Canopy temperature and yield based selection of wheat genotypes for water deficit environment. *Open Access Libr. J.* 2: e1917.
- Belderok B., H. Mesdag and D. A. Donner. 2000. Bread-Making Quality of Wheat: A century of breeding in Europe. Springer Science & Business Media, New York, NY 10013-1578, USA p. 3.

- Beltrano J. and M. G. Ronco. 2008. Improved tolerance of wheat plants (*Triticum aestivum* L.) to drought stress and re-watering by the arbuscular mycorrhizal fungus *Glomus claroideum*: Effect on growth and cell membrane stability. *Braz. J. Plant Physiol.* 20: 29-37.
- Beltrano J., M. G. Ronco and A. C. Arango. 2006. Soil drying and rewatering applied at three grain developmental stages affect differentially growth and grain protein deposition in wheat (*Triticum aestivum* L.) *Braz. J. Plant Physiol.* 18(2): 341-350.
- Bentahar S., D. Abdelhamid and Y. Nadia. 2015. Morpho-physiological markers associated with water use efficiency in Algerian durum wheat at different water regimes. *Int. J. Adv. Res.* 3(10): 875-889.
- Beringer H. 1982. Potassium requirement of tropical crops and physiological functions of potassium. In: Phosphorus and potassium in the tropics. The Malaysian Soc. Soil Sci., Malaysia. pp. 271-283.
- Bhatt R. M. and N. K. Srinivasa-Rao. 2005. Influence of pod load on response of okra to water stress. *Indian J. Plant Physiol.* 10: 54-59.
- Bijanazadeh E. and Y. Emam 2010. Effect of defoliation and drought stress on yield components and chlorophyll content of wheat. *Pakistan J. Biol. Sci.* 13: 699-705.
- Black C. A. 1965. Methods of soil analysis. Part II. Americ. Soc. Agron. Inc. Publisher. Madison Wisconsin, USA.
- Blum A. 1997. Constitutive traits affecting plant performance under stress. 1997.
- Blum A. 2005. Mitigation of drought stress by crop management. http://www.plantstress.com/articles/drought_m7drought_m.htm.
- Blum A. and C. Y. Sullivan. 1986. The comparative drought resistance of landraces of sorghum and millet from dry and humid regions. *Ann. Bot.* 57: 838-846.
- Blum A., S. Ramaiah, E. T. Kanemasu and G. M. Paulsen. 1990. Wheat recovery from drought stress at the tillering stage of development. *Field Crops Res.* 24: 67-85.
- Blum A. and A. Ebercon. 1981. Cell membrane stability as a measure of drought and heat tolerance in wheat. *Crop Sci.* 21: 43-47.

- Blum A., N. Klueva and H. T. Nguyen. 2001. Wheat cellular thermo-tolerance is related to yield under stress. *Euphytica*. 117: 117-123.
- Bogale A. and K. Tesfaye. 2011. Response of Ethiopian durum wheat genotypes to water deficit induced at various growth stages .*Afri. Jour. Plant Sci.* 5(15): 855-861.
- Bogale A., K. Tesfaye and T. Geleto. 2011. Morphological and physiological attributes associated to drought tolerance of Ethiopian durum wheat genotypes under water deficit condition. *J. Biodiv. Environ. Sci.* 1: 22-36.
- Bohnert H. J., D. E. Nelson and R. G. Jensen. 1996. Adaptations to environmental stresses. *Plant Cell*. 7: 1099-1111.
- Bojovic B. and J. Stojanovic. 2005. Chlorophyll and carotenoid content in wheat cultivars as a function of mineral nutrition. *Arch. Biol. Sci.* 57(4): 283-290.
- Bota J., H. Medrano and J. Flexas. 2004. Is photosynthesis limited by decreased rubisco activity and RuBP content under progressive water stress? *New Phytol.* 162: 671-681.
- Botwright T. L., A. G. Condon, G. J. Rebetzke and R. A. Richards. 2002. Field evaluation of early vigour for genetic improvement of grain yield in wheat. *Aust. J. Agric. Res.* 53: 1137-1145.
- Bray E. A. 2002. Classification of genes differentially expressed during water-deficit stress in *Arabidopsis thaliana*: an analysis using microarray and differential expression data. *Ann. Bot.* 89: 803-811.
- Budiman N. and S. Nampo. 2015. Effect of water stress on growth, yield, proline and soluble sugars contents of Signal grass and Napier grass species. *American-Eurasian J. Sust. Agric.* 9(5): 14-21.
- Buttar G. S., C. J. Singh, M. S. Ahuja and K. S. Saini. 2005. Canopy temperature: A method to estimate plant water stress and scheduling irrigation in cotton and wheat. *Jour. Agric. Physics.* 5(1): 79-83.
- Cakmak I. 2005. The role of potassium in alleviating detrimental effects of abiotic stresses in plants. *J. Plant Nutr. Soil Sci.* 168: 521-530.

- Chachar M. H., N. A. Chachar, Q. Chachar, S. M. Mujtaba, S. Chachar and Z. Chachar. 2016. Physiological characterization of six wheat genotypes for drought tolerance. *Int. J. Res.* 4(2): 184-196.
- Chandler S. S. and T. K. Singh. 2008. Selection criteria for drought tolerance in spring wheat (*Triticum aestivum* L.). Series: Coping with wheat in a changing environment abiotic stresses. The 11th Int. Wheat Gen. Symp. Proce. Appels R., R. Eastwood, E. Lagudah, P. Langridge and M. Mackay (Eds.). Lynne, Sydney University Press, Australia. pp. 1-3.
- Chandrasekar V., R K. Sairam, and G. C. Srivastava. 2000. Physiological and biochemical responses of hexaploid and tetraploid wheat to drought stress. *J. Agron. Crop Sci.* 185: 219-227.
- Chaturvedi B. K. and R. R. Gupta 1995. Selection parameters for some grain and quality attributes in spring wheat (*Triticum aestivum* L.). *Agric. Sci. Digest.* 15(4): 186-190.
- Chaves M. M. 1991. Effects of water deficits on carbon assimilation. *J. Exp. Bot.* 42: 1-16.
- Chaves M. M. and M. M. Oliveira. 2004. Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. *J. Exp. Bot.* 55: 2365-2384.
- Cheema M. A., M. Iqbal, Z. A. Cheema, Basharatullah and M. Rafique. 1999. Respose of hybrid maize to potassium. *Intl. J. Agric. Bio.* 1:267-269.
- Chorfi A. and K. Taibi. 2011. Biochemical screening for osmotic adjustment of wheat genotypes under drought stress. *Tropicultura.* 29(2): 82-87.
- Choudhury A. K. 2009. Water stress tolerance of French bean (*Phaseolus vulgaris* L.). Ph.D. Dissertation, Department of Agronomy, BSMRAU, Salna, Gazipur-1706. Bangladesh.
- Chowdhury M. K. 2012. Responses of wheat genotypes to water deficit stress tolerance. M.S. Thesis, Department of Crop Physiology and Ecology, HSTU, Dinajpur, Bangladesh.
- Clark J. M. and T. N. McCaig. 1982. Evaluation of techniques for screening for drought resistance in wheat. *Crop Sci.* 22: 503-506.
- Clarke J. M., De Pauw R. M. and Townley-Smith T. M. 1992. Evaluation of methods for quantification of drought tolerance in wheat. *Crop Sci.* 32: 728-732.

- Clément C., L. Chavant, M. Burrus and J. C. Audran. 1994. Anther starch variations in *Lilium* during pollen development. *Sex. Plant Reprod.* 7: 347-356.
- Cobb J. N., G. DeClerck, A. Greenberg, R. Clark and S. McCouch. 2013. Next-generation phenotyping: Requirements and strategies for enhancing our understanding of genotype-phenotype relationships and its relevance to crop improvement. *Theor. Appl. Genet.* 126: 867-887.
- Collaku A. 1989. Analysis of the structure of correlations between yield and some quantitative traits in bread wheat. *Buletinii Shkencave Bujqe'sore.* 28: 137-144.
- Colom M. R. and C. Vazzana. 2003. Photosynthesis and PSII functionality of drought-resistant and drought sensitive weeping love grass plants. *Environ. Exp. Bot.* 49: 135-144.
- Copeland L. O. 1976. Principles of seed science and technology. Burgess Pub. Com., minneapolis, Minnesota, USA. pp. 164-165.
- Cornic C. and A. Massacci. 1996. Leaf photosynthesis under drought stress. In: *Photosynthesis and Environment*. Baker N. R. (Eds). Kluwer Acad. Publs. pp. 347-366.
- Cornic G. 2000. Drought stress inhibits photosynthesis by decreasing stomatal aperture not by affecting ATP synthesis. *Trends Plant Sci.* 5: 187-188.
- Dadbakhsh A., A. Yazdansepar, and M. Ahmadizadeh. 2011. Study drought stress on yield of wheat (*Triticum aestivum* L.) genotypes by drought tolerance indices. *Adv. Envid. Biol.* 5(7):1804-1810.
- Damm S., B. Hofmann, A. Gransee and O. Christen. 2013. Zur Wirkung von Kalium auf ausgewählte bodenphysikalische Eigenschaften und den Wurzeltiefgang landwirtschaftlicher Kulturpflanzen. *Arch. Agron. Soil Sci.* 59: 1-1.
- Damon P. M. and Z. Rengel 2007. Wheat genotypes differ in potassium efficiency under glasshouse and field conditions. *Aust. J. Agric. Res.* 58: 816-823.
- Dastfal M. and M. Ramazanpoor. 2000. Assessment of drought tolerance of wheat cultivar in climatic condition in Darab. *Collection Article Abstract of Iranian Agronomy and Plant Breeding Conference*, Babolsar, Mazandaran, Iran. p. 250.

- Dat J., S. Vandenabeele, E. Vranov'a, M. van Montagu, D. Inz'e, and F. van Breusegem. 2000. Dual action of the active oxygen species during plant stress responses. *Cellular Mole. Life Sci.* 57(5): 779-795.
- Datta J. K., T. Mondal, A. Banerjee and N. K. Mondal. 2011. Assessment of drought tolerance of selected wheat cultivars under laboratory condition. *J. Agril. Tech.* 7: 383-393.
- Davies W. J. and J. Zhang. 1991. Root signals and the regulation of growth and development of plants in drying soil. *Ann. Review Plant Physio. Plant Mole. Biol.* 42(1): 55-76.
- De La Guardia M. D. and M. Benlloch. 1980. Effects of potassium and gibberellic acid on stem growth of whole sunflower plants. *Physiolog. Planta.* 49: 443-448.
- De Souza P. I., D. B. Egli and W. P. Bruening. 1997. Water stress during seed filing and leaf senescence in soybean. *Agron. J.* 89: 807-812.
- Delfine S., R. Tognettir, F. Loreto and A. Alvino. 2002. Physiological and growth responses to water stress in field grown bell pepper (*Capsicum annuum* L.). *J. Hort. Sci. Biotechnol.* 77(6): 697-704.
- Denčić S., R. Kastori, B. Kobiljski and B. Duggan. 2000. Evaporation of grain yield and its components in wheat cultivars and land races under near optimal and drought conditions. *Euphytica.* 1: 43-52.
- Deora V. S., M. A. Shah, A. R. Joshi and A. Joshi. 2001. Effect of moisture stress on wheat genotypes. *Crop Res. Hisar.* 21(1): 24-26.
- Dhanda S. S., G. S. Sethi and R. K. Beh. 2004. Indices of drought tolerance in wheat genotypes at early stages of plant growth. *J. Agron. Crop Sci.* 190(1): 6-12.
- Dhindsa R. A., P. Plumb-Dhindsa and T. A. Thorpe. 1981. Leaf senescence: Correlated with increased permeability and lipid peroxidation, and decreased levels of superoxide dismutase and catalase. *J. Exp. Bot.* 126: 93-101.
- Digby P., N. Galway and P. Lane. 1989. *Genstat 5: A second course.* Oxford Sci. Publication, Oxford. pp. 103-108.

- Dodig D., M. Zoric', M. Jovic', V. Kandic', R. Stanisavljevic' and G. Šurlan-momirovic. 2015. Wheat seedlings growth response to water deficiency and how it correlates with adult plant tolerance to drought. *J. Agril. Sci.* 153: 466-480.
- Dodig D., S. Quarrie, S. Stanković, S. Milijić and S. Denčić. 2010. Characterizing wheat genetic resources for responses to drought stress. <http://www.wg-crop.icidonline.org/38doc.pdf>.
- Dorion S., S. Lalonde and H. S. Saini. 1996. Induction of male sterility in wheat by meiotic-stage water deficit is preceded by a decline in invertase activity and changes in carbohydrate metabolism in anthers. *Plant Physiol.* 111: 137-145.
- Dubcovsky J. and J. Dvorak. 2007. Genome plasticity a key factor in the success of polyploidy wheat under domestication. *Sci.* 316: 1862-1866.
- Duggan B. L. and D. B. Fowler. 2006. Yield structure and kernel potential of winter wheat on canadian prairies. *Crop Sci.* 46: 1479-1487.
- Dulai S., I. Molnar, J. Pronay, A. Csernak, R. Tarnai and M. Molnár-Láng. 2006. Effects of drought on photosynthetic parameters and heat stability of PSII in wheat and in *Aegilops* species originating from dry habitats. *Acta Biologica Szegediensis.* 50: 11-17.
- Edmeades C. O., S. C. Chapman, J. Balanus, M. Banziger, and H. R. Lafitte. 1994. Recent evaluation of progress in selection for drought tolerance. *Tropi. Afri. Regional Maize Conf.* Harare, Zimbabwe.
- Ehdaie B., G. A. Alloush, M. A. Madore and J. G. Waines. 2006. Genotypic variation for stem reserves and mobilization in wheat: I. Postanthesis changes in internode dry matter. *Crop Sci.* 46: 735-746.
- EL Sabagh A., C. Barutçularand M. S. Islam. 2017. Relationships between stomatal conductance and yield under deficit irrigation in maize (*Zea mays* L.). *J. Expt. Bio. Agril. Sci.* 5(1): 14-20.
- EL-Abady M., S. E. Seadh, A. El-ward, A. Ibrahim and A. A. M. EL-Emam. 2009. Irrigation withholding and potassium foliar application effects on wheat yield and quality. *Int. J. Sustain. Crop Prod.* 4(4): 33-39.

- El-Ashry M. Soad and M. A. El-Kholy. 2005. Response of wheat cultivars to chemical desiccants under water stress conditions. *J. Appl. Sci. Res.* 1(2): 253-262.
- El-Basyoni I., M. Saadalla, S. Baenziger, H. Bockelman and S. Morsy. 2017. Cell membrane stability and association mapping for drought and heat tolerance in a worldwide wheat collection. *Sustainability*. 1606 (9): 1-16.
- El-Hadi A. H. A., K. M. Ismail and M. A. El-Akahawy. 1997. Effect of potassium on the drought resistance of crops in Egyptian conditions. In: Johnston A. E. (Ed.). Food security in the WANA region, the essential need for balanced fertilization, Int. Potash Ins., Basel Switzerland. pp. 328-336.
- Elhafid R., D. H. Smith. M. Karrou and K. Samir. 1998. Morphological attributes associated with early season drought tolerance in spring wheat in a Mediterranean environment. *Euphy*. 101: 273-282.
- El-Kholy M. A. and M. S. Gaballah. 2005. Productivity of wheat cultivars as affected by seeding methods and reflectant application under water stress condition. *J. Agron.* 4: 23-30.
- El-Sabbagh A., S. A. Abd El-Hafez, A. Z. El-Bably and E. I. Abou-Ahmed. 2002. Response of wheat crop to irrigation intervals and foliar application of potassium. *J. Agric. Res. Tanta Univ.* 28(4): 525-538.
- El-Tayeb M. 2006. Differential response of two *Vicia faba* cultivars to drought: growth, pigments, lipid peroxidation, organic solutes, catalase and peroxidase activity. *Acta Agronomica Hungarica*. 54(1):25-37.
- Epstein E. 1972. Mineral Nutrition of Plants: Principles and Perspectives. Wiley, New York, USA.
- Erickson I. J., D. L. Ketring and J. F. Stone. 1991. Response of internal tissue water balance of peanut to soil water. *J. Agron.* 72: 73-80.
- Esmail R. M., S. E. I. Eldessouky, S. A. Mahfouze and I. S. EL-Demardash. 2016. Evaluation of new bread wheat lines (*Triticum aestivum* L.) under normal and water stress conditions. *Int. J. Chem. Tech. Res.* 9(5): 89-99.

- Evans L. T., I. F. Wardlaw and R. A. Fischer. 1975. Wheat. In: Crop physiology. Cambridge University Press., Cambridge, UK. pp. 101-149.
- Fábián A., K. Jäger, M. Rakszegi and B. Barnabás. 2011. Embryo and endosperm development in wheat (*Triticum aestivum* L.) kernels subjected to drought stress. Plant Cell Reports. 30: 551-563.
- FAO (Food and Agriculture Organization), 2010. Bioenergy and Food Security. Food and Agriculture Organization, Rome, Italy.
- FAO (Food and Agriculture Organization), 2013. Food and Agricultural Organization of the United Nations (FAO), FAO statistical database. 2013. Available: <http://faostat.fao.org>.
- FAO and UNDP (Food and Agricultural Organization/United Nations Development Programme). 1988. Land resources appraisals of Bangladesh for agricultural development. Agro-ecological regions of Bangladesh. Report No. 2. Report prepared for the Govt. People's Repub. Bangladesh by the FAO of United Nations, United Nations Development Programme. BGD/81/035, pp. 212-221.
- FAOSTAT (Food and Agriculture Organization Statistics), 2016. FAOSTAT database of World Agriculture, 2006. Food and Agriculture Organization, Statistics division. Rome, Italy.
- Fard A. K. and S. Sedaghat. 2013. Evaluation of drought tolerance indices in bread wheat recombinant inbred lines. European J. Exp. Biol. 3(2): 201-204.
- Farhad M. S., A. M. Babak, Z. M. Reza, R. S. M. Hassan and T. Asshin. 2011. Response of proline, soluble sugars, photosynthetic pigments and antioxidant enzyme in potato (*Solanum tuberosum* L.) to different irrigation regimes in greenhouse condition. Aust. J. Crop Sci. 5(1): 55-60.
- Farooq J., I. Khaliq, M. A. Ali, M. Kashif, Q. Ali, A. Rehman, M. Naveed, W. Nazeer and A. Farooq. 2011. Inheritance pattern of yield attributes in spring wheat at grain filling stage under different temperature regimes. Aust. J. Crop Sci. 5(13): 1745-1753.
- Farooq M., A. Wahid, N. Kobayashi, D. Fujita and S. Basra. 2009. Plant drought stress: Effects, mechanisms and management. Agron. Sustain. Dev. 29: 185-212.

- Farooq M., A. Wahid, N. Kobayashi, D. Fujita and S. M. A. Basra. 2009. Plant drought and molecular approaches. Haworth Press, New York, USA. pp. 23-25.
- Farquhar G. D., S. Von Caemmerer and J. A. Berry. 2001. Models of photosynthesis. *Plant Physiol.* 125: 42-5.
- Farshadfar E., M. Farshadfar and F. Moradi. 2011. Screening agronomic, physiological and metabolite indicators of drought tolerance in bread wheat (*Triticum aestivum* L.). *Am. J. Sci. Res.* 38: 88-96.
- Farshadfar E., M. Ghasemi and F. Rafii. 2014. Evaluation of physiological parameters as a screening technique for drought tolerance in bread wheat. *J. Biodiv. Envir. Sci.* 4: 175-186.
- Farshadfar E., M. Qaitoli and R. Haghparast. 2008. Chromosomal localization of the genes controlling agronomic and physiological indicators of drought tolerance in barley using disomic addition lines. *Asian J. Plant Sci.* 7(6): 536-543.
- Farshadfar E., S. Jalali and M. Saeidi. 2012. Introduction of a new selection index for improvement of drought tolerance in common wheat (*Triticum aestivum* L.). *Euro. J. Exp. Biol.* 2: 1181-1187.
- Faye I., O. Diouf, A. Guissé, M. Sène and N. Diallo. 2006. Characterizing root responses to low phosphorus in pearl millet (*Pennisetum glaucum* L. R. Br.). *Agron. J.* 98: 1187-1194.
- Fayez K. A. and S. A. Bazaid. 2013. Improving drought and salinity tolerance in barley by application of salicylic acid and potassium nitrate. *J. Saudi Soc. Agril. Sci.* 13: 45-55.
- Feldman M. 2001. Origin of cultivated wheat. In: Bonjean A. P. and W. J. Angus. (eds). *The world wheat book: a history of wheat breeding*. Lavoisier Publishing, Paris, France. pp. 3-56.
- Feldman M. and E. R. Sears. 1981. The wild gene Resources of wheat. *Sci. Am.* 244: 102-112.
- Fernandez G. C. J. 1992. Effective selection criteria for assessing stress tolerance. In: *Proc. of the Int. Sympo. on Adaptation of vegetables and other food crops in temperature and water stress*. Kuo C.G. (Ed.). AsianVegetable Research and Development Centre, Tainan, Taiwan pp. 257-270.

- Fischer R. A., D. Rees, K. D. Sayre, Z. M. Lu, A. G. Condon and A. Larque Saavedra. 1998. Wheat yield progress associated with higher stomatal conductance and photosynthetic rate, and cooler canopies. *Crop Sci.* 38: 1467-1475.
- Fisher R. A. and R. Maurer. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. *Aust. J. Agric. Res.* 29: 897-907.
- Flexas J., J. Bota, F. Loreto, G. Cornic and T. D. Sharkey. 2004. Diffusive and metabolic limitations to photosynthesis under drought and salinity in C₃ plants. *Plant Biol.* 6: 269-279.
- Foyer C.H., H. Vanacker, L. D. Gomez and J. Harbinson. 2002. Regulation of photosynthesis and antioxidant metabolism in maize leaves at optimal and chilling temperatures: review. *Plant Physiol. Biochem.* 40: 659-668.
- Frederick J. R., T. J. Wooley, J. D. Hesketh and D. B. Peters. 1991. Seed yield and argonomic traits of old and modern soybean cultivars under irrigation and soil water deficit. *Field Crops Res.* 27: 71-82.
- Fusheng L. 2006. Potassium and water interaction. International workshop on soil potassium and K fertilizer management. Agric. Col., Guangxi Univ., China.
- Galle A., J. Csiszar, I. Tari and L. Erdei. 2002. Changes in water and chlorophyll fluorescence parameters under osmotic stress in wheat cultivars. *Acta Biologica Szegediensis.* 46(3-4): 85-86.
- Gáspár L., C. Pálma, F. Fodor, B. Hoffmann, P. Nyitrai, K. István and É. Sárvári. 2005. Greenhouse testing of new wheat cultivars compared to those with known drought tolerance. *Acta Biologica Szegediensis.* 49(1-2): 97-98.
- Gebbing T., H. Schnyder and W. Kühbauch. 1999. The utilization of pre-anthesis reserves in grain filling of wheat. Assessment by steady-state ¹³CO₂/¹²CO₂ labelling. *Plant Cell Env.* 22: 851-858.
- Gechev T. S., C. Dinakar, M. Benina, V. Toneva, and D. Bartels. 2012. Molecular mechanisms of desiccation tolerance in resurrection plants. *Cell. Mol. Life Sci.* 69: 3175-3186.

- Gething P. A. 1990. Potassium and water relationships. In: Potash facts. IPI, Bern, Switzerland.
- Ghazal H. M., M. Z. Wassouf, M. M. Nachit and A. A. Iaradat. 1998. Yield and yield components of durum wheat as influenced by irrigation and nitrogen fertilization. Proc. 3rd Int. Triticeae Symp, Aleppo., Syria, 4-8 May, 1998. pp. 445-449.
- Ghobadi M., S. Khosravi, D. Kahrizi and F. Shirvani. 2011. Study of water relations, chlorophyll and their correlations with grain yield in wheat (*Triticumaestivum* L.) genotypes. World Acad. Sci. Engin. Tech. 78: 582-585.
- Gholamin R. and K. Majid. 2010. Study of some physiological responses of drought stress in hexaploid and tetraploid wheat genotypes in Iran. Middle-East J. Sci. Res. 6(3): 246-250.
- Gibson T. S., J. Spiers and C. J. Brady. 1984. Salt tolerance in plants. II. *In vitro* translation of m-RNAs from salt-tolerant and salt-sensitive plants on wheat germ ribosomes: responses to ions and compatible solutes. Plant Cell Environ. 7: 579-587.
- Giunta F., R. Motzo and M. Deidda. 1995. Effects of drought on leaf area development, biomass production and nitrogen uptake of durum wheat grown in a Mediterranean environment. Aust. J. Agric. Res. 46: 99-111.
- González Á. and L. Ayerbe. 2011. Response of coleoptiles to water deficit: growth, turgor maintenance and osmotic adjustment in barley plants (*Hordeum vulgare* L.). Agril. Sci. 2: 159-166.
- Goudarzi M. and H. Pakniyat. 2008. Evaluation of wheat cultivars under salinity stress based on some agronomic and physiological traits. J. Agric. Soci. 4: 35-38.
- Graan T. and J. S. Boyer. 1990. Very high CO₂ partially restores photosynthesis in sunflower at low leaf water potentials. Planta. 181: 378-384.
- Greenwood D. J. and T. V. Karpinets. 1997. Dynamic model for the effects of K fertilizer on crop growth, K uptake and soil K in arable cropping:1-Description of the model. Soil Use Managt. 13: 178-183.
- Grover A., A. Kapoor, D. Kumar, H. E. Shashidhar and S. Hittalmani. 2004. Genetic improvement for abiotic stress responses. In: Plant Breeding-Mendelian to Molecular

- Approaches. Jain H. K. and M. C. Kharkwal (Ed.). Narosa Publishing House, New Delhi, India. pp. 167-193.
- Grzebisz W., R. Musolf, W. Szczepaniak and P. Barłóg. 2009. Effect of artificially imposed water shortages against a background of potassium supply on dry matter, nitrogen and potassium accumulation by winter wheat. *Fertilizers Fertilization* 34: 40-52.
- Grzesiak M. T., S. K. A., I. Marcin', F. Janowiak, A. Rzepka and T. Hura. 2012. The relationship between seedling growth and grain yield under drought conditions in maize and triticale genotypes. *Acta Physiologiae Plantarum*. 34: 1757-1764.
- Guan L. M., J. Zhao and J. G. Scandalios. 2000. Cis-elements and trans-factors that regulate expression of the maize Cat1 antioxidant gene in response to ABA and osmotic stress: H₂O₂ is the likely intermediary signaling molecule for the response. *Plant J.* 22(2): 87-95.
- Guerfel M., O. Baccouri, D. Boujnah, W. Chaibi and M. Zarrouk. 2009. Impacts of water stress on gas exchange, water relations, chlorophyll content and leaf structure in the two main Tunisian olive (*Olea europaea* L.) cultivars. *Sci. Hort.* 119(3): 257-263.
- Gunes A., A. Inal, M. Adak, E. Bagci, N. Cicekand and F. Eraslan. 2008. Effect of drought stress implemented at pre-or post-anthesis stage on some physiological parameters as screening criteria in chickpea cultivars. *Russian J. Plant Physiol.* 55(1): 59-67.
- Guoxiong C., T. Krugman, T. Fahima, A. B. Korol and E. Nevo. 2002. Comparative study on morphological and physiological traits related to drought resistance between xeric and mesic *Hordeum spontaneum* lines in Israel. *Barley Genetics Newsletter*. 32: 22-33.
- Gupta N. K., S. Gupta and A. Kumar. 2001. Effect of water stress on physiological attributes and their relationship with growth and yield of wheat cultivars at different stages. *J. Agron. Crop Sci.* 186: 55-62.
- Guttieri M. J., J. C. Stark, K. Brien and E. Souza. 2001. Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. *Crop Sci.* 41: 327-335.
- Hafid R. E., D. H. Smith, M. Karrou and K. Samir. 1998. Morphological attributes associated with early-season drought tolerance in spring durum wheat in a Mediterranean environment. *Euphytica*. 101: 273-282.

- Hagyo A., C. S. Farkas, A. Lukacs, Sz.Csorba, and T. Nemeth. 2007. Water cycle of different wheat genotypes under different water stresses. *Cereal Research Communications*. 35: 437-440.
- Hair J. R., R. E. Anderson, R. L. Tatham, and W .C. Black. 1995. *Multivariate data analysis with readings* (4th ed.) Prentice- Hall, Englewood Cliffs, New Jersey, USA. p. 498.
- Hammad S. A. R. and O. A. M. Ali. 2014. Physiological and biochemical studies on drought tolerance of wheat plants by application of amino acids and yeast extract. *Ann. Agril. Sci.* 59(1): 133-145.
- Hanif R., Naeem-ud-Din, A. Subhani, G. Rabbani, M. Tariq, M. S. Iqbal and M. Koukab. 2013. Performance based evaluation of different genotypes of Mungbean (*Vigna radiata*) under rainfed conditions of Chakwal. *J. Agri. Food Appl. Sci.* 1: 13-15.
- Hare P. D. and W. A. Cress. 1997. Metabolic implications of stress-induced proline accumulation in plants. *Plant Growth Regul.* 21: 79-102.
- Hare P. D., W. A. Cress and J. Van Staden. 1998. Dissecting the roles of osmolyte accumulation during stress. *Plant Cell Environ.* 21: 535-553.
- Hasan M. A., J. U. Ahmed, M. M. Bahadur, M. M. Haque and S. Sikder. 2007. Effect of late planting heat stress on membrane thermostability, proline content and heat susceptibility index of different wheat cultivars. *J. Natn. Sci. Foundation Sri Lanka*. 35(2): 109-117.
- Hashem A., M. N. A. Majumdar, A. Hamid and M. M. Hossain. 1998. Drought stress effects on seed yield, yield attributes, growth, cell membrane stability and gas exchange of synthesized *Brassica napus* L. *J. Agron. Crop Sci.* 180: 129-136.
- Hellevang K. J. 1995. Grain moisture content effects and management. Department of Agricultural and Biosystems Engineering, North Dakota State University. USA. <http://www.ag.ndsu.edu/pubs/plantsci/crops/ae905w.htm> (Last accessed on February 2, 2016).
- Hemantaranjan A. 2014. Heat Stress Responses and Thermo tolerance. *Adv. Plants Agric. Res.* 1: 1-10.

- Heun M., R. Schafer-Pregl, D. Klawan, R. Castagna, M. Accerbi, B. Borghi and F. Salamini. 1997. Site of einkorn wheat domestication identified by DNA fingerprinting. *Sci.* 278: 1312-1314.
- Hlavinka P., M. Trnkaa, D. Semerádova, M. Dubrovsky, Z. Zaluda and M. Mozyň. 2009. Effect of drought on yield variability of key crops in Czech Republic. *Agric. Forest Met.* 149: 431-442.
- Hoad S. P., G. Russell, M. E. Lucas and I. J. Bingham. 2001. The management of wheat, barley and oats root systems. *Adv. Agron.* 74: 193-246.
- Hoang T. B. and T. Kobata. 2009. Stay-green in rice (*Oryza sativa* L.) of drought-prone areas in desiccated soils. *Plant Prod. Sci.* 12: 397-408.
- Homayoun H., M. S. Daliri and P. Mehrabi. 2011. Study of PEG stress effects on wheat (*Triticum aestivum* L.) cultivars at germination stage. *Middle-East J. Sci. Res.* 9(1): 71-74.
- Homayouni H. and V. Khazarian. 2014. Effect of deficit irrigation on soluble sugars, starch and proline in three corn hybrid. *Indian J. Sci. Res.* 7(1): 910-917.
- Horton P., A. V. Ruban and R. G. Walters. 1996. Regulation of light harvesting in green plants. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 47: 655-684.
- Hsu S. Y., Y. T. Hsu and C. H. Kao. 2003. The effect of polyethylene glycol on proline accumulation in rice leaves. *Biol. Plant.* 46: 73-78.
- Hubbard R. M., M. G. Ryan, V. Stiller and J. S. Sperry. 2001. Stomatal conductance and photosynthesis vary linearly with plant hydraulic conductance in Ponderosa pine. *Plant Cell Env.* 24: 113-21.
- Hunt R. 1978. The fitted curve in plant growth studies. *Math and plant physio.* (Eds. Rose, D. A. and Edwards, D.A.C.). Aca. Press, London. pp. 283-298.
- Hurkman W. J., K. F. McCue, S. B. Altenbach, K. Anna, C. K. Tanaka, K. M. Kothari, E. L. Johnson, D. B. Bechtel, J. D. Wilson, O. D. Anderson, F. M. DuPont. 2003. Effect of temperature on expression of genes encoding enzymes for starch biosynthesis in developing wheat endosperm, *Plant Sci.* 164: 873-881.

- Hussain F., A. Khan, and M. Jamal. 1987. Response of wheat genotype to water stress. Sarhad. J. Agric. 3(4): 533-542.
- Hussain I., N. Akhtar and S. Hussain. 2007. Evaluation of weaning food “khitchri” incorporated with different levels of fish protein concentrate. J. Anim. Plant Sci. 17: 33-35.
- Hussain M., M. A. Malik, M., Farooq, M. Y. Ashraf and M. A. Cheema. 2008. Improving drought tolerance by exogenous application of glycinebetaine and salicylic acid in sunflower. J. Agron. Crop Sci. 194: 193-199.
- Ihsan M. Z., F. S. El-Nakhlawy, S. M. Ismail, S. Fahad and I. Daur. 2016. Wheat phenological development and growth studies as affected by drought and late season high temperature stress under arid environment. Frontiers Plant Sci. 7: 1-14.
- Imanparast F., A. Tobeh and A. Gholipouri. 2013. Potassium Humate effect on the drought stress in wheat. Intl.J. Agron. Plant Produc. 4(1): 98-103.
- Inamullah Z., A. Swati, Latif A. and Siraj-u-Din. 1999. Evaluation of lines for drought tolerance in wheat (*Triticum aestivum* L.). Scientific Khyber, 12(2): 39-48.
- Innes P., R. D. Blackwell, R. B. Austin and M. A. Ford. 1981. The effects of selection for number of ears on the yield and water economy of winter wheat. J. Agril. Sci. 97: 523-532.
- Iqbal M., K. Ahmad, I. Ahmad, M. Sadiq and M. Y. Ashraf. 1999. Yield and yield components of durum wheat (*Triticum durum* Desf.) as influenced by water stress at various growth stages. Pakistan J. Biol. Sci. 2: 1438-1440.
- Iqbal M., N. I., Raja, F. Yasmeen, M. Hussain, M. Ejaz and M. A. Shah. 2017. Impacts of Heat Stress on Wheat: A Critical Review. Adv. Crop Sci. Technol. 5: 1-9.
- IRRI (International Rice Research Institute) 2014. STAR (Statistical Tool for Agricultural Research).version 2.0.1. PBGB Division, Int. Rice Res. Ins, Los Baños, Laguna, Philippines.
- Iturbe Ormaetxe, I., P. R. Escuredo, C. Arrese-Igor and M. Becana. 1998. Oxidative damage in pea plants exposed to water deficit or paraquat. Plant Physiol. 116: 173-181.

- Izanloo A., A. G. Condon, P. Langridge, M. Tester and T. Schnurbusch. 2008. Different mechanisms of adaptation of cyclic water stress in two South Australian bread wheat cultivars. *J. Exp. Bot.* 59: 3327-3346.
- Jahanbin M. A., M. Roshdi and M. Zaefizadeh. 2012. Effects of osmotic stress on germination and germination indices of synthetic wheat. *Ann. Biol. Res.* 3(2): 995-999.
- Jajarmi V. 2009. Effect of water stress on germination indices in seven wheat cultivar. *World Aca. Sci., Eng. Tech.* 49: 105-106.
- Jamal M., M. S. Nazir, S. H. Shah and A. Nazir. 1995. Wheat response to water stress at different growth stages. I. Effect on earing, maturity and plant height. *J Plant Physiol.* 145: 363-366.
- Jamal M., M. S. Nazir, S. H. Shah and A. Nazir. 1996. Varietals rcspnse of wheat to water stress at different growth stages and effect on grain yield, straw yield, harvest index and protein content in grains. *Rachis.* 2: 38-45.
- Jantasuriyarat C., M. I. Vales, C. J. W. Watson and O. Riera-Lizarazu. 2004. Identification and mapping of genetic loci affecting the freethreshing habit and spike compactness in wheat (*Triticum aestivum* L.). *Theoretical and Applied Genetics.* 108: 261-273.
- Jatoi S. A., A. Javaid, M. Iqbal, O. U. Sayal, Masood M. S. and Siddiqui S.U. 2011. Genetic diversity in radish germplasm for morphological traits and seed storage proteins. *Pak. J. Bot.* 43: 2507-2512.
- Jatoi W. A., M. J. Baloch, M. B. Kumbhar, N. U. Khan and M. I. Kerio. 2011. Effect of water stress on physiological and yield parameters at anthesis stage in elite spring wheat cultivars. *Sarhad J. Agric.* 27: 332-339.
- Jenks M. A., P. M. Hasegawa and S. J. Mohan. 2007. *Advances in Molecular Breeding toward Drought and Salt Tolerant Crops*, Springer, Dordrecht. The Netherlands. p. 817.
- Ji X., B. Shiran, J. Wan, D. C. Lewis, C. L. D. Jenkins, A. G. Condon, R. A. Richards and R. Dolferus. 2010. Importance of pre-anthesis anther sink strength for maintenance of grain number during reproductive stage water stress in wheat. *Plant Cell Environ.* 33(6): 926-942.

- Jiang M. and J. Zhang. 2002. Water stress-induced abscisic acid accumulation triggers the increased generation of reactive oxygen species and up-regulates the activities of antioxidant enzymes in maize leaves. *J. Expt. Bot.* 53(379): 2401-2410.
- Jiang Y. and B. Huang. 2002. Protein alterations in tall fescue in response to drought stress and abscisic acid. *Crop Sci.* 42: 202-207.
- Jin J., G. Wang, X. Liu, X. Pan, S. J. Herbert and C. Tang. 2006. Interaction between phosphorus nutrition and drought on grain yield, and assimilation of phosphorus and nitrogen in two soybean cultivars differing in protein concentration in grains. *J. Plant Nutr.* 29: 1433-1449.
- Kameli A. and D. M. Loesel. 1993. Carbohydrates and water status in wheat plants under water stress. *New Pl. Phytol.* 125: 609-614.
- Kameli A. and D. M. Loesel. 1995. Contribution of sugars and other solutes to osmotic adjustment in wheat leaves under water stress. *J. Plant Physiol.* 145: 363-366.
- Karim A., A. Hamid and A. Lalic. 2000. Grain growth and yield performance of wheat under subtropical conditions: II. Effect of water stress at reproductive stage. *Cereal Res. Commun.* 1: 101-108.
- Kaur J., I. S. Sheoran and H. S. Nainawatee. 1988. Effect of heat stress on photosynthesis and respiration in a wheat mutant in photosynthesis. *Mole. Biol. Bioener.* 28: 297-303.
- Kaur K., A. K. Gupta and N. Kaur. 2007. Effect of water deficit on carbohydrate status and enzymes of carbohydrate metabolism in seedlings of wheat cultivars. *Indian J. Biochem. Biophysics.* 44: 223-230.
- Kavi-Kishor P. B., S. Sangam, R. N. Amrutha, P. Sri-Laxmi, K. R. Naidu, K. R. S. S. Rao, S. Rao, K. J. Reddy, P. Theriappan and N. Sreenivasulu. 2005. Regulation of proline biosynthesis, degradation, uptake and transport in higher plants: Its implications in plant growth and abiotic stress tolerance. *Current Sci.* 88: 424-438.
- Kaydan D. and G. Yagmur. 2008. Germination, seedling growth and relative water content of shoot in different seed sizes of triticale under osmotic stress of water and NaCl. *Afri. J. Biotech.* 7(16): 2862-2868.

- Keyvan S. 2010. The effects of drought stress on yield, relative water content, proline, soluble carbohydrates and chlorophyll of bread wheat cultivars. *J. Animal Plant Sci.* 8(3): 1051-1060.
- Khakwani A. A., M. D. Dennett and M. Munir. 2011a. Drought tolerance screening of wheat varieties by inducing water stress conditions. *J. Sci. Technol.* 33: 135-142.
- Khakwani A. A., M. D. Dennett and M. Munir. 2011b. Early growth response of six wheat varieties under artificial osmotic stress condition. *Pak. J. Agri. Sci.* 48(2): 121-126.
- Khakwani A. A., M. D. Dennett, M. Munir and M. Abid. 2012a. Growth and yield response of wheat varieties to water stress at booting and anthesis stages of development. *Pak. J. Bot.* 44(3): 879-886.
- Khakwani A. A., M. D. Dennett, M. Munir and M. S. Baloch. 2012b. Wheat yield response to physiological limitations under water stress condition. *The J. Anim. Plant Sci.* 22(3): 773-780.
- Khalesro S. and M. Aghaalkhani. 2006. Effect of salinity and water Deficit stress on seed germination. *Pajouhesh and Sazandegi.* 77: 153-163 (in Persian).
- Khan A. H., M. Y. Ashraf and A. R. Azmi. 1993. Osmotic adjustment in wheat: A response to water stress. *Pakistan J. Sci. Ind. Res.* 36(4): 151-155.
- Khan A. J., F. Azam, A. Ali, M. Tariq and M. Amin. 2005. Inter-relationship and path co-efficient analysis for biometric traits in drought tolerant wheat (*Triticum aestivum* L.). *Asian J. Plant Sci.* 4(5): 540-543.
- Khan M. B., N. Hussain and M. Iqbal. 2001. Effect of water stress on growth and yield components of maize variety YHS 202. *J. Res. Sci.* 12(1): 15-18.
- Khan M. H., M. M. Ali, S. R. Vhuiyan, and F. Mahmud. 2013. Genetic divergence in rapeseed-mustard (*B. rapa* L.). *Bangladesh J. Agric. Res.* 38(3): 417-423.
- Khan N. and F. N. Naqvi. 2011. Effect of water stress in bread wheat hexaploids. *Current. Res. J. Bio. Sci.* 3: 487-498.
- Khan N., M. Qasim, S. Ali and N.S. Kisana. 2004. Genotypic variation in wheat genotypes under agroclimatic condition of Kaghan valley. *Asian J. Plant Sci.* 3: 569-570.

- Khan S. U, A. Bano, U. Jalal and A. R. Gurmani. 2012. Absciscic acid and salicylic acid seed treatment as potent inducer of drought tolerance in wheat (*Triticum aestivum* L.). Pak. J. Bot. 44: 43-49.
- Khan M. B., H. Ali and M. Asif. 2002. The response of different irrigation levels to growth and yield of different wheat (*Triticum aestivum* L.) cultivars. J. Res. Sci. 13: 71-75.
- Khanna-Chopra R., S. S. P. Rao, M. Maheswari, I. Xiabing and S. K. Shivshankar. 1994. Effect of water deficit on accumulation of dry matter, carbon and nitrogen in the kernel of wheat genotypes differing in yield stability. Ann. Bot. 74(5): 503-511.
- Khanzada B. S., A. Ala, M. Yasin Ashraf, M. U. Shirazi, S. M. Alam, R. Ansari, M. Ali, Mukhtiar Ali, S. M. Mujataba and M. A. Khan. 2001. Effect of water stress on yield and yield components of different Guar (*Cyamopsis tetragonaloba* L.) genotypes. Pak. J. Biol. Sci. 4 (4): 371-374.
- Khayantnezhad M., R. Gholamin, S. Jamaati-e-Somarin and R. Zabihi-e-Mahmooddabad. 2010. Study of water stress effect on wheat genotypes on germination indexes. Middle-East J. Sci. Res. 6(6): 657-660.
- Khondakar Z. H., A. Aslam, S. Rehman and T. H. Khan. 1983. Influence of soil moisture stress on yield, grain quality, availability and uptake of N, P and K by wheat. Int. J. Tropical Agric. 1(3): 211-220.
- Khosh K. A. and B. Ando. 1995. Effect of food environments, particularly sodium ion on the synthesis of chlorophyll and plant growth C₄. Abstracts Third Crop Science Congress of Iran. Tabriz University, Iran. p. 14.
- Kidambi S. P., A. G. Matches and T. P. Bolger. 1990. Mineral concentration in alfalfa and sainfoin as influenced by soil moisture level. Agron. J. 82: 229-236.
- Kiliç H. and T. Yağbasanlar. 2010. The effect of drought stress on grain yield, yield components and some quality traits of durum wheat (*Triticum turgidum* ssp. durum) cultivars. Not. Bot. Hort. Agrobot. Cluj. 38(1): 164-170.
- Kılıç H., İ. Özberk and F. Özberk. 1999. Bazı makarnalık buğday çeşitlerinin sıcak ve kurağa toleranslarının belirlenmesi. GAP I. Tarım Kongresi 26-28 Mayıs, s: 727-734, Şanlıurfa.

- Kirby E. J. M. 2002. Botany of wheat plant. In: Curtis B. C., S. Rajaram , H. Gomez Macpherson (eds). Bread wheat. Improvement and Production. Food and Agriculture Organisation, Rome, Italy.
- Knott C. A., D. A. V. Sanford and E. J. Souza. 2009. Genetic variation and the effectiveness of early-generation selection for soft winter wheat quality and gluten strength. *Crop Sci.* 49: 113-119.
- Kocheva K., P. Lambrev, G. Georgiev, V. Goltsev and M. Karabalieva. 2004. Evaluation of chlorophyll fluorescence and membrane injury in the leaves of barley cultivars under osmotic stress. *Bioelectro Chem.* 63: 121-124.
- Koonjul P. K., J. S. Minhas, C. Nunes, I. S. Sheoran, and H. S. Saini. 2005. Selective transcriptional down-regulation of anther invertases precedes the failure of pollen development in water-stressed wheat. *J. Exp. Bot.* 56: 179-190.
- Kramer P. J. 1983. Water relation of plants. Academic Press, Orlando. pp. 342-389.
- Kraus T. E., B. D. McKersie and R. A. Fletcher. 1995. Paclobutrazol induced tolerance of wheat leaves to paraquat may involve increased antioxidant enzyme activity. *J. Plant Physiol.* 145: 570-576.
- Krishnasamy V. and D. V. Seshu. 1990. Germination after accelerated aging and associated characters in rice varieties. *Seed Sci. Tech.* 18: 353-359.
- KulKarni M., T. Borseand and S. C. Czech. 2008. Mining anatomical traits: A novel modeling approach for increased water use efficiency under drought conditions in plants. *J. Genet. Plant Breed.* 44: 11-21.
- Kumbhar M. B., A. S. Larik, H. M. Hafiz and M. J. Rind. 1983. Interrelationship of polygenic traits affecting grain yield in *Triticum aestivum* L..Wheat Information Services. 57: 42-45.
- Lagerwerff J. V., G. Ogata, and H. E. Eagle. 1961. Control of osmotic pressure of culture solutions with polyethylene glycol. *Sci.* 133(3463): 1486-1487.
- Lalonde S., D.U. Beebe and H. S. Saini. 1997. Early signs of disruption of wheat anther development associated with the induction of male sterility by meiotic-stage water deficit. *Sex. Plant Reprod.* 10: 40-48.

- Larbi A. and A. Mekliche. 2004. Relative water content and leaf senescence as screening tools for drought tolerance in wheat. In: Cantero-Martinez C. and D. Cabina (Eds.). Mediterranean rainfed agriculture: Strategies for sustainability: Final Sem. Reg. Action Prog. on Rainfed Agriculture, 2-3 June 2003, Zaragoza, Spain. Options Mediterraneennes. Series A, Seminaires Mediterraneens. Paris: Intl. Centre Adv. Mediterranean Agron. Studies. 60: 193-196.
- Larher F., G. N. Rotival, P. Lemesle, M. Plasman and A. Bouchereau. 1996. The glycine betaine inhibitory effect on the osmoinduced proline response of rape leaf discs. *Plant Sci.* 113: 21-31.
- Lawlor D. W. and G. Cornic. 2002. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. *Plant Cell Environ.* 25: 275-294.
- Lee S. H., N. Ahsana, K. W. Lee, D. H. Kim, D. G. Lee, S. S. Kwak, S.Y. Kwon, T. H. Kim and B. H. Lee. 2007. Simultaneous over expression of both CuZn superoxide dismutase and ascorbate peroxidase in transgenic tall fescue plants confers increased tolerance to a wide range of abiotic stresses. *J. Plant Physiol.* 164: 1626-1638.
- Levitt J. 1980. Stress terminology. In: Turner N. C. and P. J. Kramer (eds). *Adaptation of plants to water and high temperature stress*. John Wiley Sons., New York, USA. pp. 439-473.
- Lindhauer M. G. 1989. The role of K^+ in cell extension, growth and storage of assimilates. In: Proc. 21st colloquium of IPI, held at Louvain-la-Neuve, Belgium, IPI, Bern. pp. 161-187.
- Liu E. K., X. R. Mei, C. R. Yan, D. Z. Gong and Y. Q. Zhang. 2016. Effects of water stress on photosynthetic characteristics, dry matter translocation and WUE in two winter wheat genotypes. *Agril. Water Manage.* 167: 75-85.
- Liu H. S. and F. M. Li. 2005. Root respiration, photosynthesis and grain yield of two spring wheat in response to soil drying, *Plant Growth Regul.* 46: 233-240.
- Liu W. J., S. Yuan, N. H. Zhang, T. Lei, H.G. Duan, H. G. Liang and H. H. Lin. 2006. Effect of water stress on photosystem II in two wheat cultivars. *Biol. Plant.* 50: 597-602.

- Lopes M. S. and M. P. Reynolds. 2010. Partitioning of assimilates to deeper roots is associated with cooler canopies and increased yield under drought in wheat. *Funct. Plant Biol.* 37: 147-156.
- Lopez C., G. M. Banowetz, C. J. Peterson, and W. E. Kronstad. 2003. Dehydrin expression and drought tolerance in seven wheat cultivars. *Crop Sci.* 43: 577-582.
- Losch R., C. R. Jensen and M. N. Anderson. 1992. Diurnal courses and factorial dependencies of leaf conductance and transpiration of differently potassium fertilized and watered field grown barley plants. *Plant Soil.* 140: 205-224.
- Lugoian C. and S. Ciulca. 2011. Evaluation of relative water content in winter wheat. *J. Hort. For. Biotechnol.* 15(2): 173-177.
- Mafakheri A., A. Siosemardeh, B. Bahramnejad, P. Struik and E. Sohrabi. 2010. Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Aust. J. Crop Sci.* 4: 580-585.
- Mahalanobis P.C. 1936. On the generalized distance in statistics. *Proc. Nat. Sci. Ind.* pp. 49-55.
- Mahamed M. B., E. Sarobol, T. Hordofa, S. Kaewrueng and J. Verawudh. 2011. Effects of soil moisture depletion at different growth stages on yield and water use efficiency of bread wheat grown in semi arid conditions in Ethiopia. *Kasetsart J. (Nat. Sci.).* 45: 201-208.
- Mahmood A., M. A. Mian, M. Ihsan, M. Ijaz, G. Rabbani and M. S. Iqbal. 2013. Chakwal-50: A high yielding and disease resistant wheat variety for rainfed region. *J. Anim. Plant Sci.* 23: 833-839.
- Majid S. A., R. Asghar and G. Murtaza. 2007. Potassium-calcium interrelationship linked to drought tolerance in wheat (*Triticumaestivum* L.). *Pak. J. Bot.* 39(5): 1609-1621.
- Makela P., M. Kontturi, E. Pehu and S. Somersalo. 1999. Photosynthetic response of drought-and salt-stressed tomato and turnip rape plants to foliar applied glycine betaine. *Physiol. Plant.* 105:45-50.

- Malek-Mohammadi M., A. Maleki, S. A. Siaddat and M. Beigzade. 2013. The effect of zinc and potassium on the quality yield of wheat under drought stress conditions. *Int. J. Agric. Crop Sci.* 6(16): 1164-1170.
- Malik M.A. and F. Hassan 2002. Response of wheat genotypes on suppression of weeds under rainfed conditions. *Pak. J. Agri., Agril. Engg. Vet. Sci.* 18(1-2): 18-22.
- Mamnouie E., R. Fotouhi Ghazvini, M. Esfahany and B. Nakhoda. 2006. The effects of water deficit on crop yield and the physiological characteristics of barley (*Hordeum vulgare* L.) varieties. *J. Agric. Sci. Technol.* 8: 211-219.
- Manivannan P., C. A. Jaleel, B. Sanker, A. Kishorekumar, R. Somassundaram, G. M. Alagu Lakshmanan and R. Panneerselvam. 2007. Growth, biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought stress. *Colloids Surf. Bionterfaces.* 59: 141-149.
- Maqsood M., M. A. Shehzad, A. Wahid and A. A. Butt. 2013. Improving drought tolerance in maize (*Zea mays*) with potassium application in furrow irrigation systems. *Int. J. Agric. Biol.* 15: 1193-1198.
- Maralian H., A. Ebadi, T.R. Didar and B. Haji-Eghrari. 2010. Influence of water deficit stress on wheat grain yield and proline accumulation rate. *African J. Agric. Res.* 5(4): 286-289.
- Maria A. M., A. A. Gendy, A. H. Selim and A. M. Abd El-All. 2008. Response of wheat plants grown under water stress in relation to Jasmonic acid. *Minufiya J. Agric. Res.*, 33(6): 1355-1375.
- Mark T. and B. Antony 2005. Abiotic stress tolerance in grasses from model plants to crop plants. *Plant Physiol.* 137: 791-793.
- Marschner P. 2012. Marschner's Mineral Nutrition of Higher Plants, 3rd Ed., Academic Press: London, UK. pp. 178-189.
- Marschner H. 1995. Mineral nutrition of higher plants. 2nd ed., Academic press, San Diego, California, USA.

- Martinez J. P., H. Silva, J. F. Ledent and M. Pinto. 2007. Effect of drought stress on the osmotic adjustment, cell wall elasticity and cell volume of six cultivars of common beans (*Phaseolus vulgaris* L.). *European J. Agron.* 26: 30-38.
- Martiniello P. and J. A. Teixeira da Silva. 2011. Physiological and bio agronomical aspects involved in growth and yield components of cultivated forage species in Mediterranean environments: A review. *European J. Plant Sci. Biotech.* 5(Special Issue 2): 64-98.
- Mbave Z. A. 2013. Water stress effects on growth, yield and quality of wheat (*Triticum aestivum* L.). Ph.D. thesis, M. Inst. Agrar: Agronomy, Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa.
- McCue R. F. and A. D. Hanson. 1990. Drought and salt tolerance: towards understanding and application. *Tibtech.* 8: 358-362.
- Menconi M. C., L. M. Sgherri, C. Pinzino and F. Navari-Izzo. 1995. Activated oxygen production and detoxification in wheat plants subjected to a water deficit programme. *J. Exp. Bot.* 46: 1123-1130.
- Mengel K. and E. A. Kirkby. 2001. *Principles of Plant Nutrition*. 5th ed., Kluwer Academic Publishers, P.O. Box 17, 3300 AA, Dordrecht, The Netherlands. p. 864.
- Merah O. 2001. Potential importance of water status traits for durum wheat improvement under Mediterranean conditions. *J. Agri. Sci.* 137: 139-145.
- Metwali E. M., M. H. Eid and T. Y. Bayoumi. 2011. Agronomical Traits and Biochemical Genetics Markers Associated with Salt Tolerance in Wheat Cultivars (*Triticum aestivum* L.). *Aust. J. Basic App. Sci.* 5(5): 174-183.
- Michel B. E. 1983. Evaluation of the Water Potentials of Solutions of Polyethylene Glycol 8000. *Plant Physiol.* 72: 66-70.
- Mickky B. M. and H. S. Aldesuquy. 2017. Impact of osmotic stress on seedling growth observations, membrane characteristics and antioxidant defense system of different wheat genotypes. *Egypt. J. Basic Appl. Sci.* 4: 47-54.

- Miller T. E. 1987. Systematics and evolution. In: Wheat Breeding. Chapter 1. Lupton F.G.H. (ed.). Chapman and Hall, London. pp. 1-30.
- Mirbahar A. A., G. S. Markhand, A. R. Mahar, S. A. Abro and N. A. Kanhar. 2009. Effect of water stress on yield and yield components of wheat (*Triticum aestivum* L.) varieties. Pak. J. Bot. 41(3): 1303-1310.
- Mirzaei A., R. Naseri and R. Soleimani. 2011. Response of different growth stages of wheat to moisture tension in a semiarid land. World Appd. Sci. J. 12(1): 83-89.
- Moaveni P. 2011. Effect of water deficit stress on some physiological traits of wheat (*Triticum aestivum*). Agril. Sci. Res. J. 1(1): 64-68.
- Moayedi A. A., A. Nasrulhaq-Boyce and H. Tavakoli. 2011a. Application of physiological and biochemical indices for screening and assessment of drought tolerance in durum wheat genotypes. Aust. J. Crop Sci. 5(8): 1014-1018.
- Mohammadi M. M., A. Maleki, S. A. Siaddat and M. Beigzade. 2013. The effect of zinc and potassium on the quality yield of wheat under drought stress conditions. Int. J. Agric. Crop Sci. 6(16): 1164-1170.
- Mohammadkhani N. and R. Heidar. 2008. Drought-induced Accumulation of Soluble Sugars and Proline in Two Maize Varieties. World Appl. Sci. J. 3 (3): 448-453.
- Mohi-Ud-Din M., M. A. Rahman and J. U. Ahmed. 2007. Changes in SPAD value and soluble carbohydrate concentration during senescence of wheat flag leaf under heat stressed environment. J. Asiat. Soc. Bangladesh Sci. 33(2): 121-130.
- Molnár I., L. Gáspár, É. Sárvári, S. Dulai, B. Hoffmann, M. Molnár- Láng and G. Galiba. 2004. Physiological and morphological responses to water stress in *Aegilops biuncialis* and *Triticum aestivum* genotypes with differing tolerance to drought. Funct. Plant Biol. 31: 1149-1159.
- Morgan J. M. 1984. Osmoregulation and water stress in higher plants. Ann. Rev. Plant Physiol. 35: 299-319.
- Mosaad M. G., G. Ortiz-Ferranru and V. Mahalakshmi. 1995. Tiller development and contribution to yield under different moisture regimes in two *Triticum* species. J. Agron. Crop Sci. 48(10): 173- 180.

- Mostajeran A. and V. Rahimi-Eichi. 2009. Effects of drought stress on growth and yield of rice (*Oryza sativa* L.) cultivars and accumulation of proline and soluble sugars in sheath and blades of their different ages leaves. *American-Eurasian J. Agric. Environ. Sci.* 5(2): 264-272.
- Motzo R. and F. Giunta. 2007. The effect of breeding on the phenology of Italian durum wheats: In: Baker F. W. G. (ed). *Drought resistance in cereals*. CAB International. pp. 81-88.
- Moud A. M. and K. Maghsoudi. 2008. Application of coleoptile growth response method to differentiate osmoregulation capability of wheat (*Triticum aestivum* L.) cultivars. *Res. J. Agron.* 2: 36-43.
- Moustafa M. A., L. Boersma, and W. E. Kronstad. 1996. Response of four spring wheat cultivars to drought stress. *Crop Sci.* 36: 982-986.
- Mujtaba S. M., M. Ali, M. Y. Ashraf, B. Khanzada, S. M. Farhan, M. U. Shirazi, M. A. Khan, A. Shereen and S. Mumtaz. 2007. Physiological responses of wheat (*Triticum aestivum* L.) genotypes under water stress conditions at seedling stage. *Pak. J. Bot.* 39(7): 2575-2579.
- Mullet J. E. and M. S. Whitsitt. 1996. *Plant cellular responses to water deficit*. Springer, Netherlands. 20: 119-124.
- Murty B. R. and V. Arunachalam. 1966. The nature of genetic divergence in relation to breeding system in crop plants. *Indian J. Genet.* 26A: 188-198.
- Musick J. T. and D. A. Dusek. 1980. Planting date and water deficit effects on development and yield of irrigated wheat. *Agron. J.* 72: 45-52.
- Naeem M. K., M. Ahmad, M. Kamran, M. K. N. Shah and M. S. Iqbal. 2015. Physiological responses of wheat (*Triticum aestivum* L.) to drought stress. *Int. J. Plant Soil Sci.* 6(1): 1-9.
- Naidu N. V. and A. Satyanarana. 1991. Study on the genetic divergence over environments in Mungbean (*Vigna radiata* L.) Wilezek. *Indian J. Genet.* 51(4): 454-460.
- Nakayama N., H. Saneoka, R. E. Moghaieb, G. S. Premachandra and K. Fujita. 2007. Response of growth, photosynthetic gas exchange, translocation of ¹³C-labelled

- photosynthate and N accumulation in two soybean (*Glycine max* L. Merrill) cultivars to drought stress. Intl. J. Agric. Biol. 9(5): 669-674.
- Nalam V. J., M. I. Vales, C. J. W. Watson, S. F. Kianian and O. Riera-Lizarazu. 2006. Map-based analysis of genes affecting the brittle rachis character in tetraploid wheat (*Triticum turgidum* L.). Theoretical and Applied Genetics. 112: 373-381.
- Nasri M. 2005. Interaction of nutrient elements and drought stress in cultivars of *Brassica napus*. The 2nd Int. Conf. on Integrated approaches to sustain and improve plant production under drought stress. September 24-28 2005, Rome, Italy. p. 109.
- Nayyar H. and D. Gupta. 2006. Differential sensitivity of C₃ and C₄ plants to water deficit stress: Association with oxidative stress and antioxidants. Environ. Exp. Bot. 58: 106-113.
- Nazarli H. and F. Faraji. 2011. Response of proline, soluble sugars and antioxidant enzymes in wheat to different irrigation regimes in greenhouse condition. Cercetari Agronomice in Moldova. 4(148): 27-33.
- Nelson D., P. Repetti, T. Adams, R. Creelman, J. Wu, D. Warner, D. Anstrom, R. Bensen, P. Castiglioni and M. Donnarummo. 2007. Plant nuclear factor Y (NF-Y) B subunits confer drought tolerance and lead to improved corn yields on water-limited acres. Proc Natl. Acad. Sci. USA. 104: 16450-16455.
- Nesbitt M. 1998. Where was einkorn wheat domesticated? Trends Plant Sci. 3: 1360-1385.
- Nicolas M. E., R. M. Gleadow and M. J. Dalling. 1985. Effect of post-anthesis drought on cell division and starch accumulation in developing wheat grains. Ann. Bot. 55: 433-444.
- Nikolaeva M. K., S. N. Maevskaya, A. G. Shugaev and N. G. Bukhov. 2010. Effect of drought on chlorophyll content and antioxidant enzyme activities in leaves of three wheat cultivars varying in productivity. Russ. J. Plant Physiol. 57: 87-95.
- Nohong B. and S. Nompo. 2015. Effect of water stress on growth, yield, proline and soluble sugars contents of Signal grass and Napier grass species. Ame-Eurasian J. Sustain. Agric. 9(5): 14-21.
- Noorka I. R. and I. Khaliq. 2007. An efficient technique for screening wheat (*Triticum aestivum* L.) germplasm for drought tolerance. Pak. J. Bot. 39(5): 1539-1546.

- Noorka I. R., I. Khaliq and M. Kashif. 2007. Index of transmissibility and genetic variation in spring wheat seedlings under water deficit conditions. *Pak. J. Agric. Sci.* 44(4): 604-607.
- Nosrati S., M. G. Zanzan and D. E. Asli. 2014. Fluctuations of proline concentration and soluble sugars content affected drought stress in canola (*Brassica napus* L.) seedlings. *J. App. Sci. Agric.* 9(2): 497-502.
- Nouri A., A. Etminan, J. A. Teixeira da Silva and R. Mohammadi. 2011. Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turgidum* var. durum Desf.). *Australian J. Crop Sci.* 5(1): 8-16.
- Nouri-Ganbalani A., Nouri-Ganbalani G. and D. Hassanpanah. 2009. Effect of drought stress condition on the yield and yield components of advanced wheat genotypes in Ardabil, Iran. *J. Food, Agric. Env.* 7(3&4): 228-234.
- Okçu G., M. D. Kaya and M. Atak. 2005. Effects of salt and drought stresses on germination and seedling growth of pea (*Pisum sativum* L.), *Turk. J. Agr. For.* 29: 237-242.
- Oktem A. G. and A. Oktem. 2005. Effect of nitrogen and intra spaces on sweet corn characteristics. *Asian J. Plant Sci.* 4: 361-364.
- Olivares-Villegas J. J., M. P. Reynolds and G. K. McDonald. 2007. Drought adaptive attributes in the Seri/Babax hexaploid wheat population. *Funct. Plant Biol.* 34: 189-203.
- Oosterhuis D. M. and P. M. Cartwright. 1983. Spike differentiation and floret survival in semi-dwarf spring wheat as affected by water stress and photoperiod. *Crop Sci.* 23: 711-717.
- Öztürk A., B. Taşkesenligil, K. Haliloğlu, M. Aydin and Ö. Çağlar. 2016. Evaluation of bread wheat genotypes for early drought resistance via germination under osmotic stress, cell membrane damage, and paraquat tolerance. *Turk. J. Agric.* 40: 146-159.
- Ozturk L. and Y. Demir. 2002. In vivo and in vitro protective role of proline. *Plant Growth Regul.* 38: 259-264.
- Pandey R. M. and R. Singh. 2010. Genetic studies for biochemical and quantitative characters in grain amaranth (*Amaranthus hypochondriacus* L.). *Plant Omics J.* 3(4): 129-134.

- Parchin R. A., A. Najaphy, E. Farshadfar and S. Hokmalipour. 2011. Evaluation of wheat genotypes under drought stress based on phonological traits. Intl. J. Agri. Crop Sci. 3(1): 12-19.
- Passioura J. B. 2007. The drought environment: Physical, biological and agricultural perspectives. J. Expt. Bot. 58(2): 113-117.
- Pastenes C., P. Pimenteland J. Lillo. 2005. Leaf movements and photoinhibition in relation to water stress in field grown beans. J. Exp. Bot. 56: 425-433.
- Pastori G. M. and V. S. Trippi. 1992. Oxidative stress induces high rate of glutathione reductase synthesis in a drought resistant maize strain. Plant Cell Physiol. 33: 957-961.
- Patel A. L. and J. Singh. 1998. Nutrients uptake and distribution in aerial parts of wheat under water stress at different growth stages. Ann. Agri. Bio. Res. 3: 5-8.
- Patil R. 2010. Effect of potassium humate and deproteinised Juice (DPJ) on seed germination and seedling growth of wheat and jowar. Ann. Biol. Res. 1(4): 148-151.
- Pecetti L., P. Annicchiaro and A.B. Damania. 1996. Geographic variation in tetraploid wheat (*Triticum turgidum* spp. *Turgidum convar.* Durum) landraces from two provinces in Ethiopia. Genet. Resour. Crop Evol. 43: 395-407.
- Pel Z. M., Y. Murata and G. Benning. 2000. Calcium channels activated by hydrogen peroxide mediate abscisic acid signalling in guard cells. Natu. 406: 731-734.
- Percival J. 1921. The wheat plant. A monograph. London, Duckworth, England.
- Perna J. and N. Menzies. 2010. Shoot and root growth and potassium concentration of maize as affected by potassium fertilizer placement. World Congress of Soil Science, Soil Solutions for a Changing World 1-6 August 2010, Brisbane, Australia. pp. 222-225.
- Perry M. W. and R. K. Belford. 2000. The structure and development of the cereal plant. Chapter 2. In: Anderson, W. K. and J. R. Garlinge (eds). The Wheat Book Principles and Practice. Agriculture Western Australia, pp. 23-36.
- Petersen L. 2010. Analytical methods of soil, water, plant material and fertilizer. Soil Resource Development Institute, 2: 17-70.

- Pettigrew W. T. 2008. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. *Physiol. Plantarum*, 133(4): 670-681.
- Pierre C. S., C. J. Peterson, A. S. Ross, J. B. Ohm, M. C. Verhoeven, M. Larson and B. Hoefer. 2008. White wheat grain quality changes with genotypes, nitrogen fertilization and water stress. *Agron. J.* 100: 414-420.
- Plaut Z., B.J. Butow, Blumenthal C. S. and Wrigley C.W. 2004. Transport of dry matter into developing wheat kernels. *Field Crops Res.* 96: 185-198.
- Podsiado C., Z. Koszanski and I. I. Zbiec. 1999. Response of some spring barley cultivars to irrigation and mineral fertilization. Part 2. Canopy architecture and yield structure. *Folia Univ. Agric. Stetinensis, Agric.* (73): 131-137.
- Prasad P. V. V., S. R. Pisipati, Z. Ristic, U. Bukovnik and A. K. Fritz. 2008b. Impact of night time temperature on physiology and growth of spring wheat. *Crop Sci.* 48: 2372-2380.
- Premachandra G. S., H. Saneoka, and S. Ogata. 1991. Cell membrane stability and leaf water relations as affected by potassium nutrition of water-stressed maize. *J. Exp. Bot.* 42: 739-745.
- Premachandra G. S., H. Saneoka, K. Fujita, and S. Ogata. 1992. Leaf water relations, osmotic adjustment, cell membrane stability, epicuticular wax load and growth as affected by increasing water deficits in sorghum. *J. Exp. Bot.* 43: 1569-1576.
- Premachandra G. S., H. Saneoka, K. Fujita and S. Ogata. 1993. Water stress and potassium fertilization in field grown maize (*Zea mays* L.): Effect on leaf water relations and leaf rolling. *J. Agron. Crop Sci.* 170: 195-200.
- Qadir G., M. Saeed, and M. A. Cheema 1999. Effect of water stress on growth and yield performance of four wheat cultivars. *Pak. J. Biological Sci.* 1: 236-239.
- Qamar R., Ehsanullah, M. Munir, G. Mustafa and A. Ghafar. 2012. Effect of irrigation scheduling on growth, radiation use efficiency and yield of wheat. *Crop Environ.* 3: 23-27.

- Qayyum A., S. Ahmad, S. Liaqat, W. Malik, E. Noor, H. M. Saeed and M. Hanif. 2012. Screening for drought tolerance in maize (*Zea mays* L.) hybrids at an early seedling stage. *Afr. J. Agric. Res.* 7(24): 3594-3604.
- Rad R. N., M. A. Kadir, H. Z. Jaafar and D. Gement 2012. Physiological and biochemical relationship under drought stress in wheat (*Triticum aestivum* L.). *Afr. J. Biotechnol.* 11: 1574-1578.
- Radford P. J. 1967. Growth analysis formulae, their use and abuse. *Crop Sci.* 7: 171-175.
- Rahdari P., S. M. Hoseini and S. Tavakoli. 2012. The studying effect of drought stress on germination, proline, sugar, lipid, protein and chlorophyll content in Purslane (*Portulaca oleraceae* L.) leaves. *J. Medicinal Plants. Res.* 6(9): 1539-1547.
- Rahman M., A. Tabassam, M. Kazi and Y. Zafar. 2006a. A step towards wheat genome initiative studies to combat drought in Pakistan using DNA fingerprinting tool. *Int. Symp. on strategies for crop improvement against abiotic stresses.* September 18-20, Department of Bot., University of Agric., Faisalabad, Pakistan. p. 15.
- Rahman M., I. Ullah, M. Ashraf, J. M. Stewart and Y. Zafar. 2006b. Genotypic variation for drought tolerance in cotton (*Gossypium hirsutum* L.): Productivity, osmotic adjustment and cellular membrane stability. *Int. Symp on strategies for crop improvement against abiotic stresses.* September 18-20, Department of Bot., University of Agric., Faisalabad, Pakistan. p. 14.
- Rajala A., K. Hakala, P. Makela, S. Muurinen and P. Peltonen-Sainio. 2009. Spring wheat response to timing of water deficit through sink and grain filling capacity. *Field Crops Res.* 114: 263-271.
- Rajcan I. and M. Tollenaar. 1999. Source-sink ratio and leaf senescence in maize: II. Nitrogen metabolism during the grain filling period. *Field Crops Res.* 60: 255-265.
- Rajiki E. 1982. Drought sensitive phase in the development of wheat and the possibility of testing drought resistance in phytotron. *Cereal Res. Commun.* 10: 213-221.
- Rama Rao N. 1986. Potassium nutrition of pearl millet subjected to moisture stress. *J. Potassium Res.* 2: 1-12.

- Ramanjulu S. and D. Bartels. 2002. Drought and dessication-induced modulation of gene expression in plants. *Plant Cell Environ.* 25: 141-151.
- Rasheed M., W. M. Bhutta, M. Anwar-ul-Haq and A. Ghaffar. 2004. Genotypic response of maize hybrids to NP applications. *Int. J. Agric. Biol.* 4: 721-722.
- Rashid A. J., C. Stark, A. Tanveer and T. Mustafa. 1999. Use of canopy temperature measurements as a screening tool for drought tolerance in spring wheat. *J. Agron. Crop Sci.* 182: 231-238.
- Rasool G., J. K. Khattak and A. U. Bhatti. 1987. Comparative effect of potassium sulphate vs. potassium chloride on the yield and the chemical composition of maize under D. I Khan Conditions. *Pak. J. Agric. Res.* 8: 29-31.
- Rauf M., M. Munir, M. Hassan, M. Ahmed and M. Afzal. 2007. Performance of wheat genotypes under osmotic stress at germination and early seedling growth stage. *African J. Biotechnol.* 6(8): 971-975.
- Raza M. A. S., M. F. Saleem, G. M. Shah, M. Jamil and I. H. Khan. 2013. Potassium applied under drought improves physiological and nutrient uptake performances of wheat (*Triticum aestivum* L.). *J. Soil Sci. Plant Nutr.* 13(1): 175-185.
- Raza M. A. S., M. F. Saleem, I. H. Khan, M. Jamil, M. Ijaz, and M. A. Khan. 2012. Evaluating the drought stress tolerance efficiency of wheat (*Triticum aestivum* L.) cultivars. *Russian J. Agril. Socio-Econ. Sci.* 12(12): 41-46.
- Reynolds M. P., K. A. Mujeeb and M. Sawkins. 2005. Prospects for utilizing plant-adaptive mechanisms to improve wheat and other crops in drought & salinity-prone environments. *Ann. Appl. Biol.* 146(2): 239-259.
- Reynolds M. P., M. Balota, M. I. B. Delgado, I. Amani and R. A. Fischer. 1994. Physiological and morphological traits associated with spring wheat yield under hot, irrigated conditions. *Aust. J. Plant Physiol.* 21: 717-730.
- Reynolds M. P., R. P. Singh, A. Ibrahim, O. A. Ageeb, A. Larque-Saavedra and J. S. Quick. 1998. Evaluating physiological traits to compliment empirical selection for wheat in warm environments. *Euphytica.* 100: 85-94.

- Reynolds M., S. Nagarajan, M. A. Razzaque and O. A. A. Ageeb. 2014. Heat tolerance. In: Application of Physiology in Wheat Breeding: Reynolds M. P., J. I. Ortiz-Monasterio, A. Mc. Nab and D. F. Mexico. (Eds.). CIMMYT, Mexico. pp. 124-135. SPEI. Available:<http://sac.csic.es/spei/map/maps.Html>.
- Rhodes D. and A. D. Hanson. 1993. Quaternary ammonium and tertiary sulfonium compounds in higher-plants. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 44: 357-384.
- Rhodes D., P. E. Verslues and R. E. Sharp. 1999. Role of amino acids in abiotic stress resistance. In: *Plant Amino Acids: Biochemistry and Biotechnology*. Singh B. K. (Ed.). Marcel Dekker, NY, USA. pp. 319-356.
- Riaz R. and M. A. Chowdhry. 2003. Genetic analysis of some economic traits of wheat under drought conditions. *Asian J. Plant Sci.* 2: 790-796.
- Richards R. A. Rebetzke G. I. and A. F. Herwaarden. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Sci.* 42:111-121.
- Richards R. A., A. G. Condon and G. J. Rebetzke. 2001. Traits to improve yield in dry environments. *DF, CIMMYT, Mexico.* pp. 88-100.
- Ritchie S.W., H. T. Nguyen and A. S. Holaday. 1990. Leaf water content and gas exchange parameters of two wheat genotypes differing in drought resistance. *Crop Sci.* 30: 105-111.
- Rivero R. M., M. Kojima, A. Gepstein, H. Sakakibara, R. Mittler, S. Gepstein and E. Blumwald. 2007. Delayed leaf senescence induces extreme drought tolerance in a flowering plant. *Proc. Natl. Acad. Sci. USA.* 104: 19631-19636.
- Royo C. 2004. Leaf and green area development of durum wheat genotypes grown under Mediterranean conditions. *European J. Agron.* 20: 419-430.
- Royo C., D. Villegas, L. F. Garcia del Moral, S. Elhani, N. Aparicio, Y. Rharrabti and J. L. Araus. 2002. Comparative performance of carbon isotope discrimination and canopy temperature depression as predictors of genotypes differences in durum wheat yield in Spain. *Aust. J. Agric. Res.* 53: 561-569.

- Royo C., M. Abaza, R. Blanco and L. F. Garcia del Moral. 2000. Triticale grain growth and morphometry as affected by drought stress, late sowing and simulated drought stress. *Aust. J. Plant Physiol.*, 27: 1051-1059.
- Saadalla M. M., J. S. Quick and J. F. Shanahan. 1990. Heat tolerance in winter wheat: II. Membrane thermostability and field performance. *Crop Sci.* 30: 1248-1251.
- Saeedipour S. 2012. Effect of post-anthesis water deficit on yield and some physiological parameters on two wheat cultivars. *Afr. J. Agric. Res.* 7: 3446-3452.
- Saeidi M., F. Moradi, A. Ahmadi, R. Spehri, G. Najafian and A. Shabani. 2010. The effects of terminal water stress on physiological characteristics and sink- source relations in two bread wheat (*Triticum aestivum* L.) cultivars. *Iranian J. Crop Sci.* 12: 392-408.
- Saini H. S. and D. Aspinall. 1981. Effect of water deficit on sporogenesis in wheat (*Triticum aestivum* L.). *Ann. Bot.* 48: 623-633.
- Saini H. S., M. Sedgley and D. Aspinall. 1984. Developmental anatomy in wheat of male sterility induced by heat stress, water deficit or abscisic acid. *Australian J. Plant Physiol.* 11: 243-253.
- Sairam R. K., D.S. Shukla and D. C. Saxena. 1998. Stress induced injury and antioxidant enzymes in relation to drought tolerance in wheat genotypes. *Biol. Plantarum.* 40: 357-364.
- Sairam R. K. and D. C. Saxena. 2000. Oxidative stress and antioxidants in wheat genotypes: possible mechanism of water stress tolerance. *J. Agron. Crop Sci.* 184: 55-61.
- Sairam R. K., P. S. Deshmukh, D. S. Shukla and S. Ram. 1990. Metabolic activity and grain yield under moisture stress in wheat genotypes. *Indian J. Plant Physiol.* 33(3): 226-231.
- Sakamoto A. and N. Murata. 2002. The role of glycine betaine in the protection of plants from stress: clues from transgenic plants. *Plant Cell Environ.* 25: 163-171.
- Saleem M. 2003. Response of durum and bread wheat genotypes to drought stress biomass and yield component. *Asian J. Plant Sci.* 2: 290-293.
- Saleem M., M. Shafi, J. B. Zahidullah and S. Anwar. 2007. Response of wheat varieties to water regime. *Sarhad J. Agric.* 23(1): 115-122.

- Samar Raza M. A., M. F. Saleem, G. M. Shah, M. Jamil and I. H. Khan. 2013. Potassium applied under drought improves physiological and nutrient uptake performances of wheat (*Triticum Aestivum* L.). J. Soil Sci. Plant Nutr. 13(1): 175-185.
- Sangakkara U. R., M. Frehner and J. Nosberger. 2000. Effect of soil moisture and potassium fertilizer on shoot water potential, photosynthesis and partitioning of carbon in mungbean and cowpea. J. Agron. Crop Sci. 185: 201-207.
- Sangakkara U. R., U. A. Hartwig and J. Nosberger. 1996. Response of root branching and shoot water potentials of french bean (*Phaseolus vulgaris* L.) to soil moisture and fertilizer potassium. J. Agron. Crop Sci. 177: 165-173.
- Sangtarash M. H. 2010. Responses of different wheat genotypes to drought stress applied at different growth stages. Pak. J. B. Sci., 13:114-119.
- Sarkar A. K. and A. Bandyopadhyay. 1991. Response of wheat cultivars to post- flowering foliar application of potassium nitrate solution. Indian Agric. 35 (4): 269-272.
- Sarker A. M., M. S. Rahman and N. K. Paul. 1999. Effect of soil moisture on relative water content, chlorophyll, proline and sugar accumulation in wheat. J. Agron. Crop Sci. 183: 225-229.
- Sayar R., H. Bchini, M. Mosbahi and H. Khemira. 2010. Response of durum wheat (*Triticum durum* Desf.) growth to salt and drought stresses. Czech J. Genet. Plant Breed. 46: 54-63.
- Selote D. S. and R. Khanna-Chopra. 2004. Drought-induced spikelet sterility is associated with an inefficient antioxidant defence in rice panicles. Physiol. Plant. 121: 462-471.
- Serraj R. and T. R. Sinclair. 2002. Osmolyte accumulation: can it really help increase crop yield under drought conditions? Plant Cell Environ. 25: 333-341.
- Setter T. L. and Carlton G. 2000. The structure and development of the cereal plant. Chapter 2. In: Anderson W. K. and Garlings J. R.(eds). The Wheat Book, Principles and Practice. Agriculture Western Australia. pp. 23-36.
- Setter T. L., A. F. Brain and J. Melkonian. 2001. Loss of kernel set due to water deficit and shade in maize: carbohydrate supplies, ABA and cytokinin. Crop Sci. 41: 1530-1540.

- Shabbir R. N., M. Y. Ashraf, E. A. Waraich, R. Ahmad and M. Shahbaz. 2015. Combined effects of drought stress and NPK foliar spray on growth, physiological processes and nutrient uptake in wheat. *Pak. J. Bot.* 47(4): 1207-1216.
- Shafeeq S., M. Rahman and Y. Zafar. 2006. Genetic variability of different wheat (*Triticum aestivum* L.). *Pak. J. Bot.* 38: 1671-1678.
- Shah N. H. and G. M. Paulsen. 2003. Interaction of drought and high temperature on photosynthesis and grain-filling of wheat. *Plant Soil.* 257: 219-226.
- Shahbaz M., M. Iqbal, and M. Ashraf. 2011. Response of differently adapted populations of blue panic grass (*Panicum antidotale* Retz.) to water deficit conditions. *J. Appl. Bot. Food Qual.* 84(2): 134-141.
- Shalaby E. M., Rahim H. M. A., Mosaad M. G. and Masoud M. M. 1988. Effect of watering regime on morpho-physiological traits and harvest index and its components of wheat. *Assiut. J. Agric. Sci.* 19(5): 195-207.
- Shamsi K. and S. Kobraee. 2011. Breadwheat production under drought stress conditions. *Ann. Biol. Res.* 2: 352-358.
- Shangguan Z., M. Shao and J. Dyckmans. 1999. Interaction of osmotic adjustment and photosynthesis in winter wheat under soil drought. *J. Plant Physiol.* 154: 753-758.
- Shehzadi S. 1999. Effect of different water regimes on growth, yield and anatomy of wheat (*Triticum aestivum* L.). M.Sc. Thesis, Dept. Bot., Univ. Agric., Faisalabad, Pakistan.
- Sheoran I. S. and H. S. Saini. 1996. Drought-induced male sterility in rice: Changes in carbohydrate levels and enzyme activities associated with the inhibition of starch accumulation in pollen. *Sex. Plant Reprod.* 9:161-169.
- Shinozaki K. and K. Yamaguchi-Shinozaki. 1997. Gene expression and signal transduction in water-stress response. *Plant Physiol.* 115(2): 327-334.
- Shpiler L. and A. Blum. 1991. Heat tolerance for yield and its components in different wheat cultivars. *Euphytica.* 51: 257-263.
- Sial M. A., M. U. Dahot, M. A. Arain, G. S. Markhand, M. H. Naqvi, K. A. Laghari and A. A. Mirbahar. 2009. Effect of water stress on yield and yield components of semi-dwarf bread wheat (*Triticum aestivum* L.). *Pak. J. Bot.* 41(4): 1715-1728.

- Siddique K. H. M., D. Tennant, M. W. Perry and R. K. Belford. 1990. Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean type environment. *Aust. J. Agric. Res.* 41: 431-447.
- Siddique M. R. B., A. Hamid and M. S. Islam. 1999. Drought stress effects on yield and yield attributes of wheat. *Bangladesh J. Agril. Res.* 24: 621-628.
- Siddique M. R. B., A. Hamid and M. S. Islam. 2000. Drought stress effects on water relations of wheat. *Bot. Bull. Acad. Sin.* 41: 35-39.
- Simane B., J. M. Peacock and P. C. Struik. 1993. Differences in development and growth rate among drought-resistant and susceptible cultivars of durum wheat (*Triticum turgidum* L. Var. Durum). *Plant Soil.* 157:155-166.
- Simons K. J., J. P. Fellers, H. N. Trick, Z. Zhang, Y. S. Tai, B. S. Gill and J. D. Faris. 2006. Molecular characterization of the major wheat domestication gene Q. *Genetics* 172: 547-555.
- Sinclair T. R. and M. M. Ludlow. 1985. Who taught plants thermodynamics? The unfulfilled potential of plant water potential. *Aust. J. Plant Physio.* 12(3): 213-217.
- Singh D. P., A. Kumar, P. Singh and B. D. Chaudhary. 1990. Soil water use, seed yield, plant water relation and their inheritance in oilseed *Brassicas* under progressive soil moisture stress. *Proc. Intl. Cong. Plant Physiol., New Delhi, India.* pp. 841-848.
- Singh G. and H. Chaudhary. 2006. Selection parameters and yield enhancement of wheat (*Triticum aestivum* L.) under different moisture stress condition. *Asian J. Plant Sci.* 5: 894-898.
- Singh G. P., H. B. Chaudhary, Y. Rajbir, and S. Tripathi. 2008. Genetic analysis of moisture stress tolerance in segregating populations of bread wheat (*T. aestivum* L.). *Indian J. Agric. Sci.* 78(10): 848-852.
- Singh P., H. M. Ibrahim, M. Flury, W. F. Schillinger and T. Knappenberger. 2013. Critical water potentials for germination of wheat cultivars in the dryland Northwest USA. *Seed Sci. Res.* 23: 189-198.
- Sneath P. H. A. and Sokal R. R. 1973. *Numerical Taxonomy: The Principles and Practice of Numerical Classification.* W. F. Free-Man and Co., San Francisco, USA. p. 573.

- Srinivas V. and D. Balasubramanian. 1995. Proline is a protein-compatible hydrotrope. *Langmuir*. 11: 2830-2833.
- Subhani A., M. Tariq, M. S. Jafar, R. Latif, M. Khan, M. S. Iqbal and M. S. Iqbal. 2012. Role of soil moisture in fertilizer use efficiency for rainfed areas-a review. *J. Bio. Agric. Healthcare*. 2: 1-9.
- Sullivan G. Y. 1971. Techniques for measuring plant drought stress. In: *Drought injury and Resistance in Crops*. Larson K. L. and J. D. Eastin (Eds). Crop Sci.Soc. Am. Madison Wis. USA.
- Sultan M. A. R. F., L. Hui, L. J. Yang and Z. H. Xian. 2012. Assessment of drought tolerance of some *Triticum* L. species through physiological indices czech. *J. Genet. Plant Breed*. 48: 178-184.
- Taiz L. and E. Zeiger. 2002. *Plant Physiology*. 3rd ed. Sinauer Associates, Inc., Sunderland, MA, USA.
- Taiz L. and E. Zeiger. 2006. *Stress physiology*. 4th ed., Sinauer Associates, Inc., MA, USA. pp. 671-702.
- Taiz L. and E. Zeiger. 2010. *Plant Physiology*. 5th Ed., Sinauer Associates Inc., Sunderland, USA. p. 782.
- Taiz L. and E. Zeiger. 1991. *Plant Physiology*. The Benjamin/Cummings Publishing Co. Inc., California. Pp. 346-350.
- Talebi R. 2011. Evaluation of chlorophyll content and canopy temperature as indicators for drought tolerance in durum wheat (*Triticum durum* Desf.). *Aust. J. Basic Appl. Sci*. 5: 1457-1462.
- Talebi R., F. Fayaz and A. M. Naji. 2009. Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.). *General Appl. Plant Physiol*. 35(1-2): 64-74.
- Talukder S. K., M. A. Babar, K. Vijayalakshmi, J. Poland, P.V.V. Prasad, R. Bowden and A. Fritz. 2014. Mapping QTL for the traits associated with heat tolerance in wheat (*Triticum aestivum* L.). *BMC Genet*. 15: 1-13.

- Tardieu F., P. Kesavan, J. Bocianowski, M. Bilal, Y. Sohrabi, T. Dai, Q. Qanmber, A. Latif, J. Ashraf and U. Farhan. 2012. Any trait or trait-related allele can confer drought tolerance: Just design the right drought scenario. *J. Exp. Bot.* 63: 25-31.
- Tasmina T., A. R. Khan, A. Karim, N. Akter and R. Islam. 2016. Physiological changes of wheat varieties under water deficit condition. *Bangladesh Agron. J.* 19(2): 105-114.
- Teng S., Q. Qian, D. Zeng, Y. Kunihiro, K. Fujimoto, K. Huang and L. D. Zhu. 2004. QTL analysis of leaf photosynthetic rate and related physiological traits in rice (*Oryza sativa* L.). *Euphy.* 135: 1-7.
- Thalooth T. A., H. A. El-Zeiny and A. O. M. Saad. 1990. Application of potassium fertilizer for increasing salt tolerance of broad bean (*Vicia faba* L.). *Bull. Egypt. Soc. Physiol. Sci.* 10: 181-193.
- Tompkins D. K., D. B. Fowler and A. T. Wright. 1991. Water use by no till winter wheat influence of seed rate and row spacing. *Agron. J.* 83(2): 766-769.
- Tripathy J. N., J. Zhang, S. Robin, T. T. Nguyen and H.T. Nguyen. 2000. QTLs for cell-membrane stability mapped in rice (*Oryza Sativa* L.) under drought stress. *Theor. App. Genet.* 100: 1197-1202.
- Turner L. B. 1985. Changes in the phosphorus content of *Capsicum annuum* leaves during water stress. *J. Plant Physiol.* 121(5): 429-439.
- Turner N. C. and M. M. Jones. 1980. Turgor maintenance by osmotic adjustment: A review and evaluation. In: *Adaptation of plants to water and high temperature stress*. Turner N.C. and P.J. Kramer (eds.). John Wiley Sons., New York, USA. pp. 87-103.
- Tyagi P. K., D. P. Singh and R. K. Pannu. 2000. Effect of post-anthesis chemical desiccation on plant water relations, canopy temperature, photosynthesis and grain yield in wheat genotypes. *Ann. Biol.* 16: 111-119.
- Ullah I., M. Rahman, M. Ashraf and Y. Zafar. 2006. Genotypic variation for physiological and productivity traits in cotton (*Gossypium hirsutum* L.) under contrasting water regimes. *Int. Symp. on strategies for crop improvement against abiotic stresses*. September 18-20, Dep. of Bot., University of Agriculture, Faisalabad, Pakistan, pp. 14-15.

- Umar S. 2006. Alleviating adverse effects of water stress on yield of sorghum, mustard and groundnut by potassium application. Pak. J. Bot. 38(5): 1373-1380.
- Umar S. and Moinuddin. 2002. Genotypic differences in yield and quality of groundnut as affected by potassium nutrition under erratic rainfall conditions. J. Plant Nutr. 25: 1549-1562.
- Umar S. and S. K. Bansal. 1995. Potassium requirement of mustard under moisture stress condition. J. Plant Physiol. Biochem. 22: 130-135.
- Umar S., M. M. R. K. Afridi and R. S. Dwivedi. 1990. Effect of K application on physiological parameters and pod yield of groundnut under water stress conditions. Richtig. Dunggenn. Mehr.1(1): 1-6.
- Usherwood N. R. 1985. The role of potassium in crop quality. In: Potassium in agriculture. Munson R. D. (Ed). Madison, Wisconsin, USA. pp. 489-514.
- Van Herwaarden A. F., J. F. Angus, R. A. Richards and G. D. Farquhar. 1998. 'Haying-off', the negative grain yield response of dryland wheat to nitrogen fertilizer. II. Carbohydrate and protein dynamics. Aust. J. Agric. Res. 49: 1083-1094.
- Velloso T. M. 1997. Performance of perennial ryegrass (*Lolium perenne* L.) seed crops under water stress conditions. A Thesis, Doctor of Philosophy. Oregon State University, USA.
- Vendruscolo A. C. G., I. Schuster. M. Pileggi, C. A. Scapim, H. B. C. Molinari, C. J. Marur, L. G. C. Vieira. 2007. Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat, J. Plant. Physiol. 164(10): 1367-1376.
- Vieira da Silva, J., A. W. Naylor and P. J. Kramer. 1974. Some ultra structural and enzymatic effects of drought stress in cotton (*Gossypium hirsutum* L.) leaves. Proc. Nat. Acad. Sci. 71: 3243-324.
- Wahid A. and E. Rasul. 2005. Photosynthesis in leaf, stem, flower and fruit In: Pessarakli M. (Ed). Hand book of Photosynthesis, 2nd Ed., CRC Press, Florida, USA. pp. 479-497.
- Wang C. R., X. H. Tian and S. X. Li. 2004. Effects of ridge mulching with plastic sheets for rainfall harvesting cultivation on water use efficiency and yield of winter wheat. J. Agric. Sci. 3(1): 14-23.

- Wardlaw I. F. and J. Willenbrink. 2000. Mobilization of fructan reserves and changes in enzyme activities in wheat stems correlate with water stress during kernel filling. *New Phytol.* 148:413-422.
- Warrier A. and Bhardwaj S. N. 1987. Hormonal regulation of grain growth under water stress conditions in bread wheat. *Indian J. Agric. Sci.* 57(7): 483-487.
- Wei J., C. Li, Y. Li, G. Jiang and G. Cheng. 2013. Effect of external potassium (K) supply on drought tolerances of two contrasting winter wheat cultivars. *PLoS ONE* 8(7): e69737.
- Wilson J. 1981. Analysis of growth, photosynthesis and light interception for single plants and stands. *Ann. Bot.* 48: 507-512.
- Witham H., D. F. Blades and R. H. Devin. 1986. *Exercise in plant physiology* (2nd edition), PWS Publishers, Boston, USA. pp. 128-131.
- WRC (Wheat Research Centre), 2013. Research report on crop management. Wheat Research Centre, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur, Bangladesh.
- WRC (Wheat Research Centre), 2017. Development of wheat varieties and modern production technology (*Gomer Unnot Jat O Adhunik Utpadon Projukti*). Wheat Research Centre, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur, Bangladesh.
- Wuest, S. B. and L. K. Lutch. 2012. Soil water potential requirement for germination of winter wheat. *Soil Sci. Soc. Am. J.* 77: 279–283 doi:10.2136/sssaj2012.0110.
- Wyrwa P., J. B. Diatta and W. Grzebisz. 1998. Spring triticale reaction to simulated drought and potassium fertilization. In: *Proc. of the 11th Int. Symp. on Codes of good fertilizer practice and balanced fertilization*, September 27-29, 1998, Pulawy, Poland, pp. 255-259.
- Xu W., D. T. Rosenow and H. T. Nguyen. 2000. Stay-green trait in grain sorghum: Relationship between visual rating and leaf chlorophyll concentration. *Plant Breed.* 119: 365-36.

- Yadav S. K., N. J. Lakshmi, M. Maheswari, M. Vanaja and B. Venkateswarlu. 2005. Influence of water deficit at vegetative, anthesis and grain filling stages on water relation and grain yield in sorghum. *Indian J. Plant Physiol.* 10: 20-24.
- Yang J. and J. Zhang. 2006. Grain filling of cereals under soil drying. *New Phytol.* 169: 223-236.
- Yang J., J. Zhang, Z. Wang, Q. Zhu and L. Liu. 2001. Water deficit-induced senescence and its relationship to the remobilization of pre-stored carbon in wheat during grain filling. *Agron. J.* 93: 196-206.
- Yang W. J., P. J. Rich, J. D. Axtell, K. V. Wood, C. C. Bonham, G. Ejeta, M. V. Mickelbart and D. Rhodes. 2003. Genotypic variation for glycine betaine in sorghum. *Crop Sci.* 43: 162-169.
- Yang X. H., X. G. Wen, H. M. Gong, Q. T. Lu, Z. P. Yang, Y. L. Tang, Z. Liang, C. M. Lu. 2007. Genetic engineering of the biosynthesis of glycine betaine enhances thermo tolerance of photosystem II in tobacco plants. *Planta.* 225: 719-733.
- Yasin M., M. Sarwar and G. Nabi. 1993. Growth and some important mineral concentration of wheat varieties in relation to soil moisture stress. *Pak. J. Agric. Res.* 14(2&3): 136-142.
- Yeganehpour F., S. Z. Salmasi, J. Kolvanagh, S. Golezani, K. G. and S. Dastborhan. 2016. Changes in growth, chlorophyll content and grain yield of Coriander (*Coriandrum sativum* L.) in response to water stress, chemical and biological fertilizers and salicylic acid. *Int. J. Adv. Biol. Biomed. Res.* 5(1): 228-236.
- Yıldızıtugay E., C. Özfidan Konakçı, M. Küçüködük and Y. Duran. 2014. Modulation of osmotic adjustment and enzymatic antioxidant profiling in *Apera intermedia* exposed to salt stress. *Turk. J. Bot.* 38: 99-111.
- Yoshida S., D. A. Forno, J. H. Cpck and K. A. Gomez. 1976. Laboratory Manual for physiological Studies of rice (Third edition). The International Rice Research Institute, Los Banos, Laguna, Philipines. pp. 46-49.
- Yürekli F., I. Türkan, B. Porgali and S. F. Topcuoğlu. 2001. Indoleacetic acid, gibbellic acid, abscisic acid levels in NaCl-treated tomato species differing in salt tolerance. *Israel J. Plant Sci.* 49: 269-277.

- Yurekli F., I. Türkan, B. Porgali and S. F. Topcuoğlu. 2001. Indoleacetic acid, gibberellic acid, abscisic acid levels in NaCl-treated tomato species differing in salt tolerance. *Israel J. Plant Sci.* 49: 269-277.
- Zafarnaderi N., S. Aharizad and S. A. Mohammadi. 2013. Relationship between grain yield and related agronomic traits in bread wheat recombinant inbred lines under water deficit condition. *Ann. Biol. Res.* 4: 7-11.
- Zahan M. I., Bhuiyan M. S. R. and Hossain M. S. 2008. Genetic divergence in Oleiferous *Brassica* species. *J. Sher-e-Bangla Agric. Univ.* 2(1): 1-6.
- Zaharieva M., E. Gaulin, M. Havaux, E. Acevedo and P. Monneveux. 2001. Drought and heat responses in the wild wheat relative *Aegilops geniculata* Roth. *Crop Sci.* 41(4): 1321-1329.
- Zahra V. and E. Farshadfar. 2011. Correlation between field and laboratory indicators of drought tolerance in wheat-barley disomic addition lines. *Ann. Biol. Res.* 2(6): 546-553.
- Zain N. A. M., M. R. Ismail, M. Mahmood, A. Puteh and M. H. Ibrahim. 2014. Alleviation of water stress effect on MR 220 rice by application of periodical water stress and potassium fertilization. *Molecules.* 19: 1795-1819.
- Zamurrad M., M. Tariq, F. H. Shah, A. Subhani, M. Ijaz, M. S. Iqbal and M. Koukab. 2013. Performance based evaluation of groundnut genotypes under medium rainfall conditions of Chakwal. *J. Agric. Food Appl. Sci.* 1:9-12.
- Zhang H., T. Y. Oweis, S. Garabet and M. Pala. 1998. Water-use efficiency and transpiration efficiency of wheat under rainfed conditions and supplemental irrigation in a Mediterranean-type environment. *Plant Soil.* 201: 295-305.
- Zhang J., B. Dell, E. Conocono, I. Waters, T. Setter and R. Appels. 2009. Water deficits in wheat: fructan exohydrolase (1-FEH) mRNA expression and relationship to soluble carbohydrate concentrations in two varieties. *New Phytol.* 181: 843-850.
- Zhang L., M. Gao, Li. Shengxiu, A. K. Alva and M. Ashraf. 2014. Potassium fertilization mitigates the adverse effects of drought on selected *Zea mays* cultivars. *Turk. J. Bot.* 38: 713-723.

- Zhang X., J. Cai, B. Wollenweber, F. Liu, T. Dai, W. Cao and D. Jiang. 2013. Multiple heat and drought events affect grain yield and accumulations of high molecular weight glutenin sub units and glutenin macropolymers in wheat. *J. Cereal Sci.* 57: 134-140.
- Zhang X., S. Chen, H. Sun, D. Pei and Y. Wang. 2001. Dry matter, harvest index, grain yield and water use efficiency as affected by water supply in winter wheat. *Irrig. Sci.* 27: 1-10.
- Zhang H. P. and T. Oweis. 1998. Water yield relation and optimal irrigation scheduling of wheat in Mediterranean regions. *Agric. Water Manage.* 3: 195-211.
- Zhao C. X., X. P. Deng, S. Q. Zhang, Q. Ye, E. Steudle and L. Shan. 2004. Advances in the studies on water uptake by plant roots. *Acta Bot. Sin.* 46: 505-514.
- Zhao T. J., S. Sun, Y. Liu, J. M. Liu, Q. Liu, Y. B. Yan and H. M. Zhou. 2006. Regulating the drought responsive element (DRE)-mediated signaling pathway by synergic functions of trans-active and trans-inactive DRE binding factors in *Brassica napus*. *J. Biol. Chem.* 281: 10752-10759.
- Zhou Y., H. M. Lam and J. Zhang. 2007. Inhibition of photosynthesis and energy dissipation induced by water and high light stresses in rice. *J. Exp. Bot.* 58: 1207-1217.
- Zhu J. M., S. Alvarez, E. L. Marsh, M. E. Noble, J. J. Cho, M. Sivaguru, S. X. Chen, H. T. Nguyen, Y. J. Wu, D. P. Schachtman. 2007. Cell wall proteome in the maize primary root elongation zone. II. Region-specific changes in water soluble and lightly ionically bound proteins under water deficit. *Plant Physiol.* 145: 1533-1548.
- Zivcak M., M. Brestic and K. Olsovska. 2009. Application of chlorophyll fluorescence for screening wheat (*Triticum aestivum* L.) genotype susceptibility to drought and high temperature. *Vagos.* 82: 82-87.

APPENDICES

Appendix 1. General and physical characteristics of the soil of the experimental site

General characters	Description	
Location	Wheat Research Centre, Experimental field, Dinajpur	
AEZ	Old Himalayan Piedmont Plain (AEZ-1)	
General Soil type	Non-Calcareous Brown Floodplain Soil	
Parent material	Piedmont alluvium	
Soil series	Ranishankail	
Drainage	Moderately well drained	
Flood level	Above flood level	
Topography	High land	
Physical characters	Value	
Bulk density (g cm ⁻³)	1.53	
Particle size (%)	0-15 CM (Mean ± SE)	15-30 CM (Mean ± SE)
Sand (2-0.02mm)	43.4 ± 0.168	41.5 ± 0.336
Silt (0.02-0.002mm)	41.7 ± 0.269	37.0 ± 0.581
Clay (< 0.002mm)	14.5 ± 0.336	21.0 ± 0.262
Textural class	Loam	Loam

Source: Analysis of initial soil samples was done in SRDI, Noahali, Bangladesh

Appendix 2. Chemical Characteristics of the soil of the experimental site

Depth of soil	Chemical characteristics	Content	Interpretation
0-15 cm	pH	5.655±0.003	Moderately acidic
	Organic carbon (%)	0.920±0.058	Low
	Organic matter (%)	1.590±0.099	Low
	Total N (%)	0.080±0.005	Very low
	Available P (ppm)	38.815±0.735	Very high
	Exchangeable K (meq/100g soil)	0.17±0.006	Low
	Sulphur (S)	15.56±0.267	Medium
	Boron (B)	0.285±0.049	Low
	Ece	0.48±0.029	Non saline
	CEC (meq/100g soil)	0.942±0.037	
15 -30 cm	pH	6.225±0.073	Moderately acidic
	Organic carbon (%)	0.68±0.006	Very low
	Organic matter (%)	1.175±0.009	Low
	Total N (%)	0.059±0.001	Very low
	Available P (µg/g)	16.125±1.811	Medium
	ExchangeableK (meq/100g soil)	0.125±0.003	Low
	Sulphur (S) (µg/g)	8.7±0.471	Medium low
	Boron (B) (µg/g)	0.28±0.006	Low
	Ece (ds/m)	0.375±0.015	Non saline
	CEC (meq/100g soil)	0.878±0.009	

Source: Analysis of initial soil samples was done in SRDI, Noahali, Bangladesh

Appendix 3: Weather data for growing season of wheat, 2014-2015

Months	Date	Relative humidity (%)	Temperature		Total rainfall (mm)
			Minium (°C)	Maximum (°C)	
November	0-10	80	18.3	31.6	0.0
	11-20	80	16.2	29.3	0.0
	21-30	83	13.4	26.7	0.0
December	0 -10	86	13.7	25.5	0.0
	11-20	85	12.2	23.6	0.0
	21-31	85	10.0	23.0	0.0
January	0-10	86	11.9	21.9	0.0
	11-20	86	9.6	21.3	0.0
	21-31	85	9.9	22.6	0.0
February	0-10	79	10.7	25.4	0.0
	11-20	78	13.1	26.3	27.0
	21-28	83	17.2	29.5	1.0
March	0-10	75	15.9	29.0	1.0
	11-20	70	15.9	30.9	0.0
	21-31	78	18.7	32.1	0.0
April	0-10	80	19.6	31.4	1.0
	11-20	79	20.3	31.7	36.0
	21-30	84	20.4	30.0	29.0

Source: Wheat Research Centre, Dinajpur

Appendix 4: Weather data for growing season of wheat, 2015-2016

Months	Date	Relative humidity (%)	Temperature		Total rainfall (mm)
			Minium (°C)	Maximum (°C)	
November	0-10	83	15.4	30.4	0.0
	11-20	83	16.5	29.7	0.0
	21-30	79	14.4	29.7	0.0
December	0-10	86	14.5	26.3	0.0
	11-20	88	9.8	22.6	0.0
	21-31	76	7.9	24.8	0.0
January	0-10	82	9.9	25.4	24.0
	11-20	83	8.7	23.8	0.0
	21-31	86	8.6	20.6	0.0
February	0-10	81	11.0	25.7	0.0
	11- 20	78	13.2	28.7	0.0
	21-30	76	14.8	30.1	0.0
March	0-10	76	17.6	32.1	0.0
	11- 20	72	16.9	32.1	0.0
	21-31	74	17.9	31.8	25.5
April	0-10	79	20.5	32.8	1.0
	11- 20	76	21.7	33.8	36.0
	21-30	76	22.7	36.4	29.0

Source: Wheat Research Centre, Dinajpur

Appendix 5: Weather data for growing season of wheat, 2016-2017

Month	Date	Relative humidity (%)	Temperature		Total rainfall (mm)
			Minium (⁰ C)	Maximum (⁰ C)	
November	0 -10	82	18.5	31.6	0.0
	11 - 20	80	15.4	30.7	0.0
	21 -30	81	14.3	29.4	0.0
December	0 -10	84	13.4	28.1	0.0
	11 - 20	86	11.0	24.7	0.0
	21 -31	85	11.9	26.2	0.0
January	0 -10	84	11.4	24.6	0.0
	11 - 20	78	6.9	24.2	10.0
	21 -31	81	10.6	26.1	0.0
February	0 -10	80	11.3	26.5	0.0
	11 - 20	76	13.0	28.8	0.0
	21 -30	73	13.5	29.2	0.0
March	0 -10	73	13.2	29.8	0.0
	11 - 20	75	13.6	27.8	0.0
	21 -31	85	18.2	28.4	68.0
April	0 -10	83	19.5	30.8	4.0
	11 - 20	80	18.2	31.9	0.0
	21 -30	86	20.9	31.6	0.0

Source: Wheat Research Centre, Dinajpur

Appendix 6: Calculated mean square of different sources of variance for the following yield parameters of wheat

Sources of Variation (SV)	df	Mean square							
		Spikelets spike ⁻¹	Spike length	Grains spike ⁻¹	Thousand grain wt.	Grain yield	Biological yield	Spike m ⁻²	Plant height
Replication	2	0.997	0.614**	1.223	1.833	0.043	0.530	92.444	19.983*
Water Regimes (A)	1	71.402**	17.724**	774.694**	13.420	13.750**	87.925**	34596.0**	1834.123**
Error-1	2	1.181	0.008	4.448	3.573	0.009	0.984	32.333	1.189
Wheat genotypes (B)	5	4.710**	3.026**	201.475**	324.792**	0.322**	0.202	1837.978**	249.785**
Interaction (AB)	5	0.391	0.171	9.607**	5.598**	0.238**	0.438**	267.867**	18.337**
Error-2	20	0.412	0.074	2.605	0.948	0.022	0.123	65.322	2.488
Total	35								

Appendix 7: Calculated mean square of different sources of variance for the following growth/ vegetative parameters of wheat

Sources of Variation (SV)	df	Mean square						
		Leaf area index			Shoot length			Max. tillers m ⁻²
		40	55	70	40	55	70	45
Replication	2	0.144	0.006	0.011	6.773	22.824	6.111	8.778
Water Regimes (A)	1	8.366*	33.468**	5.898**	15.458	19.551*	371.847**	447561.000**
Error-1	2	0.413	0.450	0.075	2.940	1.107	4.492	324.333
Wheat genotypes (B)	5	0.393**	1.763**	1.757**	6.615**	86.880**	93.640**	29717.511**
Interaction (AB)	5	0.315**	0.361**	0.127**	0.406	2.223	15.944	3750.800**
Error-2	20	0.040	0.055	0.010	1.133	8.040	15.688	99.456
Total	35							

Appendix 8: Calculated mean square of different sources of variance for the following physiological parameters of wheat

Sources of Variation (SV)	df	Mean square						
		SPAD value (DAA)				Canopy temperature depression (DAA)		RWC
		8	16	24	32	16	24	16
Replication	2	0.305	0.401	2.156	0.101	0.008	0.007	1.361
Water Regimes (A)	1	112.714*	57.760**	18.634**	5.444**	125.253**	123.729**	256.00
Error-1	2	3.595	1.053	0.295	0.044	0.209	0.014	0.750
Wheat genotypes(B)	5	38.471**	153.332**	433.134**	7.319**	5.708**	18.876 **	18.044
Interaction (AB)	5	18.066**	156.261**	151.350**	0.950	9.535 **	12.092**	11.467
Error-2	20	3.759	1.768	1.390	0.651	0.077	0.112	0.589
Total	35							

Appendix 9: Calculated mean square of different sources of variance for the following physiological parameters of wheat

Sources of Variation (SV)	df	Mean square						
		Proline content		Sugar		Starch	Chlorophyll (DAA)	
		Leaf	Seed	Leaf	Seed	Seed	8	24
Replication	2	0.129	0.044	0.392	3.260	2.426	0.002	0.001
Water Regimes (A)	1	10.454**	4.958**	67.021*	1117.231**	184.779*	0.410**	0.242**
Error-1	2	0.123	0.035	2.801	2.070	7.669	0.004	0.001
Wheat genotypes(B)	5	12.332**	15.653**	224.835**	1.608**	132.261**	0.125**	0.060**
Interaction (AB)	5	12.683**	8.863**	35.816**	5.165**	213.150**	0.028**	0.006
Error-2	20	0.115	0.189	1.251	4.292	3.833	0.008	0.002
Total	35							

Appendix 10: Calculated mean square of different sources of variance for the following physiological parameters of wheat

Sources of Variation (SV)	df	Mean square						
		WRC				Days to heading	Days to anthesis	Days to maturity
		9 AM	11 AM	1.00 PM	3.00 PM			
Replication	2	1.460	0.335	1.434	0.745	1.444	0.250	0.528*
Water Regimes (A)	1	62.859**	61.937**	25.891*	77.176**	156.250**	90.250**	44.444**
Error-1	2	0.220	1.018	1.010	0.278	0.333	0.583	0.028
Wheat genotypes(B)	5	0.954	10.748**	9.353**	54.512**	34.761**	26.783**	15.844**
Interaction (AB)	5	3.525**	1.796	2.089	2.039	2.050*	1.983**	0.644*
Error-2	20	0.641	0.813	0.877	0.838	0.756	0.350	0.211
Total	35							

Appendix 11: Spike dry weight of different wheat genotypes at different days after anthesis as influenced by water deficit stress

Genotypes	Water levels	Spike dry weight of different wheat genotypes at different days after anthesis (g spike ⁻¹)											
		0	4	8	12	16	20	24	28	32	36	40	44
BARI Gom 25	Well watered	0.54	0.70	0.82	1.10	1.36	1.62	2.07	2.44	2.63	2.65	2.51	2.44
	Water stress	0.52	0.63	0.76	0.85	1.16	1.46	1.78	2.01	2.18	2.32	2.23	2.16
E 38	Well watered	0.52	0.70	0.84	1.15	1.17	1.79	1.99	2.09	2.25	2.13	2.14	2.01
	Water stress	0.55	0.60	0.81	1.13	1.36	1.54	1.84	2.14	2.18	1.88	1.75	1.41
BAW 1118	Well watered	0.51	0.69	0.82	1.15	1.53	1.64	1.98	2.32	2.42	2.38	2.42	2.21
	Water stress	0.55	0.70	0.77	0.93	1.21	1.42	1.57	1.91	1.96	2.10	1.94	1.75
E 18	Well watered	0.52	0.67	0.93	1.04	1.29	1.77	1.92	1.97	2.14	2.45	2.21	2.05
	Water stress	0.58	0.70	0.80	1.13	1.28	1.43	1.73	1.80	2.11	2.12	1.95	1.85
BARI Gom 26	Well watered	0.52	0.62	0.71	0.87	1.21	1.62	1.92	2.28	2.47	2.62	2.77	2.45
	Water stress	0.51	0.61	0.69	0.76	0.92	1.20	1.50	1.68	1.96	2.20	2.13	1.97
BAW 1130	Well watered	0.50	0.65	0.74	1.08	1.26	1.50	1.91	2.20	2.54	2.81	2.89	2.68
	Water stress	0.55	0.72	0.82	1.04	1.35	1.60	1.72	1.85	1.99	2.10	1.99	1.83

Appendix 12: Calculated mean square of different sources of variance for the following yield parameters of wheat

Sources of Variation (SV)	df	Mean square							
		Spikelets spike ⁻¹	Spike length	Grains spike ⁻¹	Thousand grain weight	Grain yield	Biological yield	Spike m ⁻²	Plant height
Replication	2	2.704*	1.092**	9.090	1.943	0.419**	0.021	93.888	25.480
Potassium levels (A)	4	3.071**	1.733**	21.394*	2.371	0.498**	4.972**	409.305*	66.336**
Error-1	8	0.436	0.136	5.024	0.874	0.014	0.116	82.296	9.383
Wheat genotypes (B)	1	1.323	21.879**	792.588**	2050.960**	0.094	0.015	30400.832**	882.702**
Interaction (AB)	4	0.557	0.070	1.157	0.993	0.039	0.155	5.643	3.046
Error-2	10	0.348	0.159	4.226	0.888	0.025	0.109	91.461	10.604
Total	29								

Appendix 13: Calculated mean square of different sources of variance for the following physiological parameters of wheat

Sources of Variation (SV)	df	Mean square							
		WRC				RWC (DAS)		LAI 60	Leaf dry weight
		9 AM	11 AM	1.00 PM	3.00 PM	65	75		
Replication	2	0.984	0.168	0.929	0.126	0.417	12.126*	0.146	0.266
Potassium levels (A)	4	13.532*	7.710	11.130*	11.587*	17.036**	13.253*	2.303**	5.745**
Error-1	8	3.062	3.180	2.721	3.339	2.845	3.150	0.048	0.151
Wheat genotypes (B)	1	2.611	2.646	8.587**	2.797	105.656**	62.785**	2.446**	2.149**
Interaction (AB)	4	0.164	0.094	0.717	1.214	7.180**	6.226*	0.289	0.790**
Error-2	10	1.728	0.727	0.940	1.439	0.869	1.454	0.121	0.047
Total	29								

Appendix 14: Calculated mean square of different sources of variance for the following physiological parameters of wheat

Sources of Variation(SV)	df	Mean square						Total dry weight
		Nitrogen content (N)		Phosphorus content (P)		Potassium content (K)		
		At 65 DAS	Harvest	At 65 DAS	Harvest	At 65 DAS	Harvest	
Replication	2	0.006	0.047	101.770	174.316	0.066**	0.036**	23.467*
Potassium levels (A)	4	0.212**	0.860**	2213.015**	2314.447**	0.073**	0.056**	19.636*
Error-1	8	0.006	0.025	131.749	149.938	0.003	0.002	4.054
Wheat genotypes (B)	1	0.128**	0.133**	4250.680**	31434.506**	0.002	0.090**	86.089**
Interaction (AB)	4	0.434**	1.072**	401.350*	274.476*	0.012**	0.012**	6.847
Error-2	10	0.008	0.015	90.212	73.601	0.002	0.001	4.414
Total	29							