GROWTH, PHYSIOLOGY AND YIELD PERFORMANCE OF DIFFERENT WHEAT GENOTYPES UNDER VARIOUS WATER DEFICIT CONDITIONS

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CERTIFICATE

*This is to certify that the thesis entitled "**GROWTH, PHYSIOLOGY AND YIELD PERFORMANCE OF DIFFERENT WHEAT GENOTYPE UNDER VARIOUS WATER DEFICIT CONDITIONS**" submitted to the Department of Agricultural Botany, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE (MS)** in Agricultural Botany, embodies the result of a piece of bonafide research work carried out by **TASLIMA YESMIN**, Registration No.**19-10024** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has been duly acknowledged

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DEDICATED TO
MY
BELOVED PARENTS

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GROWTH, PHYSIOLOGY AND YIELD PERFORMANCE OF DIFFERENT WHEAT GENOTYPES UNDER VARIOUS WATER DEFICIT CONDITIONS

ABSTRACT

A pot experiment was conducted to study the growth, physiology and yield performance of different wheat genotypes under various water deficit conditions at Sher-e-Bangla Agricultural University, Dhaka during the period from October 2019 to March 2020. The experiment consisted of two factors, and followed Completely Random Design (CRD) with four replications. Factor A: Wheat genotypes (4) *viz;* V_1: BARI Gom-29, V_2: BARI Gom-30,V_3: BARI Gom-32 and V_4: BARI Gom-33 and and Factor B:Drought level (4) *viz;* D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: no irrigation. Among different wheat genotypes BARI Gom-32 (V_3) performed better and recorded the highest 1000 grain weight (37.38 g) and grain yield plant^{-1} (32.28 g). In case of different drought levels increasing drought levels significantly reduced relative water content, membrane stability index and chlorophyll content comparable to control treatment and the lowest grain yield (23.35 g plant^{-1}) was recorded in D_3 treatment. The highest grain yield (36.18 g plant^{-1}) stover yield (20.80 g plant^{-1}) and biological yield (56.99 g plant^{-1}) was found in D_0 control treatment. In case of harvest index the highest was found in D_3 (69.35 %) treatment. In case of Interaction cultivation of BARI Gom-32 (V_3) and in absence of drought stress condition recorded the maximum grain yield plant^{-1} (38.50 g) comparable to other treatment Interactions. Increasing drought condition disrupted plant growth and development and the lowest grain yield (23.35 g plant^{-1}) was recorded inV_1D_3. Therefore, the growth and yield of wheat decreased with the increasing drought level, and cultivation of drought tolerance wheat genotype can be a suitable approach to tolerate drought stress condition in drought prone areas.

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ABBREVIATIONS

Full word	Abbreviations
Agriculture	Agric.
Agro-Ecological Zone	AEZ
And others	*et al.*
Applied	App.
Bangladesh Bureau of Statistics	BBS
Biology	Biol.
Biotechnology	Biotechnol.
Botany	Bot.
Centimeter	Cm
Cultivar	Cv.
Degree Celsius	°C
Dry weight	DW
Editors	Eds.
Emulsifiable concentrate	EC
Entomology	Entomol.
Environments	Environ.
Food and Agriculture Organization	FAO
Fresh weight	FW
Gram	g
International	Intl.
Journal	J.
Kilogram	kg
Least Significant Difference	LSD
Liter	L
Triple super phosphate	TSP
Science	Sci.
Soil Resource Development Institute	SRDI
Technology	Technol.
Serial	Sl.
Percentage	%

CHAPTER I

INTRODUCTION

Cereals are the main constituent of food and feed. Three major cereals *viz.* rice, wheat and maize are cultivated extensively due to their higher demand in food industries. These cereals along with pulses are the important source of nutrition for human population. Among cereals, wheat [*Triticum aestivum* (L.) em Thell] is one of the most important food grain crop. It is one of the earliest domesticated crop and its cultivation was started nearly ten thousand years ago (Shewry, 2009). Bread wheat is a natural hybrid of ancestral diploid and tetraploid wheat originated in south-eastern part of Turkey (Dubcovsky and Dvorak, 2007). It is a hexaploid species (2n= 6x = 42) with three sub sets of genomes (A, B and D). Wheat grains have a unique place in human diet as it fulfills 55% of carbohydrate and 20% of calorific demand of world population (Kumar *et al*., 2011). Wheat grain has 60-70% starch and 8-15% protein content (Shewry, 2009). In addition, wheat also provides small amounts of vitamins, minerals, micro-nutrients and antioxidants (Alan *et al*., 2000; Shewry and Hey, 2015).

Wheat is a major staple food for more than 4.5 billion people (IIWBR, 2015). It is cultivated in almost every country of the world contributing about 30% of total food grain production (Akter and Islam, 2017). At global level around 764.39 million metric tons wheat is produced from in an area of more than 217 million ha with an average productivity of 3.52 t/ha (USDA, 2020). Although European Union has maximum production of wheat but among various countries China is the largest producer which is followed by other Asian countries (Statista, 2020). Production of wheat in Bangladesh has increased many folds from the time of independence. During the cropping season of rabi 2020-21, Bangladesh has produced 1.18 million metric tons wheat from an area of 335 thousand hectares with an average productivity of 3.52 t/ha (USDA, 2021). Dinajpur, Rajshahi, and Rangpur are the major wheat producing districts in Bangladesh (Karim *et al*., 2010).

Green revolution has increased the production of major cereals many folds. Development of dwarf varieties of wheat and rice and improved management practices are the major causes of green revolution. At present time demand for wheat has been trending upward over the last decade due to changing food habits and increased exports of wheat-based goods. (USDA, 2021). But the situation is changing

again due to the growing population. There are estimates that global population will be around 9.7 billion in 2050 growing at a rate of 0.8% per annum (United Nations, 2019). To feed such a huge population around 880 million metric tons wheat will be required (IIWBR, 2015). Further this situation is more severe in Bangladesh as the amount of agricultural land in Bangladesh decreased by 1% every year (Islam *et al*., 2020) due to increased rural and urban settlements, industrialization, and land shifting into aquaculture (Hasan *et al*., 2013).

These facts clearly show that there is a need to increase the production of wheat to feed the growing population. But the available land under farming is decreasing continuously due to urbanization and developmental activities. Enhancement of yield per unit area is the only option to increase total production of wheat. But again this seems very difficult due to the changing climate which causes various abiotic stresses.

Drought are the major abiotic stresses faced by wheat plants. The temperature of earth is increasing due to various human activities. It is expected that annual average temperatures will increase by 0.95 per cent due to effect of climate change (Khatun and Saadat, 2021). This increasing temperature is very harmful for temperate crop like wheat. This crop requires prolonged winter season to give its maximum potential. As a temperate crop, wheat requires an optimum temperature of 12 to 22°C for proper vegetative growth and seed development (Farooq *et al*., 2011). High temperature particularly during anthesis and grain filling is very harmful for wheat. When the temperature rises beyond 32°C pollen fertility is adversely affected leading to poor grain filling (Pradhan *et al*., 2012). High temperature also affects plants indirectly by causing drought stress.

Drought is a situation where the water demand of plant exceeds its availability leading to improper functioning of plant. The Interaction effect of drought and heat leads to overall change in morphological, physiological, biochemical and molecular functioning of plants. High temperature has been shown to reduce starch deposition, total grain weight, milling yield and increase protein content (Labuschange *et al.*, 2007) and drought has been shown to reduce starch accumulation, cause grain shriveling and increase grain hardness and protein content (Jiang *et al.*, 2009). Grain hardness decreases under heat stress but increase under drought (Li *et al.*, 2013). Weakening of dough due to high temperature during grain filling has also been

reported and has been attributed to changes in protein composition (Blumenthal *et al.*, 1991). The drought stress alone commonly reduces average yield of wheat crop by more than 50% (Bayoumi*et al.*, 2008). About 40% of wheat growing areas are prone to Interaction stress of these two stresses (Zampieri*et al*., 2017). In case of wheat these can lead to reduced yield as well as deteriorated end product. Further managing of these stresses by agronomic and cultural practices is difficult. The only possible alternative to this situation is the development of tolerant varieties which can perform stably under high temperature and drought stress conditions.

The ability of improving wheat cultivars able to make maximum use of existing water and which are drought tolerant is the main objectives of sustaining yield potential in semi-arid and dry areas (Ghasemali *et al*., 2011). In plants, a better understanding of the morpho-anatomical and physio-biochemical characteristics of changes in drought resistance could be used to select or create new varieties of crops to obtain a sustainable productivity under water stress conditions (Martinez *et al*., 2007). The improvement of drought tolerance has been a principal goal of the majority of breeding programmes for a long time, as water deficit at certain stages of wheat growth is common for many wheat growing regions of the world (Farshadfar, 2012). Plant improvement for drought resistance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions where a large number of genotypes can be evaluated efficiently (Naroui Rad *et al.*, 2012). Selection efficiency could be improved if particular physiological and morphological attributes related to yield under a stress environment could be identified and employed as selection criteria for complementing traditional plant breeding (Acevedo, 1991). Keeping the above fact in mind, the present investigation entitled "Comparative studies of growth, physiology and yield performance of different wheat genotypes under drought stress" was planned with the following objectives:

i. To find independent effect of genotype and water deficiency on growth, physiology and yield of wheat.
ii. To evaluate genetic variability of wheat varieties for growth and physiology of wheat plant under water deficit conditions.
iii. To identify suitable wheat genotypes for yield contributing characters and yield of wheat plant under various water deficit conditions.

CHAPTER II

REVIEW OF LITERATURE

An attempt was made in this section to collect and study relevant information available regarding to comparative studies of growth, physiology and yield performance of different wheat genotypes under drought stress, to gather knowledge helpful in conducting the present piece of work.

2.1 Plant stress

Stress in plants refers to external conditions that adversely affect growth, development or productivity of plants (Verma *et al*., 2013). Stresses trigger a wide range of plant responses like altered gene expression, cellular metabolism, changes in growth rates, crop yields, etc. A plant stress usually reflects some sudden changes in environmental condition. However, in stress tolerant plant species, exposure to a particular stress led to acclimation to that specific stress in a time to time-dependent manner (Verma *et al*., 2013). Plant stress can be divided into two primary categories namely

i. Abiotic stress and

ii. Biotic stress.

2.2 Abiotic stress

Environmental stresses provoke numerous plant responses, varying from altered gene expression to metabolic processes. Maintaining higher plant productivity under environmental stresses is plausibly the main challenge facing modern agriculture (Gill and Tuteja, 2010). Among the environmental stresses, drought is a major abiotic stress limiting agricultural crop production and is the most important stresses worldwide (Karami, 2013). Drought, salinity, temperature extremes, nutrient deficiencies and mineral toxicities are all abiotic stresses which reduce plant growth and therefore have a major impact on crop yield. Great concern is that these stresses will be increasingly important due to climate change, land degradation and declining water quality (Carmer,2010; White *et al.,* 2010).Crops respond to the abiotic stresses with various modifications on the morphological, cellular, physiological, biochemical and molecular level (Zhou *et al.*, 2015). In the last decade, lots of studies focused on

the response of crops to a single stress (Chew *and* Halliday, 2010; Hirayama and Shinozaki, 2010). However, several abiotic stresses usually occur concurrently and crops are always subjected to a combination of different abiotic stresses in the field. Among the abiotic stresses, drought and heat stress are two critical threats to crop growth and sustainable agriculture worldwide (Lipiec *et al.,* 2013). Drought stress as a consequence of insufficient rainfall or deficient soil moisture might induce various biochemicals, physiological and genetic responses in plants, which severely restricted crop growth (Vadez *et al.,* 2012).

2.3 Drought stress

Drought affects morphological, physiological, biochemical and molecular processes in plants resulting in growth inhibition, stomata closure with consecutive reduction of transpiration, decrease in chlorophyll content and inhibition of photosynthesis and protein changes (Yordanov *et al*., 2003). Drought is one of the major abiotic stresses that severely affect and reduce the yield and productivity of food crops worldwide up to 70% (Thakur *et al*., 2010; Akram *et al*., 2013). The response of plants to drought stress is complex and involves changes in their morphology, physiology, and metabolism. Reduction of plant growth is the most typical symptom of drought stress (Arora*et al*., 2002). Drought stress leads to accumulation of reactive oxygen species (ROS), generated mostly in chloroplast and to some prolong in mitochondria, causing oxidative stress. Major ROS molecules are singlet oxygen, superoxide anion radicals, hydroxyl radicals and hydrogen peroxide (H_2O_2). Plants under drought stress display some defense mechanisms to protect themselves from the damaging effect of oxidative stress. Plants with high induced antioxidant levels have better tolerance and resistance to oxidative damage (Parida and Das, 2005).

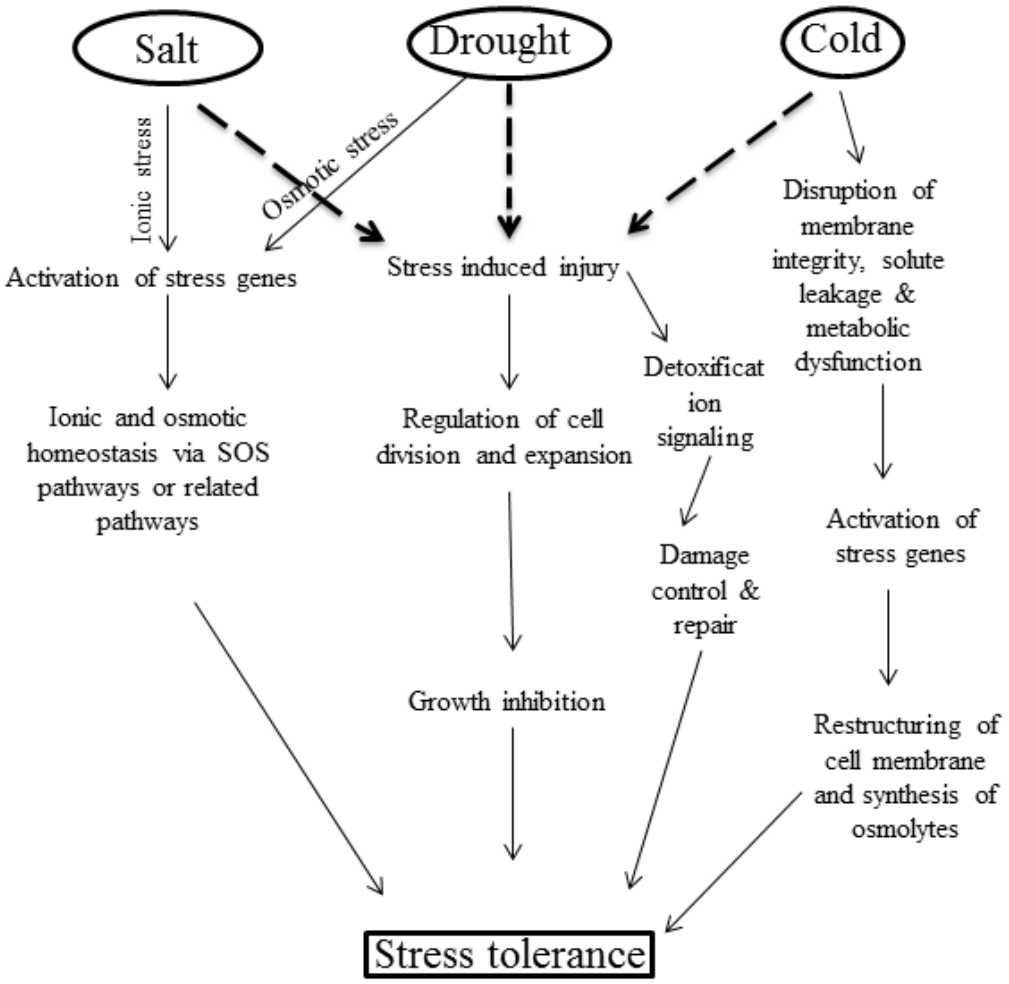


Plate. 1 Pathway under salt, drought and cold stress

Salt and drought disrupt the ionic and osmotic equilibrium of the cell resulting in a stress condition. This triggers the process, which functions to reinstate ionic and osmotic homeostasis leading to stress tolerance. Stress imposes injury on cellular physiology and results in metabolic dysfunction. This injury imposes a negative influence on cell division and growth of a plant. This is an indirect advantage to the plant as a reduction of leaf expansion reduces the surface area of leaves exposed for transpiration and thereby reducing water loss. Stress injury and ROS generated in response to stress also triggers a detoxification signaling by activating genes responsible for damage control and repair mechanism, therefore, leading to stress tolerance. Cold stress mainly exerts its malicious effect by disruption of membrane integrity and solute leakage. Moreover, other physiological factors such as rate of photosynthesis, protein assembly and general metabolic processes are severely hampered. Cold acclimation results in the restructuring of cellular membranes and synthesis of various osmolytes, which function towards

reinstating the normal cellular metabolism and stress tolerance (Mahajan and Tuteja, 2005).

2.4 Drought-induced oxidative stress in plants

Mechanisms of ROS detoxification exist in all plants and can be categorized as enzymatic (superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), peroxidase (POD), glutathione reductase (GR) and monodehydro ascorbate reductase (MDAR)) and non-enzymatic (flavanones, anthocyanins, carotenoids and ascorbic acid (AA). The degree to which the activities of antioxidant enzymes and the number of antioxidants increase under drought stress is extremely variable among several plant species and even between two cultivars of the same species. The level of response depends on the species, the development, and the metabolic state of the plant, as well as the duration and intensity of the stress. Many stress situations cause an increase in the total foliar antioxidant activity (Pastori*et al*., 2000), but little is known about the coordinative control of activity and expression of the different antioxidant enzymes in plant cells that are subjected to drought stress. Several studies have reported enhanced stress tolerance related to overproduction of chloroplastic SOD (Arisi*et al*., 1998; Foyer and Noctor, 2000).

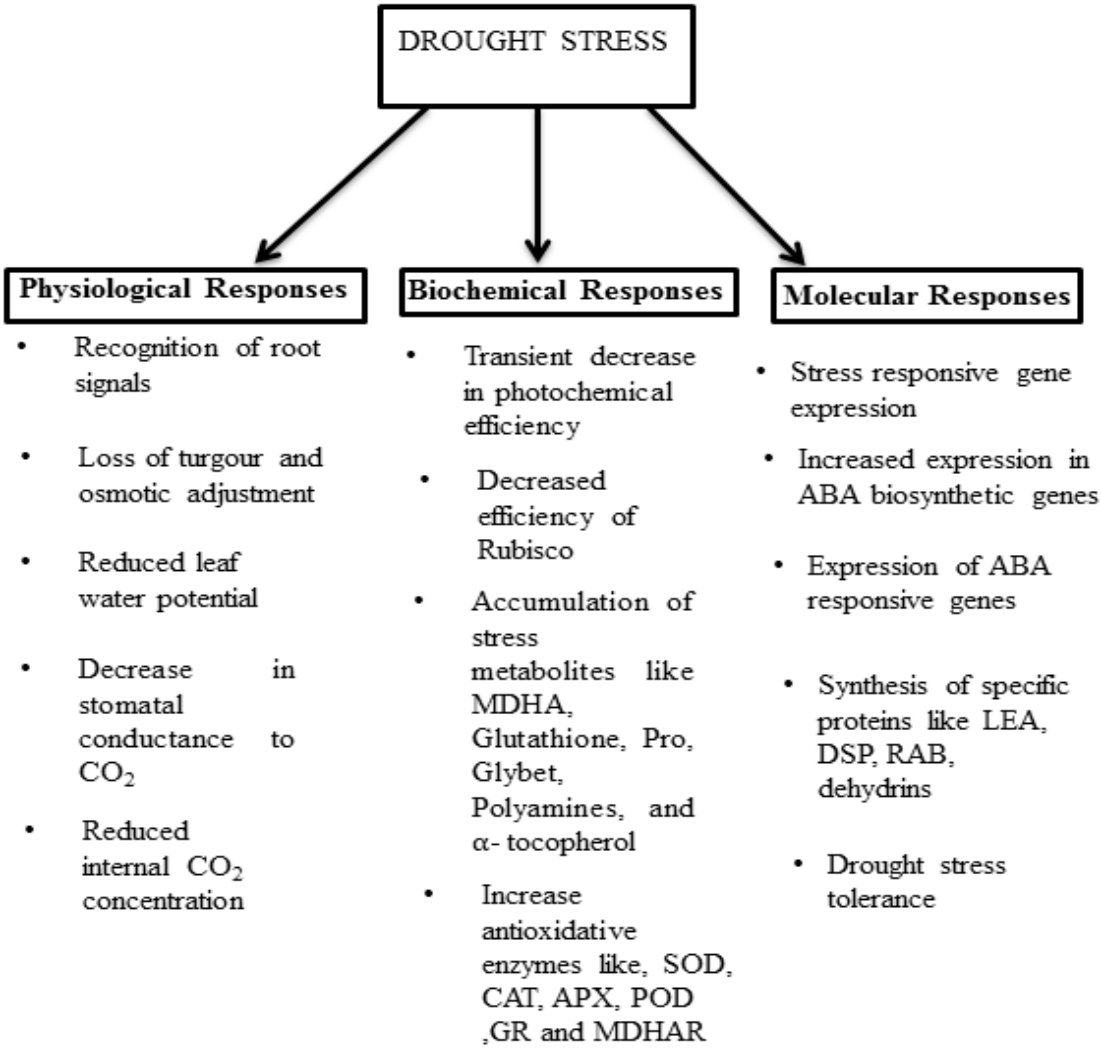


Plate 2. Physiological, biochemical and molecular responses to drought

2.5 Effect of drought stress on morphological characteristics

It has been established that drought stress is very important limiting factor at the initial phase of plant growth and establishment. It affects both elongation and expansion growth (Bhatt and Srinivasa, 2005; Kusaka*et al*., 2005; Shao *et al*., 2008).

Drought stress greatly suppresses cell expansion and cell growth due to the low turgor pressure. Osmotic regulation can enable the maintenance of cell turgor for survival or assist plant growth under severe drought conditions in pearl millet (Shao *et al*., 2008). According to Bhatt and Srinivasa (2005), the reduction in plant height is associated with a decline in the cell enlargement and more leaf senescence in *A. esculents* under water stress. Development of optimal leaf area is important to photosynthesis and dry

matter yield. Water deficit stress mostly reduced leaf growth and in turn the leaf areas in many species of plant-like *Populus* (Wullschleger*et al*., 2005), soybean (Zhang *et al*., 2004) and many other species (Farooq *et al*., 2009). Significant interspecific differences between two sympatric *Populus* species have been found in a total number of leaves, total leaf area biomass under drought stress (Wullschleger*et al*., 2005). The leaf growth is more sensitive to water stress in wheat than in maize (Sacks *et al*., 1997), *Vigna unguiculata* (Manivannan *et al*., 2007) and sunflower (Manivannam *et al*., 2008).

2.6 Effect of drought stress on photosynthesis and respiration

Drought stress induces several changes in various physiological, biochemical, and molecular component of photosynthesis. Drought can influence photosynthesis either through pathway regulation by the stomatal closure and decreasing flow of CO_2 into mesophyll tissue (Chaves *et al*., 2003; Flexas*et al*., 2004) or by directing impairing metabolic activities. The main metabolic changes are a decline in the regeneration of ribulose bisphosphate (RuBP) and ribulose 1,5 bisphosphate carboxylase/oxygenase (Rubisco) protein content (Bota *et al*., 2004), decreased Rubisco activity impairment of ATP synthesis, and photophosphorylation or decreased inorganic phosphorus. In general, during the initial onset of drought stress, decreased conductance through stomata is the primary cause of the decline in photosynthesis (Cronic, 2000). At later stage with increasing severity, drought stress causes tissue dehydration, leading to metabolic impairment. In contrast, there is evidence in some species that non-stomatal inhibition (metabolic activities) may occur first, causing a temporary increase in internal CO_2 concentration (Ci), which causes stomata to close. Recent studies suggest that both diffusive limitations through stomatal closer and non-stomatal limitation (such as oxidative damage to chloroplast) are responsible for the decline in photosynthesis under stress (Zhou *et al*., 2008).

The regulation of respiration under drought stress condition is relatively less understood. It is important to understand these responses, as photosynthesis is temporally (only during daytime) and spatially (green tissues) restricted, while respiration occurs continuously in all organs. Mitochondrial respiration plays a pivotal role in determining the growth and survival of plants. Despite the importance of respiration, studies examining the impact of drought stress on respiration are limited

(Ribas *et al*., 2005). Temperature is one of the most important environmental parameters influencing mitochondrial respiration. Respiration exponentially increases with increasing temperatures from 0^0 to 35^0 or 40^oC, reaching a plateau at 40 to 50^oC. At a temperature above 50 0C, respiration decreases because of damage to the respiratory mechanism. Drought stress can result in decreased leaf and root respiration in the short term (Byrla *et al*., 2001). Temperature quotient (Q10, the relative change in a process with a 10^oC temperature increase) for both root and leaf respiration also decreases with increasing temperatures. However, under field conditions, the relationship between temperature and root respiration is often complicated because of the occurrence of increased soil temperature with drought. In a greenhouse study under ambient and constant soil temperatures, root respiration rates decreased under drought stress conditions (Byrla *et al*., 2001). In addition, it was also observed that drought-induced decrease in root respiration was greater in warmer soils than in cooler soils.

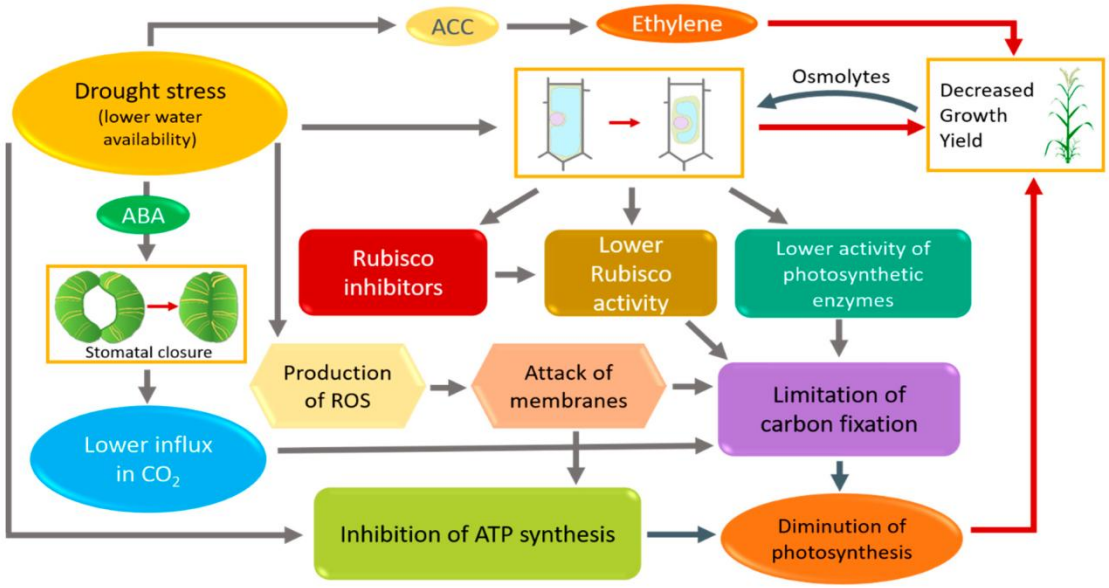


Plate 3. Effect of drought stress on photosynthesis and respiration

2.7 Effects of drought stress on productivity

The severity of drought is unpredictable because of its dependence on many factors such as occurrence, duration and soil moisture retention capacity which are hard to quantify simultaneously (Tuinstra *et al*., 1997). Drought stress causes reduction of plants growth, impairment of photosynthesis and wilting by damaging carbon and nitrogen metabolism (Sanchez *et al*., 2002). Drought stress occurs at different stages

of growth and adversely affects plants growth and yield parameters which lead to reduction in net yield (Kebede *et al*., 2001). The extent of grain losses caused by drought stress vary with genotypes and their stages of growth (Reddy et al., 2007). When drought stress occurs at the seedling stage of crop development, plant establishment is affected (Beyene *et al*., 2015). When drought stress occurs at pre-flowering period in barley and wheat for instance, grain fill phase is shortened and grain yield is reduced by decreasing the number of tillers, spike, grain per plant, grain weight and time to anthesis(Nguyen, 2001). Short duration drought stress mostly reduces grain yield while prolonged drought stress leads to complete death of plant (Farooq and Wahid, 2009). Post-anthesis drought stress is considered more detrimental to grain yield regardless of the stress severity because photosynthesis per unit leaf area is decreased leading up to 70% yield losses. As drought severity increases, photosynthesis is impaired due to a decline in RUBISCO activity which leads to reduction in grain size attributable to interruption of grain filling because of reduced level of sucrose synthase activity (Shamsul *et al*., 2017). Similarly, growth is constrained by the inactivation of adenosine –glucose –pyophysphorylation in wheat (Farooq and Wahid, 2009) while in maize, drought stress causes yield reduction by delaying silking which leads to increased anthesis to silking interval. Drought stress at flowering in maize usually leads to barrenness caused by reduction in the assimilate flux to the developing ear (De La, 2012).

2.8 Effect of drought stress on wheat

Growth attributes

Kizilgeci *et al*. (2017) revealed that, there was decrease in germination percentage and seedling growth with increase in drought stress.

Rashidian *et al.* (2016) revealed that, significant relation between water stress and tillers number ($\alpha = 0.05$). Comparing means showed that the mean of tillers number was 10.33 in normal condition and it decreased to 4.59 in stress condition. The LSD test too indicated that there was significant difference between the two means under normal and stress condition.

Pokharel *et al.* (2013) revealed that, moisture stress had a pronounced effect on number of tillers per plant. The number of tillers for the 60 wheat genotypes was found highly significant and also between optimum and moisture stressed condition as

shown by paired t-test. The average number of tillers in irrigated condition was 2.38 whereas 1.71 in stressed condition.

Kanani *et al.* (2013) reported that in normal irrigation treatment wheat produced the higher flag leaf area (13.83 cm^2) than in the drought condition (9.27 cm^2).

Khan and Naqvi (2011) found that, the plants strive to complete their life cycle as early as possible to cope with drought stress conditions. Therefore days required to initiate heading in wheat are generally decreased due to early start of reproductive stage

Akram (2011) reported drought imposed at different crop growth stages reduced LAI and crop growth rate significantly as compared to that of the fully irrigated plants. Maximum LAI (5.18) was produced (92 DAS) by fully irrigated crops. The average CGR values for at full irrigation, stress at tillering, anthesis and at both stages were 12.58, 11.48, 12.28, and 11.47 g m-2 day^{-1}, respectively. The drought imposed only at vegetative stage reduced LAI than the drought imposed at vegetative + anthesis stage.

Gupta and Gupta (2011) at Bikaner reported that growth parameters of wheat variety HD 2329 like plant height and leaf area significantly reduced under water stress condition. Maximum plant height (75.1 cm) and leaf area (123.7 cm^2) was observed at non stressed condition as compared to 73.3 cm and 100.1 cm2, respectively under water stress condition.

At Iran, Shamsi and Kobraee (2011) reported that water stress significantly decreased the plant height. Maximum plant height was observed under full irrigation stage (85.0 cm) over water stress at stem elongation (55.4 cm), booting stage (64.2 cm) and grain filling stages (79.5 cm). Imposing drought stress at stem elongation had the most impact on reducing the plant height of wheat cultivars.

Khokar *et al.* (2010) at Sindh (Pakistan) reported that reduction in number of tillers and total dry weight per metre of wheat was observed under water stress at anthesis and booting stage as compare to no water stress.

An experiment was carried out by Ahmed *et al.* (2009) to study the effect of different water stresses applied at different crop development stages on the growth component of wheat. They observed that water stress significantly reduced the plant height, effective tillers and dry matter of wheat. The water stress was applied at

prefloweringstage, tillering stage, post flowering stage and terminal stage. The highest reduction in plant height (59.3 cm) was found in terminal stage (no irrigation) in the anmol-91 variety of wheat as compare to normal irrigation (84.3 cm).

Olivares-Villegas *et al.* (2007) found that, large difference in the plant height in response to the reduced soil water availability and the range in height reduction under drought condition varied from 10 to 53%, a reduction paralleled by a yield decrease.

Karim *et al.* (2000) reported that, in non-irrigated condition, stress affect at the formation of tillers in wheat and reduce grain yield by reducing tillers per plant.

Morphological characters

Mekkei *et al.* (2014) showed that, the wheat plants which skipped from the third irrigation (at elongation and before booting stages) go to early flowering by 5 days compared with control treatment and other irrigation treatments. This may be due to the drought stress was occur in end of elongation stage and initiation of booting stage and the plant go to early flowering and early maturation**.**

Kanani *et al.* (2013) from Iran reported that leaf proline content significantly increased from 40.8 µmol/gram fresh weight in normal irrigation to 56 µmol/gram fresh weight in water stress treatment. In drought stress condition, abscisic acid hormone and proline amino acid increased by 56.3% and 37.2% respectively.

Nezhadahmedi *et al.* (2013) reported that drought stress influence plants in terms of inhibition of photosynthesis, decrease in chlorophyll content and relative water content of wheat.

Sharifa and Muriefah (2013) reported that water stress decreased chlorophyll content in wheat.

Khayatnezhad *et al*. (2011) reported that drought stress severely reduced the photosynthetic attributes, water status and chlorophyll content in wheat.

AtIran, Shamsi and Karalee (2011) reported that with an increase in the intensity ofdrought stress on wheat cultivars, there was decreased in relative water content andtotal chlorophyll content. Higher chlorophyll content (sum of the chlorophyll a and b) was observed under no water stress treatment (62 mg^{-1} fresh weight) over stress at stem elongation stage (29.07 mg^{-1} fresh wt), booting stage (36.7 mg^{-1} fresh

weight) and grain filling stage (53.9 mg^{-1} fresh weight). Higher relative water content was observed in no water stress treatment (93.06 %) as compare to stress at booting stage (67.33 %).

Johari *et al*. (2010) reported that due to water stress in wheat free proline content was increased.

Maralian *et al.* (2010) reported that the higher proline accumulation rate was observed at heading stage than tillering stage in wheat under water stress condition.

Nikolaeva *et al*. (2010) noted a decline in chlorophyll content from 13% to 15% in water stressed compared with the well-watered plants in three varieties of wheat.

Abbad *et al.* (2004) studied the effects of water stress on photosynthetic activity of the flag leaf blade and ear of durum wheat genotype. They observed increasing water stress with significantly decreased net photosynthetic rate.

Sharma and Singh (1989) observed a partial closure of stomata led to decreased conductance under water stress resulting into reduce transpiration and photosynthesis.

Yield attributes and yield

Liwani *et al*. (2019) recorded that, higher number of fertile tillers was in the irrigated condition on the other hand, when treatments were stressed, the number of fertile tillers were found to have been reduced after water stress at the tillering stage.

Saleem *et al*. (2016) revealed that, overall yield loss in all the generations and parents was more than 50% under stress conditions while the maximum loss of 77% was observed in P_2 (8126) when the minimum yield loss of 51% so ccurred in P_1 (NR 371).

Saeidi and Abdoli (2015) revealed that, the ability of plants to allocate photosynthetic assimilates to produce economic yield. A significant variation was noted for this trait among the cultivars under both well-watered and post-anthesis water stress conditions. Post anthesis water stress significantly decreased harvest index in most of the cultivars. Under well-watered conditions, Pishgam and Chamran cultivars had the highest (48.0 ± 0.8%) and lowest (41.4 ± 0.9%) harvest index, respectively. Under post-anthesis water stress Pishgam and Zarinhad the highest (42.3 ± 1.7%) and the lowest (34.2 ± 2.1%) harvest index.

Sheoran *et al.* (2015) revealed that, water stress that occurred at different growth stages showed a significant effect on the 1000 grain weight (TGW). When the stress was imposed at the tillering stage, a significant reduction in TGW was observed in all the genotypes under severe stress except AKAW 3717. The disturbed plant physiological conditions caused by drought treatment at the tillering stage might reduce the TGW. At anthesis stage, maximum reduction in TGW was observed in genotype HD 2687 (25 %), whereas at 15 Days after anthesis, genotype AKAW 3717 showed the highest reduction in TGW under severe stress. Under medium stress at 15 Days after anthesis, no significant difference for TGW was observed in C 306. In this study, two stages, i.e. at anthesis and 15 Days after anthesis, were found sensitive to TGW reduction under drought. The stem water soluble carbohydrates and the current photosynthesis are very important for grain development in wheat. This material is translocated from leaves, culm and head to the grain at the grain filling stage. The decreased TGW due to drought at anthesis and 15 Days after anthesis would have been due to decreased water supply and soluble carbohydrates and a reduction in the number of endoplast cells and amyloplasts in the grain.

Khan *et al.* (2013) studied the character association studies of seedling traits in different wheat genotypes under moisture stress conditions. The result indicated that there was significant effect of moisture stress on number of grain spike^{-1}.

Sokoto and Singh (2013) reported that water stress at tillering significantly reduced spike length and grains per spike. Whereas, water stress at flowering and grain filling significantly reduced 1000-grain weight, grain yield and harvest index. They also indicated significant ($P<0.05$) effect of sowing date on length of spike, spikelets per spike, grains per spike and grain yield. Early sown wheat significantly differed from the late sown wheat in all parameters measured. Yield and yield components decreased with delay in sowing date and it was highest at 21st November and 5th December and lowest at 19th December and 2nd January. Finally they reported that water stress at flowering and grain filling are the most critical growth stages in yield determination inwheat, because plants cannot recover, while delay in sowing resulted in reduction in yield and yield components.

Hossain *et al.* (2012) observed that high temperature (air, soil) and drought from germination to reproductive stages of the late sowing crop affected spike length, number of grains/spike and 1000 grain weight in spring wheat.

Galavi and Moghaddam (2012) revealed that, 14 % reduction in grain yield when irrigation was skipped at the maximum tillering stage as compared to a 25% reduction caused by missing irrigation after flowering. Similarly, compared to well-watered wheat, applying water at 75% and 50% of the crop requirement caused grain yield reduction of 12% and 20% respectively.

Balla *et al.* (2011) investigated the effect of high temperature and drought (during grain-filling) on the quality and components yield of five winter wheat varieties. He revealed that drought and drought + heat were found to have much greater influence on the yield and quality than heat stress alone. Averaged over the varieties, the yield losses were 57% after drought, 76% after drought + heat, and only 31% after heat stresses.

Fayaz and Arzani (2011) reported that, grain yield had a range from 6.4 t/ ha for Roshan to 9.5 t/ ha for Moreno under non stress conditions and varied from 2.9 to 5.7 t/ ha for Prego and Alamos 83 cultivars under moisture stress conditions.

Maralian *et al*. (2010) reported that yield parameter of wheat such as spike length, spikelets spike^{-1}, grains spike^{-1}, and grain weight spike^{-1} decreased under water stress condition when stress was given at before tillering stage and after heading stage. Water stress at tillering or heading stages, decreased the seed yield more than 37%.Stress at heading stage reduced straw yield more as compare to stress at tillering stage.

Talebi *et al.* (2009) observed that, significant difference among stress conditions for grain yield and suggested that high yield potential under normal conditions does not necessarily results in improved yield under stress conditions.

Samara *et al*. (2009) reported that, the effect of late terminal drought stress on barley growth, yield and physiology, and they found that drought stress during grain filling period reduced grain yield by 73 to 87%, together with all the grain yield components. Barley grain yield under severe drought stress was positively correlated with grain

filling duration and gross photosynthetic rate and negatively correlated with leaf water potential.

Rajala *et al.* (2009) revealed that, in non-irrigated condition drought occurring during the grain filling period is known to induce grain abortion and reduce grain filling capacity, i.e. sink strength adjust to reduce source capacity.

Ahmed *et al.* (2009) conducted an experiment to study the effect of different water stresses on the yield component of wheat. The highest reduction in number of grains spike^{-1} (34.51) in terminal drought over the normal irrigation (52.3), post flowering stage (48.6), pre-flowering drought (43.1), tillering stage drought (40.7).

Bayoumi *et al.* (2008) observed that drought stress caused reductions in spike length by 23.7% as compared to control.

Duggan and Fowler (2006) observed in a study that in a drought-stress condition, two factors the number of grains per spike and grain weight per spike played a significant role in the formation of grain yield. But in a favourable moisture condition, grain weight did not significantly influence grain yield.

Samarah (2005) had reported decreased grain yield under the drought stress condition as a result of decreased 1000-grain weight, the number of tillers, and the number of spikes and grains in the plant. He reported drought stress reduces grain yield per spike by decreasing the number of grains per spike.

Veesar *et al.* (2005) reported that reduction occurred in spikelets spike^{-1} of wheat when stress was given at tillering stage (10.98%) and the declines of 20.74, 46.85 and 101.23% were recorded in grain yield when stresses were subjected at tillering, booting and grain formation, respectively.

Yang *et al.* (2001) revealed that, terminal drought occurring during the grain filling period is known to induce grain abortion and reduce grain filling capacity, i.e. sink strength adjust to reduce source capacity.

Raynolds *et al.* (2000) reported that, post anthesis drought stress reduces grain filling rate, resulting in reduction of 1000 grain weight.

Reynolds *et al.* (2000) reported that post flowering drought stress reduced grain filling rate resulting in reduction of 1000 grain, spike and number of grain per spike in wheat.

Siddique *et al.* (1999) revealed that, post-anthesis drought causes high tiller mortality, reduction in photosynthesis and duration of grain filling leading to shriveling of the grains and finally reduce grain yield.

Zhong-hu and Rajaram (1994) reported that, spikes were more sensitive to drought as non-irrigated condition reduces spikes number. Water deficit around anthesis caused a decrease in plant fertility and affected wheat yield by reducing the number of grains per spike.

Shahinnia *et al*. (2005) reported that, C 306 and some of the drought-tolerant lines had high TGW and kernel number under water stressed condition, but most lines that had high Kernel number had relatively low TGW and vice versa. A kernel weight to kernel number compensation took place for efficient channelling of assimilates between the source and the sink.

Plaut *et al.* (2004) revealed that, weight of 1000 grains was sharply reduced by occurring drought stress in the post anthesis stage.

2.10 Effect of wheat genotypes

Growth attributes

Gupta *et al.* (2020) investigated the influence of planting conditions and nitrogen levels on the performance of three wheat cultivars (HD 2967, RSP 561 and WH 1105) and findings showed that WH 1105 had considerably greater plant height (105.5 cm), LAI (4.43), dry matter accumulation (277 g/m row length) and crop growth rate than the other types.

Bachhao *et al.* (2018) while studying the effect of different varieties on growth attributes found that in variety Topawan the growth parameters viz. plant count (33.36), plant height (81.49 cm), number of functional leaves/plant (1.83), total number of tillers per meter length (101.97), leaf area (0.75 cm^2) and dry matter/plant (12.15 g) were found significantly higher in variety than other varieties like Trimbak and Godawari.

Sandhu and Dhaliwal (2017) tested nine wheat varieties (PBW 725, PBW 677, HD 3086, WH 1105, HD 2967, PBW 621 and PBW 550 are timely seeded varieties, whereas PBW 658 and PBW 59 are late sown varieties) to evaluate their performance and stated that varieties HD 3086, WH 1105 and PBW 550 took considerably less days for maturity as compared to rest of the varieties. Significantly higher plant height was recorded in the wheat variety PBW- 677 than rest of the varieties.

Gill *et al*. (2014) investigated the phenological behaviour of two wheat types (PBW 343 and PBW 621) under various environmental circumstances and discovered that PBW 621 took substantially less time to complete different phenological stages like flag leaf (93 days), booting (100 days), heading (108 days), anthesis (117 days) and physiological maturity (140 days) than PBW 343.

Al-Musa *et al*. (2012) conducted an experiment in Bangladesh using four varieties i.e. BARI ghom-23, BARI ghom-24, BARI ghom-25 and BARI ghom-26 to evaluate their parameters and observed that significantly higher plant height (47.91 cm), LAI (1.84), dry matter (17.37 g per plant) was recorded by wheat variety BARI ghom-26.

Mohammad *et al*. (2011) reported the significant effect of varieties on plant height.

Lad *et al*. (2002) also recorded the significant differences among the genotypes for number of tillers indicating appreciable amount of variability among the genotypes of wheat.

Morphological characters

Almeselmani *et al.* (2011) reported that high RLWC is a resistant mechanism to drought, and is the result of more osmotic regulation or less elasticity of tissue cell wall and has significant association with yield and stress tolerance. The differences in RLWC in wheat leaves may also be due to differences in the ability of the tested varieties to accumulate and adjust osmolyte to maintain tissue turgor. The difference in RLWC of wheat cultivars that are under drought stress may be due to the differences in their ability to absorb more water from soil or the ability of the stomata to reduce the loss of water.

Saxena *et al.* (2011) reported that RWC which plays a vital role in metabolic and physiological processes that are occurring in plant tissues was found to be high in high yielding cultivars under early and late growing condition in wheat, maintaining the higher water potential.

Datta *et al.* (2011) conducted an experiment with wheat varieties (K-9107, HD-2954, RAJ-4125, HUW-234 and (NW-2036) in order to assess the relative capability of drought tolerance by measuring pH of leaf extract and RWC. They found maximum pH value in RAJ-4125 (6.45) and minimum K-9107 (6.19). They recorded highest RWC in RAJ-4125 (98.35) under controlled condition and RAJ-4125 (95.25) and NW-2036 (95.78) in case of stressed condition. Finally result was observed that RAJ-4125 variety were found to be mostly drought tolerant among the other experimental varieties.

Bayoumi *et al.* (2008) evaluated nine wheat (*Triticum aestivum*L.) genotypes under two water regimes (stress and non stress treatments). Combined analysis of variance over two seasons showed highly significant differences among wheat genotypes for all the characters under study and mean values were significantly reduced under water stress condition. The superior genotypes Sahel 1, Rufom 5 and Giza 168 which gave higher relative water content (RWC) accumulated free proline (Pro) and had lower drought susceptibility index (S) values.

Izanloo *et al.* (2008) reported that the decrease in chlorophyll content under drought stress has been considered a typical symptom of oxidative stress and may be the result of pigment photo-oxidation and chlorophyll degradation Water deficit leads to an increased depletion of chlorophyll and a decreased concentration of chlorophyll in wheat leaves.

Vendruscolo *et al*. (2007) found that proline is involved in tolerance mechanisms against oxidative stress and this was the main strategy of wheat plants to avoid detrimental effects of water stress. Under stress condition, proline is synthesized from glutamate due to loss of feedback regulation in the proline biosynthetic pathway.

Choudhary *et al.* (2005) in rice reported relatively higher RLWC in 45 day old drought tolerant than susceptible rice cultivars under osmotic stress.

Nayyar and Walia (2003) reported that in wheat, it has been found that proline concentration was higher in stress-tolerant cultivars than in susceptible cultivars.

According to Rane *et al.* (2001) RWC of flag leaf in different wheat genotypes ranged from 87.8 to 94.5% at 45 days after sowing and from 87.5 to 94.7% at 73 days after sowing under irrigation condition in pot culture experiment.

Yadav *et al.* (2001) found that RWC of flag leaf of different wheat genotypes were ranged from 68.1 to 77.0% at anthesis stage and 41.4 to 64.2% at milky stage under irrigated condition in pot culture experiment.

Mishra and Mishra (1987) founded considerable inhibition of chlorophyll synthesis during water stress, even after complete rehydration of wheat seedlings. Younger seedlings were more prone to stress than older seedlings. However, the rate of inhibition of chlorophyll synthesis varied with genotypes and plant age.

Alberte and Thornber (1977) reported that majority of chlorophyll was lost from mesophyll cells and the light harvesting chlorophyll a/b protein

Sirohi and Ghildiyal (1975) reported that variation existed in chlorophyll content of wheat leaves of different varieties. It decreased continuously from full expansion to senescence and this loss was mainly due to reduction in lamellar content of leaf.

Yield attributes and yield

Yusuf *et al.* (2019) in a study to investigate the influence of sowing dates and varieties (HS 562, HD 2967, HD 3086, HI 1544, MACS 6222, WR 544 and WH 1105) on the yield and quality performance of wheat and came to the conclusion that the wheat variety HI 1544 recorded a significantly higher number of effective tillers (94.6 per mrl), grains per ear (48.4), test weight (38.6 g) and grain yield (4920 kg ha^{-1})

Singh *et al*. (2017) conducted an experiment to study the effect of sowing environment (4th and 19th of November and 4th December) wheat varieties (HD-2967, RSP-561 and RAJ- 3077) at Chatha, Jammu and concluded that among varieties HD-2967 recorded significantly higher number of earheads/m2 (230.8), earhead length (9.33 cm), earhead weight (11.4 g), 1000 grain weight (42.4 g) and grain yield (32.85 q/ha) as compared to other two varieties.

Singh and Uma (2015) carried out a test with three sowing dates and seven wheat cultivars (BPW 621-50, HD-3086, WH-1105, DBW- 88, DBW-17, SD-2967 and PBW-550) and found that BPW 621-50 produced maximum number of effective tillers, longest ears, more number of ears per earhead, higher number of kernels/ear, higher kernel weight and higher 1000-kernel weight than the other genotypes under all sowing seasons.

Chourasiya *et al*. (2013) conducted an experiment to examine the performance of different varieties depending on the dates of sowing and found that the yield characteristics and the yield of the wheat crop varied significantly due to the variety of wheat. Among the varieties, HI 8498 produced a significant maximum grain yield (60.82 q ha^{-1}) and straw yield (80.63 q ha^{-1}) whereas GW 366 had the lowest grain and straw yield. The higher grain yield with the wheat variety HI 8498 was attributed to more yield attributes, i.e. tillering number m^{-2}, ear head m^{-2}, grain number ear^{-1} and test weight compared to the other varieties

Ram *et al*. (2012) in an experiment used three wheat varieties *viz.* PBW 550, PBW 343 and DBW 17 at Ludhiana (Punjab) with four seed rates and stated that the maximum grains/ear (50.3), ears/m2 (278.5), test weight (35 g) and biological yield (95.8 q/ha) was recorded in variety PBW 550 which was significantly higher than PBW 343 and DBW 17.

Singh *et al*. (2012) assessed the morpho-physiological and yield characteristics of twenty irrigated wheat genotypes sown in time and showed that the yield was significantly higher (5.55.7 t ha^{-1}) for DBW 17, HD 2687, HD 2894, PBW 343, PBW 550 and UP 2338, while it was lower in UP 2425, PBW 509, HI 1544 and DBW 16 (4.64.9 t ha^{-1}).

Nasim *et al*. (2012), carried out a study on the comparative performance of wheat cultivars for growth and grains production at Pakistan. In their study the growth and yield parameters of eleven wheat varieties including two advance lines *viz*., Inqlab-91, Chakwal-97, Iqbal-2000, Uqab-2000, Ufaq-2000, Wafaq-2000, Sh-2002, As-2002, Bhakkar-2001, 95153 and 97052 were compared . The planned study was conducted at University of Agriculture, Faisalabad, Pakistan. They found that the maximum spikelets and grains were counted in spike obtained from Chakwal-97, but variety Bakkhar-2002 was poor for both the characters. The spikelets in Wafaq-2000 were statistically similar with Inqlab-91 and Ufaq-2000. The number of grains per spike in Iqbal-2000 did not differed significantly over advance lines 95153 and 97052.

Kumar and Gupta (2012) revealed that, genotypes produced significantly higher grain yield/plant in normally irrigated (E1) environment than moisture stress (E2) environment. Genotypes PBW 175, RSP 81, PBW 500, K 9943 and HUW 576 showed higher grain yield/ plant in E1 environment and minimum reduction in grain

yield per plant under moisture Stress (E2) environment which is possibly due to speedy transport of photosynthates.

Lonbani and Arzani (2011) evaluated the genotypic effects on tolerance to terminal drought stress in triticale and to compare it with that of durum and bread wheat under drought stress and normal field conditions using morpho-physiological traits. Morpho-physiological traits including chlorophyll content, relative water content (RWC), excised leaf water retention (ELWR), rate of water loss (RWL), initial water content (IWC), leaf area, leaf angle, number of stomata, pollen viability, dry weight of awn and awn length were evaluated. Results of combined analyses of variances indicated the highly significant differences among genotypes for all traits.

Mattas *et al*. (2011) reported significant variations among the varieties for weight of 1000 grains weight.

Golabadi *et al.* (2008) studied genetic variation in grain yield and morpho-physiological traits in wheat. Grain yield, harvest index, excised leaf water retention and relative water content were significantly and negatively affected by drought stress. Genetic variance estimates were highest under drought stress for grain yield but for harvest index and relative water content were highest under irrigation. They suggested that selection criteria for improving grain yield must include biological yield and 1000 grain weight in nonstress environment and harvest index and number of grains per spike in stress environment with the highest direct effect.

Tripathi *et al.* (2005) studied performance of timely and late-sown cultivars under different sowing times. A field experiment was conducted during winter seasons of 2005–06 to 2006–07 at the Directorate of Wheat Research, Karnal, to evaluate the timely sown and late sown recommended cultivars under normal, late, and very late sowing conditions. They found that three timely sown cultivars (PBW 343, HD 2687, and PBW 502) performed better Thousand-grain weight was greatest in PBW 502 and the lowest in HD 2687.

Tavakol and Pakniyat (2007) evaluate ten wheat genotypes (Azar 2, Gahar, Koohdasht, Bow, Zagros, Cham, Niknejad, El Neilairi, Bohoih and Giza 164) using PEG 6000 solution (0, -5 and -8 bar) under hydroponic condition. They found increasing stress levels caused reduction in biological yield, shoot dry weight, root dry weight and root length. Azar2, Gahar, Koohdasht, Zagros and Bow were in

favouritecondition in regard criteria. Therefore, they were drought tolerant and might be suitable genotypes at water deficit conditions. Niknejad, El Neilairi and Cham were moderate and Giza 164 and Bohoih were sensitive genotypes to drought conditions.

Sharma *et al*. (2003) reported that the highest harvest index was recorded in the wheat genotypes which were grown in well irrigated environmental condition compared to that of the genotypes which were grown in mild and severe stress condition.

Gupta *et al*. (2002) also reported the highest harvest index in normal sown condition in comparison to that of the late sown wheat genotypes.

Chowdhury (1990) screened 115 genotypes of *Triticum aestivum*and *T. durum* for drought tolerance. Genotypic differences were found under drought/rainfed conditions for grain yield, biologicalyield and harvest index.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at the farm of Sher-e-Bangla Agricultural University, Dhaka to investigate the growth, physiology and yield performance of different wheat genotypes under various water deficit conditions. Materials used and methodologies followed in the present investigation have been described in this chapter.

3.1 Experimental period

The experiment was conducted during the period from October 2019 to March 2020 in Rabi season.

3.2.1 Geographical location

The experiment was conducted in the Agronomy field of Sher-e-Bangla Agricultural University (SAU). The experimental site is geographically situated at 23°77′ N latitude and 90°33′ E longitude at an altitude of 8.6 meter above sea level (Anon., 2004).

3.2.2 Agro-Ecological Zone

The experimental site belongs to the Agro-ecological zone (AEZ) of "The Modhupur Tract", AEZ-28 (Anon., 1988 a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon., 1988 b). For better understanding about the experimental site has been shown in the Map of AEZ of Bangladesh in Appendix-I.

3.2.3 Soil

The soil of the experimental field belongs to the General soil type, Shallow Red Brown Terrace Soils under Tejgaon soil series. Soil pH ranges from 5.4–5.6 (Anon., 1989). The land was above flood level and sufficient sunshine was available during the experimental period. Soil samples from 0–15 cm depths were collected from the Sher-e-Bangla Agricultural University (SAU) Farm, field. The soil analyses were done at Soil Resource and Development Institute (SRDI), Dhaka. The morphological and physicochemical properties of the soil are presented in below table.

Morphological characteristics of the experimental area

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University soil research field, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

The initial physical and chemical characteristics of soil use in this experiment

Physical characteristics	
Constituents	Percent
Sand	26
Silt	45
Clay	29
Textural class	Silty clay
Chemical characteristics	
Soil characteristics	Value
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10

Sourse: Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

3.3 Experimental materials

3.3.1 Plant material

BARI Gom -29, BARI Gom -30, BARI Gom -32 and BARI Gom -33were used as experimental materials for this experiment. The important characteristics of these are mentioned below:

BARI Gom -29

BARI Gom -29 Developed byBangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh and released in year of 2014. The main characteristics of this variety are short duration, plant height 95-100 cm. Number of tiller/plant 4-5, 55-60 days require for spike initiation,crop duration 102-108 days, spike broad, grain/spike 45-50, grain white, bright and medium, 1000 grain weight 44-48 g, tiller straight in seedling, plant deep green, very few hair present in upper node of culm. Flag leaf straight, glum of lower portion of spikelet shoulder medium broad and indented, lip tall(>12.1 mm) and spine has present in lip. Its tolerant to leaf rust and leaf blight give an average yield of 4.0-5.0 t ha^{-1}.

BARI Gom -30

BARI Gom -30 Developed byBangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh and released in year of 2014. The main characteristics of this variety are short duration, plant height 95-100 cm. Number of tiller/plant 4-5, 55-60 days require for spike initiation,crop duration 102-108 days, spike broad, grain/spike 45-50, grain white, bright and medium, 1000 grain weight 44-48 g, tiller straight in seedling, plant deep green, very few hair present in upper node of culm. Flag leaf straight, glum of lower portion of spikelet shoulder medium broad and indented, lip tall(>12.1 mm) and spine has present in lip. Its tolerant to leaf rust and leaf spot disease (blight). Heat tolerant and give an average yield of 4.0-5.0 t ha^{-1}.

BARI Gom -32

BARI Gom -32 Developed byBangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh and released in year of 2017. The main characteristics of this variety are high yielding, early in maturity and tolerant to terminal heat stress. The variety is resistant to leaf rust and tolerant to BpLB disease. The variety also shows

tolerance to wheat blast. Grains are white amber in colour and large in size (50-58g). Spikes are long with 42-47 average grains per spike. Leaves are broad and recurved. Glaucosity is medium in spike, culm and flag leaf sheath. Few hairs present in upper culm node. Lower glume beak (LGB) length is medium in length (7.0 mm). LGB spicules- numerous, LGB shoulder medium in width and elevated. Its Resistant to leaf rust and Bipolaris leaf blight. The variety also shows tolerance to wheat blast disease. and give an average yield of 4.6-5.0 t ha^{-1}.

BARI Gom -33

BARI Gom -33 Developed by Wheat Research Centre (WRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh and released in year of 2017. The Main characteristics of this variety are stem and leaf are dark green color, tillers are semi erect during heading. Flag leaf is wide and droopy. Glaucosity is weak in spike. Zn-enrich variety. and give an average yield of 4.0-5.0 t ha^{-1}.

3.3.2 Earthen pot

Earthen pots of having 12 inches diameter, 12 inches height with a hole at the centre of the bottom were used. Silt soil was used in the experiment. Twelve kilogram sun-dried soils were put in each pot. After that, pots were prepared for seed sowing.

3.4 Drought treatment

As my treatments were irrigation related, irrigation was applied very carefully. First irrigation was given at 20 DAS or CRI stage, second irrigation was given at 45 DAS or at flowering stage and third irrigation was given at grain development stage or 80 DAS according with per treatment requirement. Water deficit was maintaint through using soil moisture meter model no. MS350A.

3.5 Experimental treatment

There were two factors in the experiment namely different wheat variety and drought level as mentioned below:

Factor A: Wheat varieties (4) *viz;*

V_1: BRRI Gom-29
V_2: BARI Gom-30

V_3: BARI Gom-32 and

V_4: BARI Gom-33

Factor B: Drought level (4) *viz;*

D_0: Control (3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS).

D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS);

D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS)

D_3: No additional irrigation.

3.6 Experimental design

The experiment was laid out in completely Random Design (CRD) with 2 factor and four replications. Total 48 unit pots will be made for the experiment with 16 treatments having 3 replication. Each pot will be of required size. Soil Moisture Meter model no. MS350A was used for determination of water deficit in soil.

3.7 Detail of experimental preparation

3.7.1 Seed collection and sprouting

The seeds were collected from Wheat Research Center at Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.Healthy and disease free seeds were selected, following standard technique.

3.7.3 Preparation of the pot

The upper edge diameter of the pots was 30 cm (r= 15 cm). While filling with soil, the upper one inch of the pot was kept vacant so that irrigation can be provided using a hose pipe. The preparation of the pot was done in 6 November 2019.

3.7.4 Fertilizer management

Urea, TSP, MoP, Gypsum, Zinc-oxide and Boric acid were used at the rate of 200, 72, 66, 110, 4 and 5 kg ha^{-1}, respectively (FRG, 2018), which were 2.00, 0.72, 0.66, 1.10, 0.04 and 0.05 g pot^{-1}, respectively and mixed all of them except urea with the soil

before fill-up the pot. Urea was applied in three equal instalments at pot filling, 21 DAS and 55 DAS.

3.7.2 Seeds sowing to the pot

Before sowing, seeds were treated with Provex 200EC @ 2.5 g powder for kg^{-1} seed. Fifteen seeds were sown in each pot on 21st November 2019. After sowing, the seeds were covered with soil and lightly pressed by hand. For assessment, five plants were kept in each pot after 14 DAS.

3.10 Intercultural operations

3.10.1 Weeding

During plant growth period two hand weedings were done. First weeding was done at 20 days after sowing followed by second weeding at 15 days after first weeding.

3.10.2 Irrigation

Irrigations were done at according with par treatment requirement.

3.10.3 Plant protection measures

The wheat crop was infested by Aphid and rodent. Therefore, contact insecticide (Malathion @ 22.2 mm per 10 litres of water) was given two times and 2% zinc sulphide was applied in some times because wheat field was highly infested by rodent.

3.10.4 General observation of the experimental field

The field was observed time to time to detect visual difference among the treatment and any kind of infestation by weeds, insects and diseases so that considerable losses by pest was minimized.

3.10 Crop sampling and data collection

Pot from each replication were randomly selected and marked with sample card. Different data were recorded from selected plants at various growth stage.

3.10.5 Harvesting and post harvest operation

Maturity of crop was determined when 90% of the grains became golden yellow in color. Data on different crop characters, yield attributes and yield were collected

from the harvested five plants from each pot. Post-harvest operations like- threshing, cleaning and drying of grains were done separately for each treatment. Properly dried grain and straw were weighed and converted into g plant^{-1} basis.

3.13 Data collection

The data were recorded on the following parameters

a. Crop growth parameters:

i. Plant height (cm)
ii. Number of tillers plant^{-1}

b. Physiological parameters:

iii. SPAD value
iv. Relative water content (RWC)
v. Membrane stability index (MSI)

c. Yield contributing parameter:

vi. Days to first flowering
vii. Days to maturity
viii. Filled grains spike^{-1}
ix. Unfilled grains spike^{-1}
x. 1000 grain weight (g)

d. Yield contributing parameter

xi. Grain yield pot^{-1} (g)
xii. Straw yield pot^{-1} (g)
xiii. Biological yield pot^{-1} (g) and
xiv. Harvest index

3.14 Procedure of data collection

i. Plant height (cm)

The height of the randomly selected 2 plant from each pot was determined by measuring the distance from the soil surface to the tip of the leaf at 20 DAS interval and harvest respectively. Mean plant height of rice plant were calculated and expressed in cm.

ii. Number of tillers plant^{-1}

Number of tillers plant^{-1} were counted at 20 days interval up to harvest from pre selected hills and finally averaged as their number plant^{-1}. Only those tillers having three or more leaves were considered for counting.

iii. SPAD value

SPAD value was measured with the help of spadometer instruments. The top, middle, and bottom of each leaf blade were measured with this instrument. Then it was averaged and counted as chlorophyll content.

iv. Relative water content (RWC)

Three leaflets were randomly selected from each pot and cut with scissors. Relative water content (RWC) was measured according to Barrs and Weatherley (1962). Relative water content was measured at 50 DAT. Leaf laminas were weighed (fresh weight, FW) and then immediately floated on distilled water in a petridish for 4 h in the dark. Turgid weights (TW) were obtained after drying excess surface water with paper towels. Dry weights (DW) were measured after drying at 80^0C for 48 h. Then calculation was done using the following formula:

$$\text{RWC}\,(\%) = \frac{\text{FW- DW}}{\text{TW-DW}} \times 100$$

v. Membrane stability index (MSI)

The wheat leaf membrane stability index (MSI) was determined according to the method of Premachandra*et al*. (1990). Leaf discs (0.1 g) were thoroughly washed in running tap water and double distilled water and thereafter, placed in 10 ml of double distilled water at 40°C for 30 min. After that, the EC was recorded by Conductivity Bridge (make - Systronics; model - 306) (C1). Subsequently, the same samples were placed in the boiling water bath (100°C) for 10 min and their EC was recorded as above (C2). The membrane stability index (MSI) was calculated as, MSI (%) = (1- (C1 /C2) × 100 (Sairam *et al*., 1997).

vi. Days to first flowering

The date of flower blooming was recorded from the number of days required for flower blooming after sowing.

vii. Days to maturity

Variety wise maturity dates were recorded after sowing.

viii. Number of filled grains spike $^{-1}$

Number of filled grains were counted from 5 spikes and averaged to determine the number filled grains spike $^{-1}$.

ix. Number of unfilled grains spike $^{-1}$

Number of unfilled grains were counted from 5 spikes and averaged to determine the number unfilled grains spike $^{-1}$.

x. Weight of 1000-grain (g)

One thousand cleaned dried seeds were counted randomly from each sample and weighed by using a digital electric balance at the stage the grain retained 12% moisture and the mean weight were expressed in gram.

xi. Grain yield plant^{-1} (g)

Grain yield from each plant were taken expressed as g/plantt on about 12% moisture basis. Grain moisture content was measured by using a digital moisture tester.

xii. Straw yield plant^{-1} (g)

Straw obtained from each plant were sun dried and weighted carefully and finally converted to g/pot.

xiii. Biological yield plant^{-1} (g)

The summation of grain yield and above ground straw yield was the biological yield. Biological yield g/pot = (Grain yield g/pot + Straw yield g/pot) g.

xiv. Harvest index (%)

Harvest index was calculated on dry weight basis with the help of following formula.

$$\text{Harvest index (HI \%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Here, Biological yield = Grain yield + straw yield

3.15 Data analysis technique

The collected data were compiled and analyzed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program name Statistix 10 Data analysis software and the mean differences were adjusted by Least Significant Difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

Results obtained from the present study have been presented and discussed in this chapter with a view to comparative studies of growth, physiology and yield performance of different wheat genotypes under various water deficit conditions. The data are given in different tables and figures. The results have been discussed, and possible interpretations are given under the following headings.

4.1 Plant growth parameters

4.1.1 Plant height

Effect of variety

Plant height is an important morphological character that acts as a potential indicator of availability of growth resources in its approach.Plant height was recorded at 30, 60 90 DAS and at harvest, respectively. Different wheat genotype significantly differ plant height at different days after sowing (Figure 1). Experimental result revealed that, the highest plant height (24.58, 64.63, 80.20 and 90.38 cm) at 30, 60, 90 DAS and at harvest respectively was recorded in V_4 (BARI Gom-33) treatment. Whereas the lowest plant height (21.75, 57.38, 72.60 and 83.55 cm) at 30, 60, 90 DAS and at harvest respectively was recorded in V_1 (BARI Gom-29) treatment which was statistically similar with V_2 (21.35) and V_1(21.35) at 30 DAS and with V_2 (84.48) at harvest respectively. The variation in plant height due to the effect of varietal differences. The variation of plant height is probably due to the genetic make-up of the variety. Gupta *et al.* (2020) also found similar result with the present study and reported that height of a plant is determined by genetical character and under a given set of environment different variety will acquire their height according to their genetical make up.

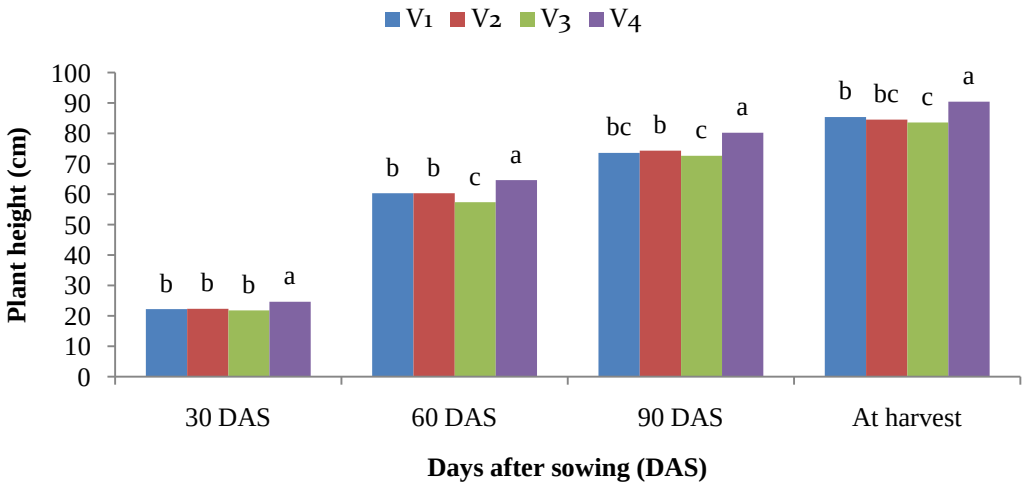


Figure 1. Effect of genotype on plant height of wheat at different DAS.

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 and V_4: BARI Gom-33.

Effect of drought levels

Different drought levels significantly influenced plant height of wheat at different DAS (Figure 2). Experimental result revealed that the highest plant height (27.68, 70.03, 85.58 and 99.20 cm) at 30, 60, 90 DAS and at harvest respectively was recorded in D_0 (Control) treatment. Increasing drought level decreased plant height and the lowest plant height (16.28, 45.07, 62.43 and 69.03 cm) at 30, 60, 90 DAS and at harvest respectively was recorded in D_3 treatment. Gradual decrease in plant height might be due to the nutrient unavailability caused by increased drought or the inhibition of cell division or cell enlargement. Gupta and Gupta (2011) reported that growth parameters of wheat variety HD 2329 like plant height and leaf area significantly reduced under water stress condition.

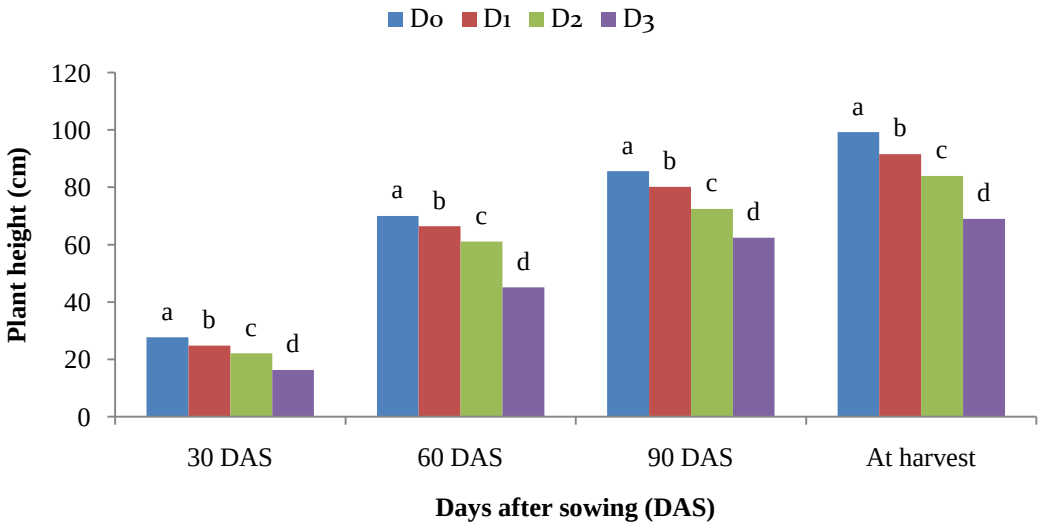


Figure 2. Effect of drought levels on plant height of wheat at different DAS.

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation : crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation : crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation.

Interaction effect of genotype and drought levels

Wheat genotypes cultivation with different drought levels had shown significant effect on plant height at different DAS (Table 1). Experimental result showed that the highest plant height (29.20, 73.20, 88.60 and 102.20 cm) at 30, 60, 90 DAS and at harvest respectively was recorded in V_4D_0 which was statistically similar with V_2D_0 at different DAS. Whereas the lowest plant height (14.10, 42.00, 58.50 and 63.30 cm) at 30, 60, 90 DAS and at harvest respectively was recorded in V_2D_3 which was statistically similar with V_1D_3 at 60 and 90 DAS.

Table 1. Interaction effect of genotype and drought levels on plant height of wheat at different DAS

Treatment Combinations	Plant height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
V_1D_0	27.40 b	69.60 bc	85.40 bc	99.00 b
V_1D_1	23.60 de	66.90 cd	79.60 e-g	90.60 de
V_1D_2	21.70 f	61.50 f	70.40 hi	84.70 g
V_1D_3	16.00 i	43.20 i	58.70 k	67.20 k
V_2D_0	28.20 ab	71.30 ab	86.60 ab	100.20 ab
V_2D_1	24.40 d	66.90 cd	80.10 ef	91.40 d
V_2D_2	22.70 ef	60.90 f	72.00 h	83.00 g
V_2D_3	14.10 j	42.00 i	58.50 k	63.30 l
V_3D_0	25.90 c	66.00 d	81.70 de	95.40 c
V_3D_1	24.20 d	62.10 ef	77.60 g	88.90 ef
V_3D_2	20.30 g	56.80 g	68.70 i	80.10 h
V_3D_3	16.60 i	44.60 i	62.40 j	69.80 j
V_4D_0	29.20 a	73.20 a	88.60 a	102.20 a
V_4D_1	27.00 bc	69.60 bc	83.40 cd	95.40 c
V_4D_2	23.70 de	65.20 de	78.70 fg	88.10 f
V_4D_3	18.40 h	50.50 h	70.10 hi	75.80 i
$LSD_{(0.05)}$	1.29	3.14	2.35	2.03
CV(%)	3.41	3.11	1.88	1.41

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.Here:D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation : crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation : crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

4.1.2 Number of tillers plant^{-1}

Effect of genotype

Cultivation of different wheat genotype significantly influenced number of tillers plant^{-1} at different days after sowing (Figure 3). Experimental result revealed that the highest number of tillers plant^{-1} (3.63, 6.38 and 6.90) at 30, 60 and 90 DAS was recorded in V_4 (BARI Gom-33) which was statistically similar with V_3 (BARI Gom-32) at different DAS. Whereas the lowest tillers plant^{-1} (3.48, 5.95 and 6.48) at 30, 60 and 90 DAS was recorded in V_1 (BARI Gom-29) which was statistically similar with V_2 (BARI Gom-30) at 30 DAS. The variation in number of tillers plant^{-1} may be due to the effect of varietal differences. Lad *et al*. (2002) also reported that significant differences among the genotypes for number of tillers indicating appreciable amount of variability among the genotypes of wheat.

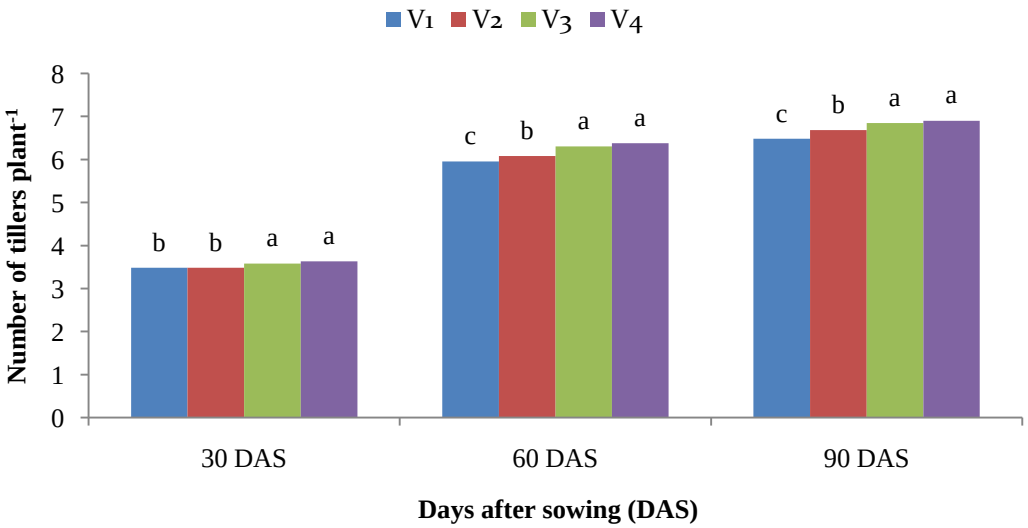


Figure 3. Effect of genotypes on number of tillers plant^{-1}of wheat at different DAS.

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

Different salt stress condition significantly influenced number of tillers plant^{-1} of wheat at different DAS. (Figure 4). Experimental result showed that, the maximum number of tillers plant^{-1} (3.93, 6.83 and 7.43) at 30, 60 and 90 DAS was recorded in D_0. With the increasing drought levels the number of tillers plant^{-1} drastically reduced.

So the lowest number of tillers plant^{-1} (2.93, 4.88 and 5.30) at 30, 60 and 90 DAS was recorded in D_3. As the drought level becomes higher and higher the reduction in number of tillers per plant was also higher. The result obtained from the present study was similar with the findings of Ahmed *et al.* (2009) who observed that water stress significantly reduced the plant height, tillers and dry matter of wheat.

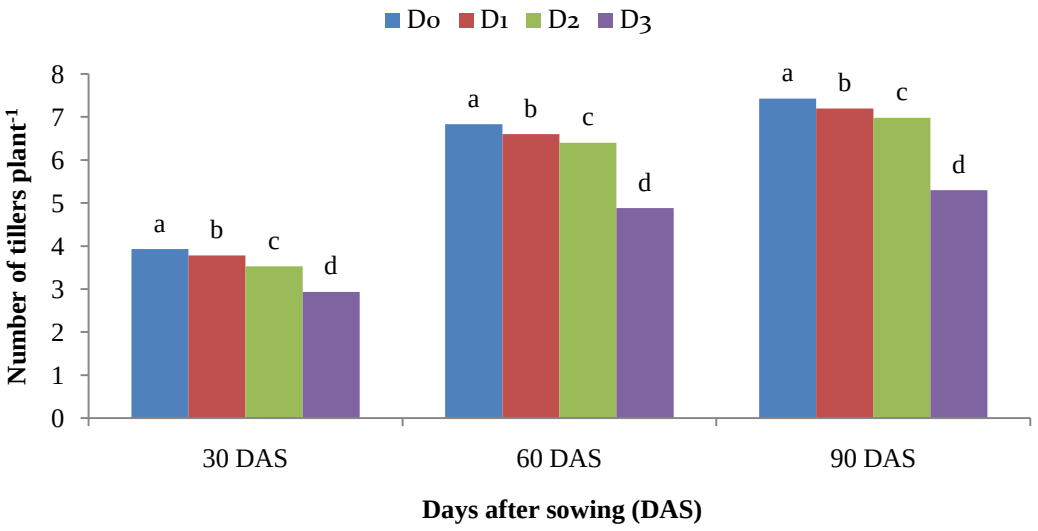


Figure 4. Effect of drought levels on number of tillers plant^{-1}of wheat at different DAS.

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation : crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation : crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Interaction effect of genotype and drought levels significantly influenced number of tillers plant^{-1} of wheat at different DAS (Table 2). Experimental result revealed that the highest number of tillers plant^{-1} (4.00, 6.90 and 7.50) at 30, 60 and 90 DAS was recorded in V_4D_0 which was statistically similar with V_3D_0 at 30, 60 and 90 DAS with V_1D_0 at 30, 60 DAS and V_2D_0 at 30 and 60 DAS. Meanwhile the lowest tillers plant^{-1} (2.80, 4.10 and 4.70) at 30, 60 and 90 DAS was recorded in V_1D_3 which was statistically similar with V_2D_3 at 30 DAS.

Table 2. Interaction effect of genotype and drought levels on tiller number plant^{-1} of wheat at different DAS

Treatment Combinations	Tillers number plant^{-1}		
	30 DAS	60 DAS	90 DAS
V_1D_0	3.90 ab	6.80 ab	7.30 bc
V_1D_1	3.80 bc	6.60 cd	7.10 de
V_1D_2	3.40 f	6.30 f	6.80 f
V_1D_3	2.80 h	4.10 i	4.70 i
V_2D_0	3.80 bc	6.80 ab	7.40 ab
V_2D_1	3.70 cd	6.60 cd	7.20 cd
V_2D_2	3.50 ef	6.40 ef	7.00 e
V_2D_3	2.90 gh	4.40 h	5.10 h
V_3D_0	4.00 a	6.80 ab	7.50 a
V_3D_1	3.70 cd	6.50 de	7.20 cd
V_3D_2	3.60 de	6.40 ef	7.00 e
V_3D_3	3.00 g	5.50 g	5.70 g
V_4D_0	4.00 a	6.90 a	7.50 a
V_4D_1	3.90 ab	6.70 bc	7.30 bc
V_4D_2	3.60 de	6.50 de	7.10 de
V_4D_3	3.00 g	5.50 g	5.70 g
$LSD_{(0.05)}$	0.19	0.17	0.15
CV(%)	3.29	1.68	1.36

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33,Here:D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation : crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation : crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

4.2 Physiological parameters

4.2.1 SPAD value

Effect of genotype

SPAD value determine leaf chlorophyll concentrations. Chlorophyll is the natural compound present in green plants that gives them their color. It helps plants to absorb energy from the sun as they undergo the process of photosynthesis. In this experiment, different genotype significantly influenced SPAD value of wheat at 30 and 65 DAS (Figure 5). The highest SPAD value (51.63 and 45.23) was recorded in V_4 which was similar with V_3 at 30 DAS. Meanwhile the lowest SPAD value (47.18 and 39.80) was recorded in V_1 which was statistically similar with V_2 at 30 DAS. Mishra and Mishra(1987) founded considerable inhibition of chlorophyll synthesis during water stress, even after complete rehydration of wheat seedlings. Younger seedlings were more prone to stress than older seedlings. However, the rate of inhibition of chlorophyll synthesis varied with genotypes and plant age.

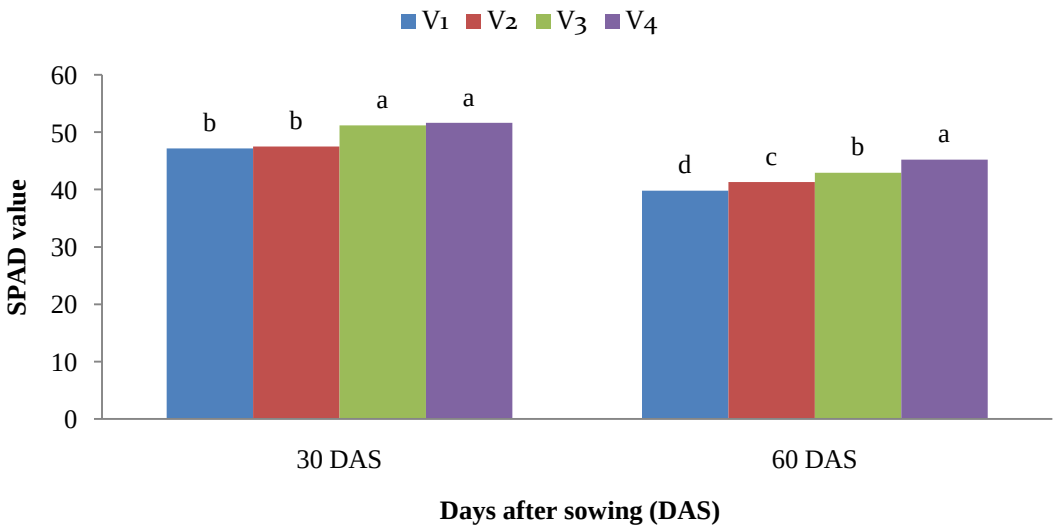


Figure 5. Effect of genotype on SPAD**value of wheat at different DAS.**

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

In this experiment, different drought levels had shown significant effect on SPAD value of wheat at 30 and 60 DAS (Figure 6). Experimental result revealed that, the highest SPAD value (55.43 and 48.35) was recorded in D_0. Meanwhile the lowest SPAD value (41.18 and 34.37) was recorded in D_3. Sharifa and Muriefah (2013) reported that water stress decreased chlorophyll content in wheat. Khayatnezhad *et al*. (2011) also reported that drought stress severely reduced the photosynthetic attributes, water status and chlorophyll content in wheat.

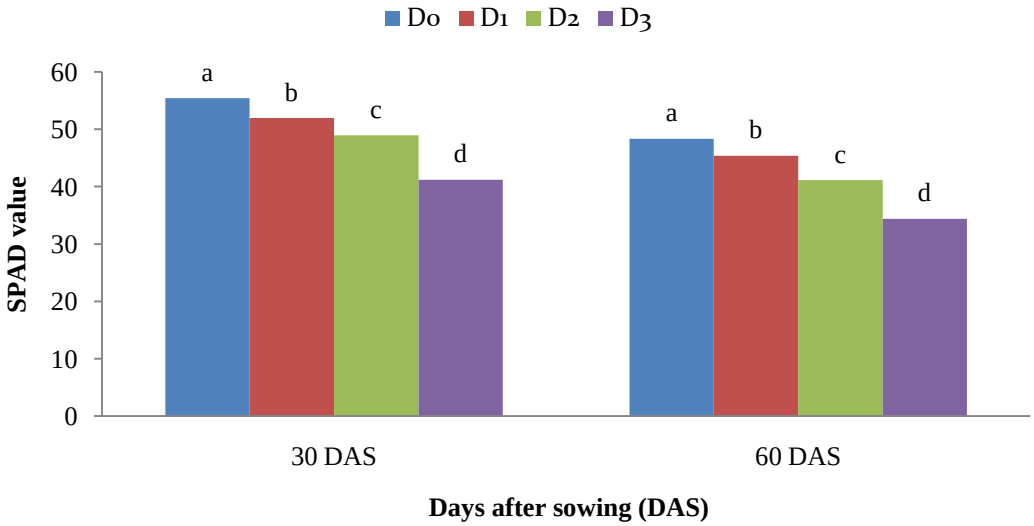


Figure 6. Effect of drought levels on SPAD **value of wheat at different DAS.**

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Different wheat genotype along with drought levels significantly influenced on the SPAD value of wheat at 30 and 60 DAS (Table. 3). Experimental result showed that, the highest SPAD value (56.50 and 49.80) at 30 and 60 DAS was recorded in V_4D_0 which was statistically similar with V_3D_0 at 30 DAS and with V_2D_0 at 60 DAS. Whereas the lowest SPAD value (35.10 and 30.00) was recorded in V_2D_3.

Table 3. Interaction effect of genotype and drought levels on SPAD **value of wheat at different DAS**

Treatment Combinations	SPAD **value**	
	30 DAS	**60 DAS**
$\mathbf{V_1D_0}$	54.70 bc	47.30 c
$\mathbf{V_1D_1}$	49.10 fg	43.00 g
$\mathbf{V_1D_2}$	46.20 h	37.60 j
$\mathbf{V_1D_3}$	38.70 j	31.30 k
$\mathbf{V_2D_0}$	54.80 bc	48.70 ab
$\mathbf{V_2D_1}$	52.30 de	45.60 ef
$\mathbf{V_2D_2}$	47.80 gh	41.00 h
$\mathbf{V_2D_3}$	35.10 k	30.00 l
$\mathbf{V_3D_0}$	55.70 ab	47.60 bc
$\mathbf{V_3D_1}$	52.70 de	46.00 de
$\mathbf{V_3D_2}$	50.00 f	41.60 h
$\mathbf{V_3D_3}$	46.40 h	36.50 j
$\mathbf{V_4D_0}$	56.50 a	49.80 a
$\mathbf{V_4D_1}$	53.70 cd	47.00 cd
$\mathbf{V_4D_2}$	51.80 e	44.40 f
$\mathbf{V_4D_3}$	44.50 i	39.70 i
$\mathbf{LSD_{(0.05)}}$	1.69	1.26
CV(%)	2.05	1.79

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33,Here:D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation : crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

4.2.2 Relative water content (RWC)

Effect of genotype

Relative water content is described as the amount of water in a leaf at the time of sampling relative to the maximal water a leaf can hold. It is an important parameter in

water relation studies, e.g. it allows the calculation of the osmotic potential at full turgor. In this experiment, relative water content was significantly varied due to different treatment. The highest relative water content (83.28 %) was recorded in V_4 which was statistically similar with V_2. Whereas the lowest relative water content (81.15 %) was recorded in V_3.Almeselmani*et al.* (2011) reported that high RLWC is a resistant mechanism to drought, and is the result of more osmotic regulation or less elasticity of tissue cell wall and has significant association with yield and stress tolerance. The differences in RLWC in wheat leaves may also be due to differences in the ability of the tested varieties to accumulate and adjust osmolyte to maintain tissue turgor. The difference in RLWC of wheat cultivars that are under drought stress may be due to the differences in their ability to absorb more water from soil or the ability of the stomata to reduce the loss of water.

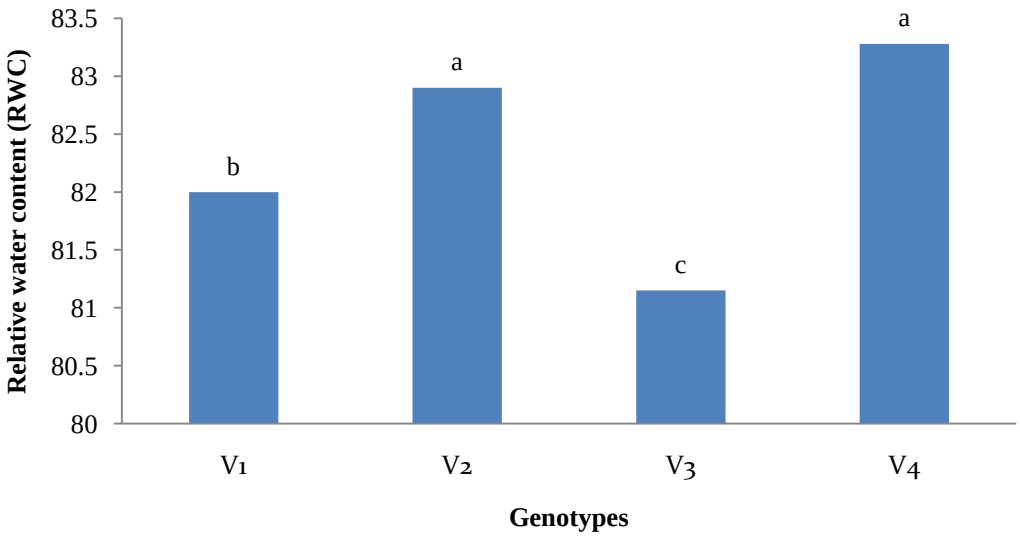


Figure 7. Effect of genotype on relative water content of wheat.

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

In this experiment, exposure of different drought levels significantly influenced on relative water content of wheat (Figure 8). Experimental result revealed that the maximum relative water content (92.13 %) was recorded in control (D_0) treatment which was gradually decreasing with increasing drought levels. The minimum relative water content (72.68 %) was recorded in D_3 treatment. Nezhadahmedi *et al.* (2013) reported that drought stress influence plants in terms of inhibition of photosynthesis,

decrease in chlorophyll content and relative water content of wheat. A decrease in RWC indicates a loss of turgor that results in limited water availability for cell extension processes.

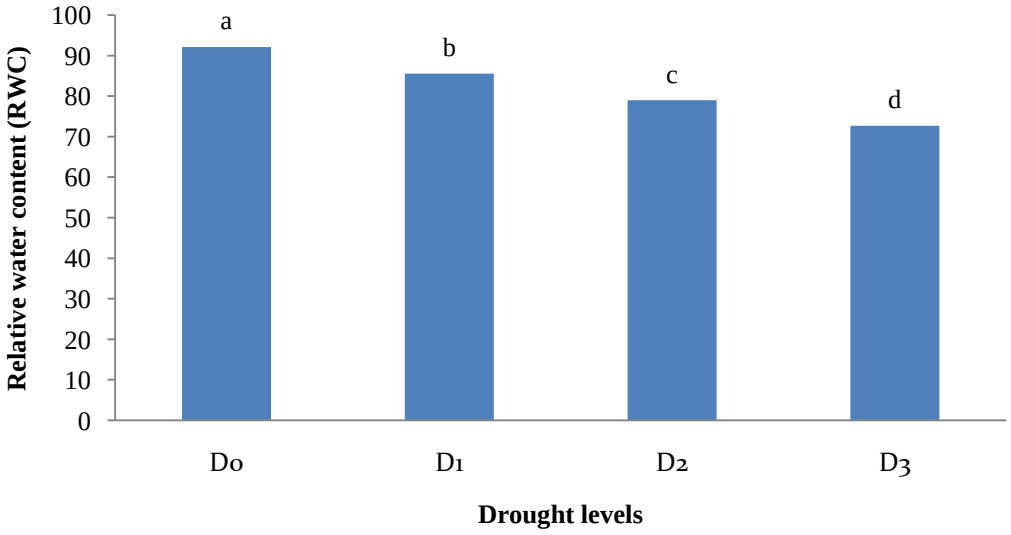


Figure 8. Effect of drought levels on relative water content of wheat.

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Interaction effect of genotype and drought levels significantly influenced on relative water content of wheat (Table 4).. Experimental result showed that, the highest relative water content (93.70 %) was recorded in V_1D_0 which was statistically similar with V_4D_0. Whereas the lowest relative water content (93.70 %) was recorded in V_1D_3 (71.50) which was statistically similar with V_3D_3 and V_4D_3.

4.2.3 Membrane stability index (MSI)

Effect of genotype

Membrane stability index was significantly varied due to different treatment (Figure 9).. The highest membrane stability index (78.38 %) was recorded in V_4 which was statistically similar with V_3. Whereas the lowest relative water content (72.10 %) was

recorded in V_1 which was statistically similar with V_2.Cellular membrane stability, measured as the conductivity of electrolytes leaking from leaf disks at high temperature, has been suggested as a screening technique to determine heat and drought tolerance in plants.

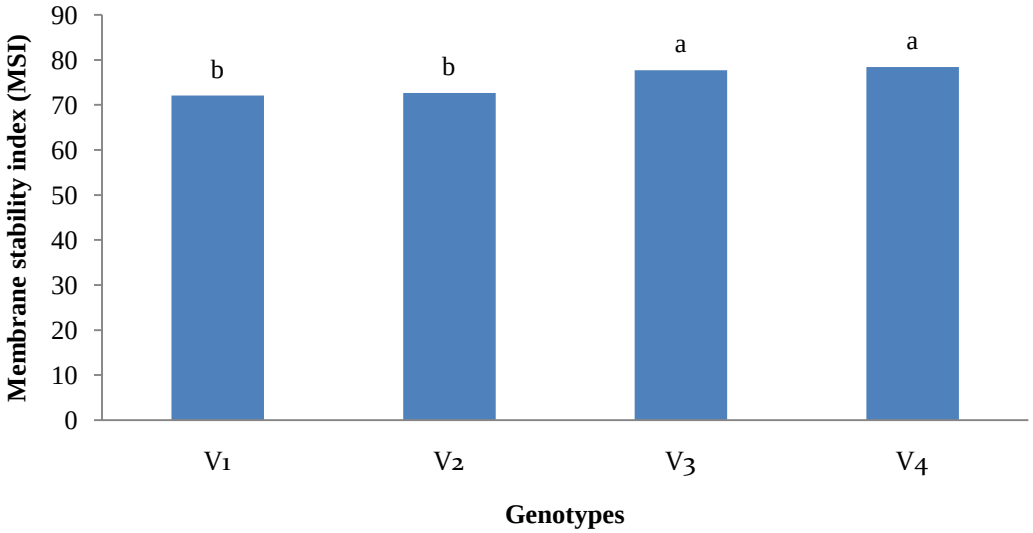


Figure 9. Effect of genotype onmembrane stability index of wheat

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

Different drought levels significantly influenced on membrane stability index of wheat (Figure 10). The highest membrane stability index (92.13 %) was recorded in D_0. Whereas the lowest membrane stability index (64.33 %) was recorded in D_3. Drought stress greatly suppresses cell expansion and cell growth due to the low turgor pressure result in poor membrane stability index (Shao *et al*., 2008).

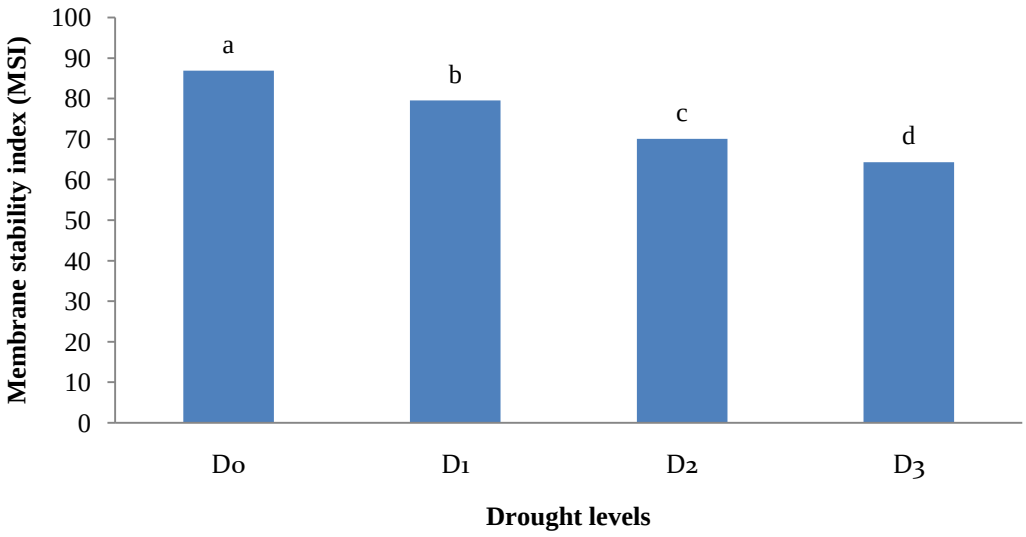


Figure 10. Effect of drought levels onmembrane stability index of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Interaction effect of genotype and drought levels significantly influenced on membrane stability index of wheat (Table 4).. Experimental result showed that, the highest membrane stability index (88.50 %) was recorded in V_4D_0 which was statistically similar with V_2D_0 and V_3D_0. Whereas the lowest membrane stability index (93.70 %) was recorded in V_1D_3 (60.60 %) which was statistically similar with V_2D_3.

Table 4. Interaction effect of variety and drought level on relative water content and membrane stability index of wheat

Treatment combinations	Relative water content	Membrane stability index (MSI)
V_1D_0	93.70 a	85.10 b
V_1D_1	86.10 e	78.20 d
V_1D_2	76.70 i	64.50 h
V_1D_3	71.50 k	60.60 i
V_2D_0	92.10 b	87.30 a
V_2D_1	84.10 f	76.20 e
V_2D_2	81.90 g	66.50 g
V_2D_3	73.50 j	60.60 i
V_3D_0	90.10 c	86.60 ab
V_3D_1	84.20 f	81.70 c
V_3D_2	77.40 i	74.20 f
V_3D_3	72.90 jk	68.30 g
V_4D_0	92.60 ab	88.50 a
V_4D_1	87.80 d	82.00 c
V_4D_2	79.90 h	75.20 ef
V_4D_3	72.80 jk	67.80 g
$LSD_{(0.05)}$	1.45	1.92
CV(%)	1.06	1.54

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33,Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

4.3 Yield contributing characters

4.3.1 Days to first flowering

Effect of genotype

Days to first flowering differed significantly due to different genotype of wheat (Figure 11). The highest 75.18 days required for first flowering was found in V_4. Meanwhile the lowest 66.75 days required for first flowering was found in V_2. The variation in production of flowering was due to the variation in genetic makeup of the cultivars.

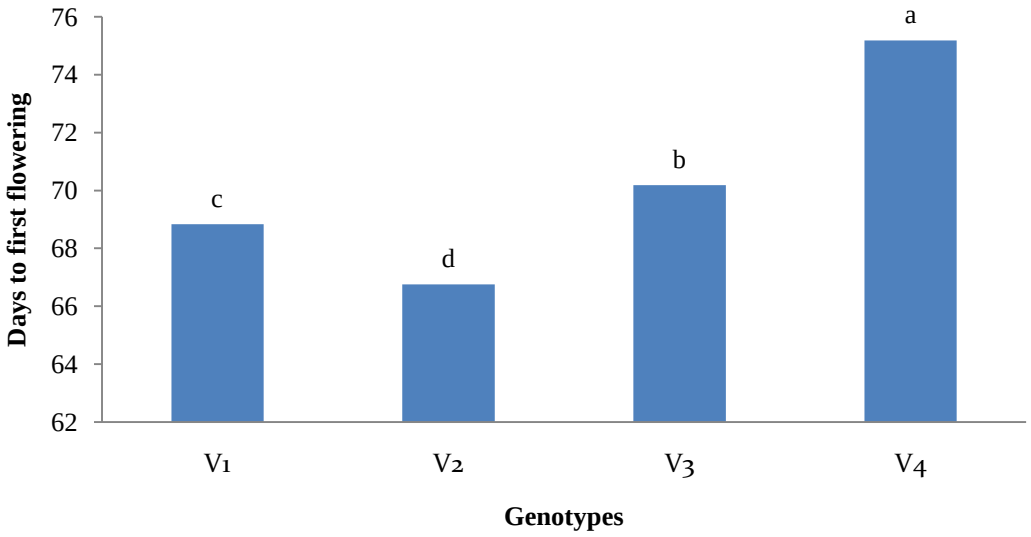


Figure 11. Effect of genotype ondays to first flowering of wheat

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

Different wheat genotype growing in drought levels significantly differed in the days to first flowering (Figure 12). Experimental result revealed that the highest 81.40 days required for first flowering was found in D_0. Meanwhile the lowest 58.60 days required for first flowering was found in D_3.Mekkei*et al.* (2014) showed that, the wheat plants which skipped from the third irrigation (at elongation and before booting stages) go to early flowering by 5 days compared with control treatment and other irrigation treatments. This may be due to the drought stress was occur in end of elongation stage and initiation of booting stage and the plant go to early flowering and early maturation.

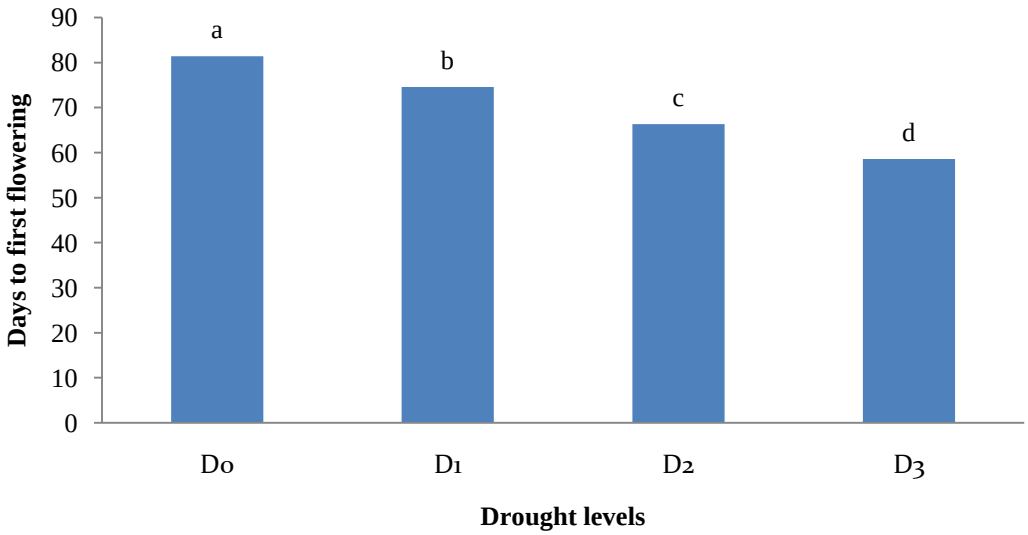


Figure 12. Effect of genotype ondays to first flowering of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Wheat genotype growing at different drought levels significantly affect the days required for first flowering of wheat (Table 5). Experimental results showed that, the highest 85.30 days required for first flowering was found in V_4M_0. Meanwhile the lowest 57.70 days required for first flowering was found in V_1D_3.

4.3.2 Days to maturity

Effect of genotype

Days to maturity differed significantly due to different genotype of wheat (Figure 13). The highest 96.68 days required for maturity was found in V_4. Meanwhile the lowest 89.00 days required for maturity was found in V_2. The variation in maturity was due to the variation in genetic makeup of the cultivars. The result was similar with the findng of Gill *et al*. (2014) who reported that PBW 621 took substantially less time to complete different phenological stages like flag leaf (93 days), booting (100 days), heading (108 days), anthesis (117 days) and physiological maturity (140 days) than PBW 343.

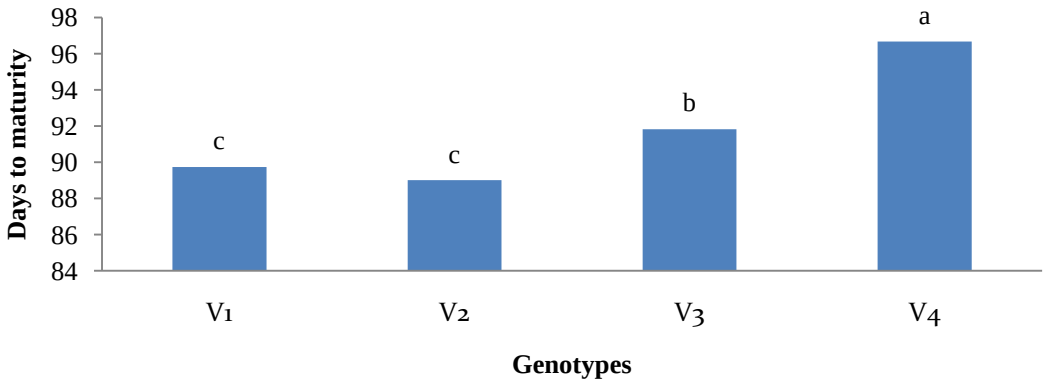


Figure 13. Effect of genotype ondays to maturity of wheat

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

Different wheat genotype growing in drought levels significantly differed in the days to maturity (Figure 14). Experimental result revealed that the highest 103.40 days required for maturity was found in D_0 (Control). Meanwhile the lowest 78.90 days required for maturity was found in D_3.Khan and Naqvi (2011) found that, the plants strive to complete their life cycle as early as possible to cope with drought stress conditions. Therefore days required to initiate heading in wheat are generally decreased due to early start of reproductive stage

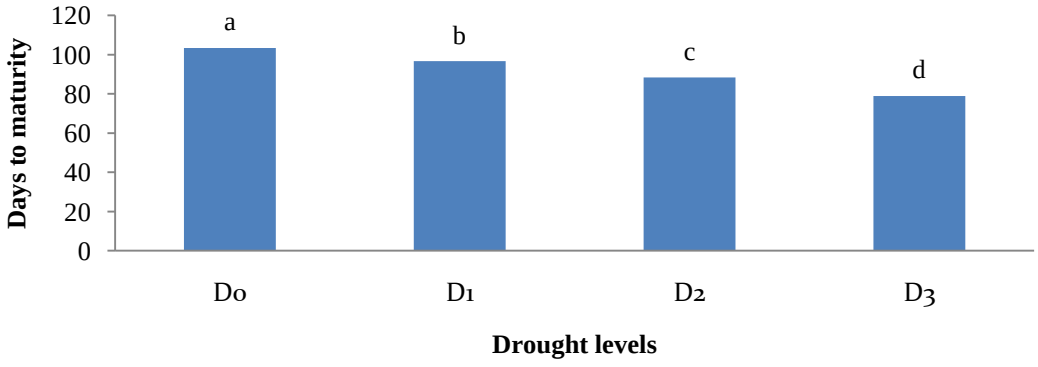


Figure 14. Effect of drought levels ondays to maturity of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

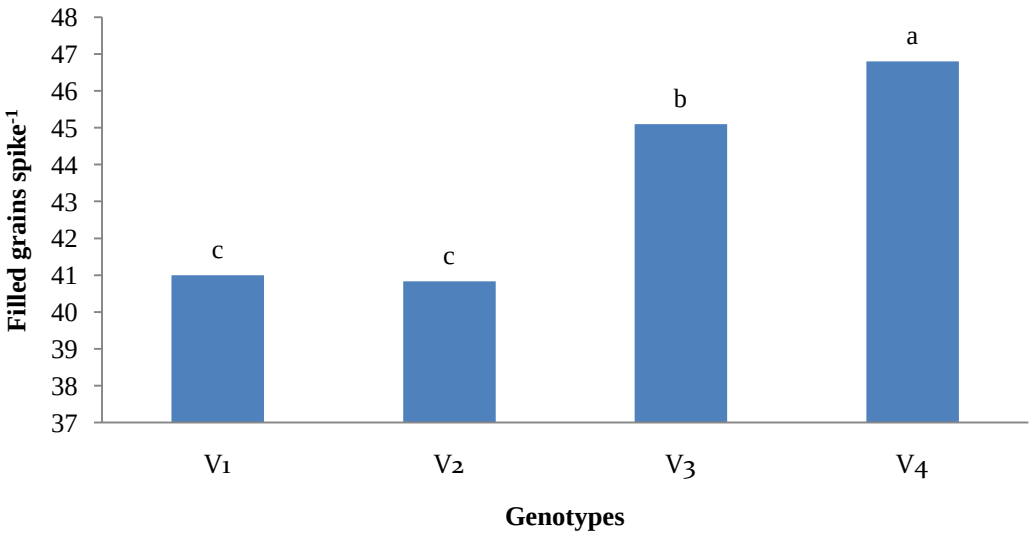
Interaction effect of genotype and drought levels

Wheat genotype growing at different drought levels significantly affect the days required for maturity of wheat (Table 5). Experimental results showed that, the highest 107.30 days required for maturity was found in V_4M_0. Meanwhile the lowest 75.30 days required for maturity was found in V_1D_3.

4.3.3 Filled grains spike^{-1}

Effect of genotype

Different genotype of wheat had showed significant effect on filled grains spike^{-1}. Experimental results showed that, the highest filled grains spike^{-1} (46.80) was recorded in V_4. Meanwhile the lowest highest filled grains spike^{-1} (40.83) was recorded in V_2 which was statistically similar with V_1. Variation in filled grains spike^{-1} may have occurred due to genetic, environmental or cultural management practices adopted.Khan *et al.* (2013) reported that that there was significant effect of moisture stress on number of grain spike^{-1}.



Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Figure 15. Effect of drought levels onfilled grains spike^{-1}of wheat

Effect of drought levels

Different wheat genotype growing in different drought levels had showed significant effect on filled grains spike^{-1}. (Figure 16). Experimental results showed that, the

highest filled grains spike^{-1} (55.30) was recorded in D_0. Meanwhile the lowest highest filled grains spike^{-1} (32.60) was recorded in D_3. When drought stress occurs at pre-flowering period in wheat for instance, grain fill phase is shortened and grain yield is reduced by decreasing the number of tillers, spike, grain per plant, grain weight and time to anthesis (Nguyen, 2001).Maralian*et al*. (2010) reported that yield parameter of wheat such as spike length, spikelets spike^{-1}, grains spike^{-1}, and grain weight spike^{-1} decreased under water stress condition when stress was given at before tillering stage and after heading stage.

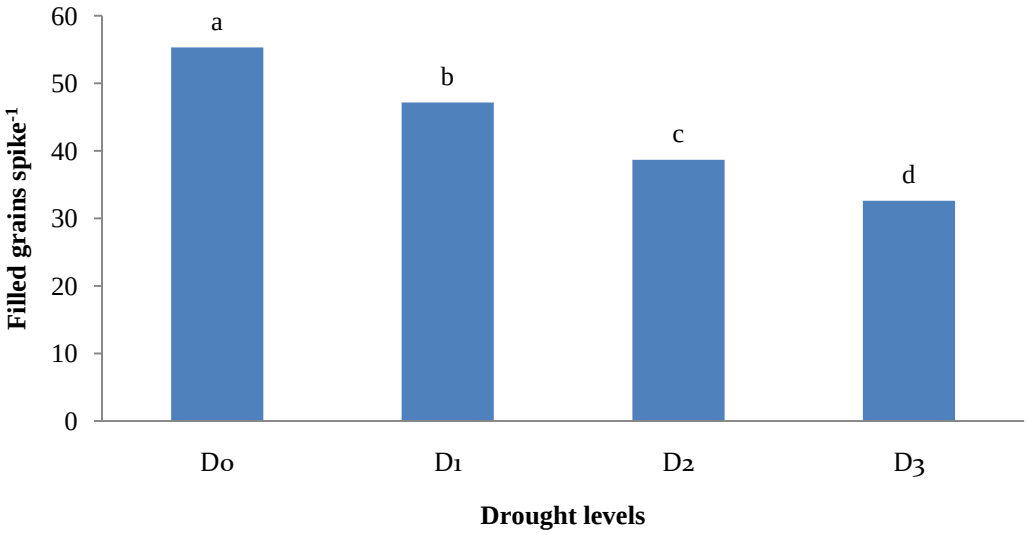


Figure 16. Effect of drought levels onfilled grains spike^{-1}of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

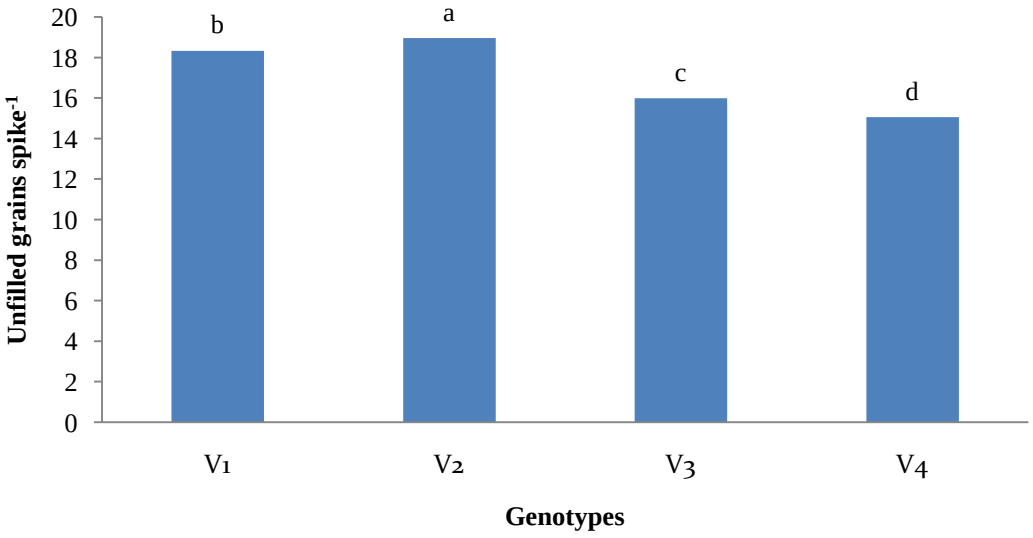
Interaction effect of genotype and drought levels

Cultivation of different wheat genotype growing at different drought levels significantly affect the filled grains spike^{-1}of wheat (Table 5). Experimental results showed that, the highest filled grains spike^{-1} (58.30) was recorded in V_4D_0 which was statistically similar with V_3D_0. Meanwhile the lowest filled grains spike^{-1} (28.60) was recorded in V_2D_3 which was statistically similar with V_2D_3.

4.3.4 Unfilled grains spike^{-1}

Effect of genotype

Different genotype of wheat had showed significant effect on unfilled grains spike^{-1} (Figure 17). Experimental results showed that, the highest unfilled grains spike^{-1} (18.95) was recorded in V_2. Meanwhile the lowest highest unfilled grains spike^{-1}(15.05) was recorded in V_4. Variation in unfilled grains spike^{-1} may be due to genetic characteristics of individual genotype.



Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Figure 17. Effect of genotype on unfilled grains spike^{-1}of wheat

Effect of drought levels

Different wheat genotype growing in different drought levels had showed significant effect on unfilled grains spike^{-1}. (Figure 10). Experimental results showed that, the highest unfilled grains spike^{-1} (27.70) was recorded in D_3. Meanwhile the lowest highest unfilled grains spike^{-1} (7.10) was recorded in D_0.

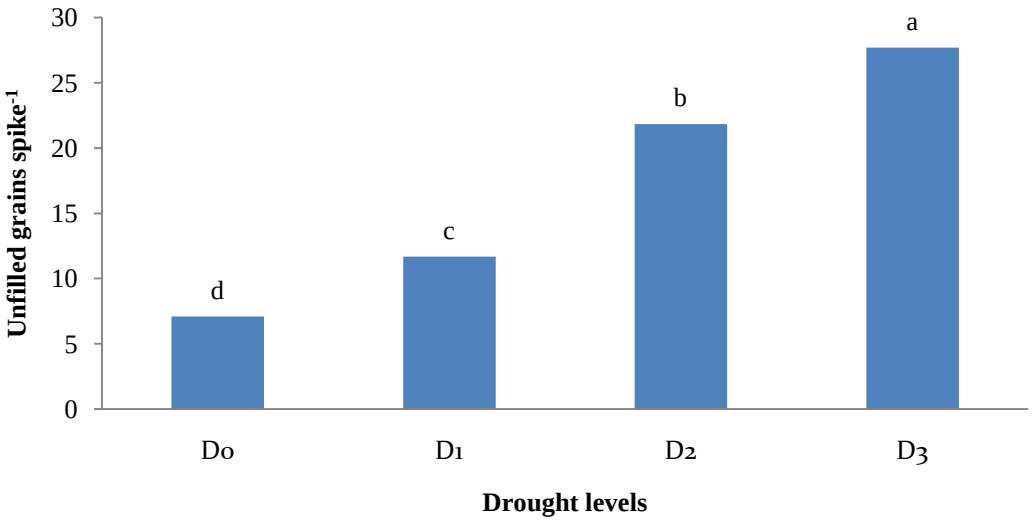


Figure 18. Effect of drought levels on unfilled grains spike^{-1} of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

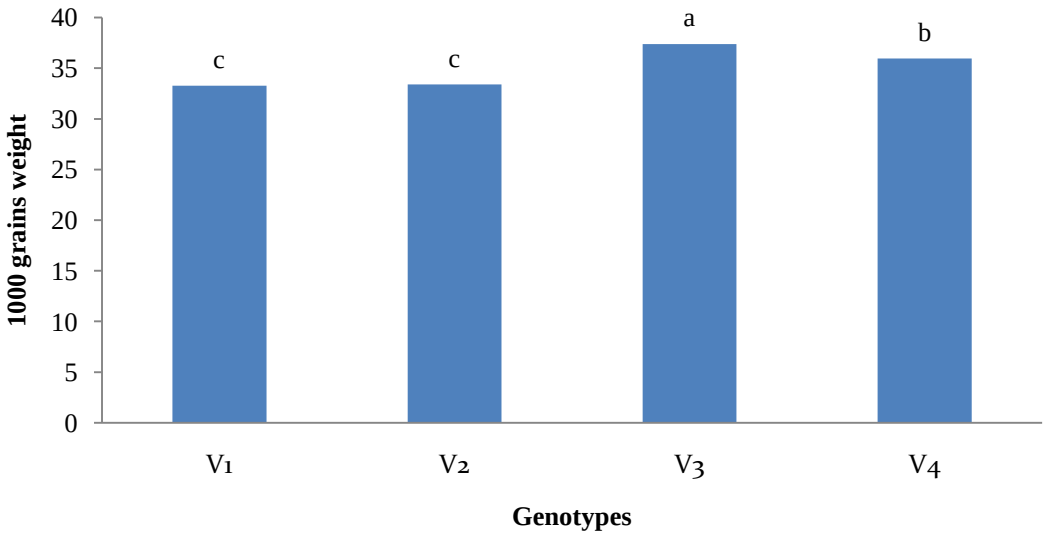
Interaction effect of genotype and drought levels

Cultivation of different wheat genotype growing at different drought levels significantly affect the unfilled grains spike^{-1} of wheat (Table 5). Experimental results showed that, the highest unfilled grains spike^{-1} (32.00) was recorded in V_2D_3. Meanwhile the lowest unfilled grains spike^{-1} (6.00) was recorded in V_3D_0 which was statistically similar with V_4D_0.

4.3.5 1000 grains weight

Effect of genotype

Different wheat genotype had shown significant effect on 1000 grains weight of wheat (Figure 19). Experimental result showed that the highest 1000 grains weight (37.38 g) was recorded in V_3. Meanwhile the lowest 1000 grains weight (33.28 g) was recorded in V_1 which was statistically similar with V_2. The differences of the 1000 grains weight among different wheat genotypes may be attributes to the genotypes performance and genetic makeup of the varieties. Mattas *et al*. (2011) reported significant variations among the varieties for weight of 1000 grains weight.



Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Figure 19. Effect of genotype on 1000 grains weightof wheat

Effect of drought levels

Different drought level significantly influenced 1000 grains weight of wheat (Figure 20). Experimental result showed that that the maximum 1000 grains weight (41.33 g) was recorded in D_0 treatment. Whereas the minimum 1000 grains weight (28.33 g) was recorded in D_3 treatment. The variation of 1000 grains weight among different treatment due to reason that water unavailability in soil can disturb normal functioning of plant metabolism, consequently leading to stunted growth and low crop productivity.Rajala *et al*. (2009) revealed that, in non-irrigated condition drought occurring during the grain filling period is known to induce grain abortion and reduce grain filling capacity, i.e. sink strength adjust to reduce source capacity.

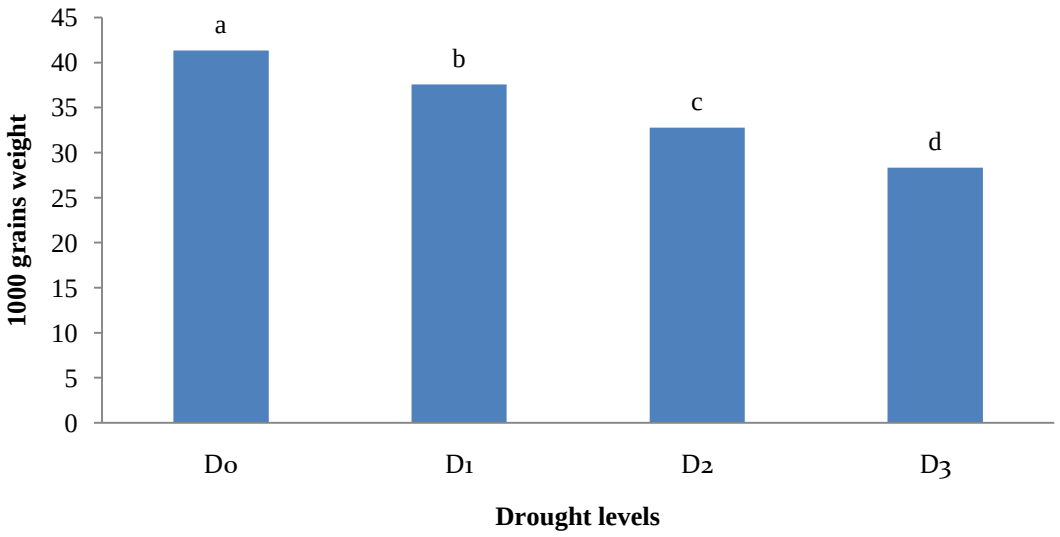


Figure 20. Effect of drought levels on 1000 grains weightof wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Cultivation of different wheat genotype growing at different drought levels significantly influenced 1000 grains weight of wheat (Table 5). Experimental results showed that, the highest 1000 grains weight (32.00) was recorded in V_3D_0 which was statistically similar with V_2D_0.Meanwhile the lowest 1000 grains weight (25.30) was recorded in V_2D_3 which was statistically similar with V_1D_3.

Table 5. Interaction effect of genotype and drought levels on days to first flowering, days to maturity, filled grains spike^{-1}, unfilled grains spike^{-1} and 1000 grains weight of wheat

Treatment combinations	Days to first flowering	Days to maturity	Filled grains spike^{-1}	unfilled grains spike^{-1}	1000 grains weight
V_1D_0	81.30 b	103.30 b	52.80 b	7.70 k	40.20 b
V_1D_1	74.00 d	96.00 c	46.40 de	12.40 h	36.40 de
V_1D_2	62.30 g	84.30 e	35.50 h	25.00 cd	31.00 f
V_1D_3	57.70 i	75.30 g	29.30 i	28.20 b	25.50 g
V_2D_0	79.00 c	101.00 b	53.70 b	8.30 k	41.10 ab
V_2D_1	71.70 e	93.70 c	44.60 ef	13.30 h	37.40 cd
V_2D_2	63.00 g	85.00 e	36.40 h	22.20 e	29.80 f
V_2D_3	53.30 j	76.30 g	28.60 i	32.00 a	25.30 g
V_3D_0	80.00 bc	102.00 b	56.40 a	6.00 l	43.50 a
V_3D_1	73.70 d	95.70 c	47.70 cd	11.10 i	39.20 bc
V_3D_2	67.30 f	89.30 d	40.40 g	20.70 f	35.90 de
V_3D_3	59.70 h	80.30 f	35.90 h	26.10 c	30.90 f
V_4D_0	85.30 a	107.30 a	58.30 a	6.40 l	40.50 b
V_4D_1	79.00 c	101.00 b	49.90 c	9.90 j	37.30 cd
V_4D_2	72.70 de	94.70 c	42.40 fg	19.40 g	34.40 e
V_4D_3	63.70 g	83.70 e	36.60 h	24.50 d	31.60 f
$LSD_{(0.05)}$	1.67	3.07	2.58	1.19	2.72
CV(%)	1.42	2.00	3.57	4.21	4.66

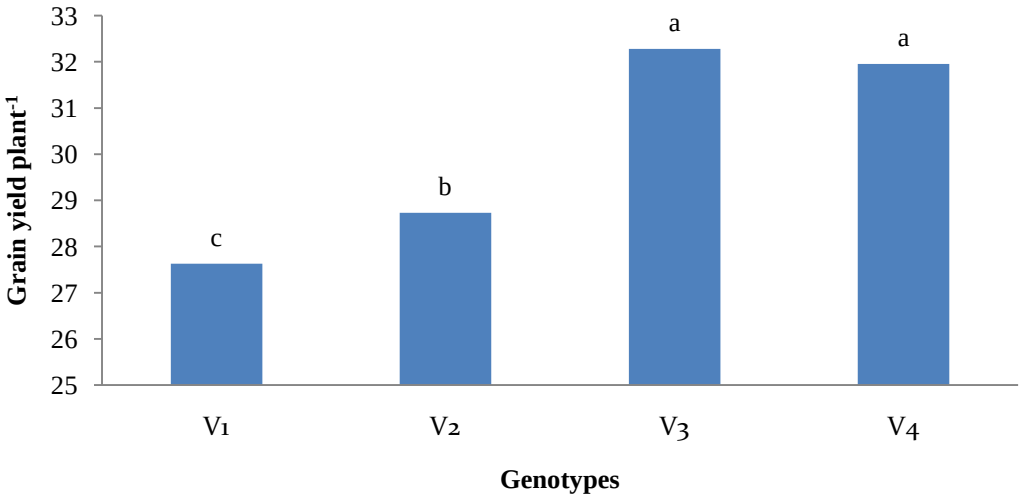
In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33,Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

4.4 Yield characters

4.4.1 Grain yield plant^{-1}

Effect of genotype

Different wheat genotype significantly influenced grain yield plant^{-1} of wheat (Figure 21). Experimental result showed that, the highest grain yield plant^{-1} (32.28 g) was recorded in V_3 which was statistically similar with V_4. Whereas the lowest grain yield plant^{-1} (27.63 g) was recorded in V_1. Different wheat genotype have individual genetic makeup which influenced the growth and yield among different genotypes. Similar result also found by Singh *et al*. (2017) who concluded that among varieties HD-2967 recorded significantly higher number of earheads/m^2 (230.8), earhead length (9.33 cm), earhead weight (11.4 g), 1000 grain weight (42.4 g) and grain yield (32.85 q/ha) as compared to other two varieties. Singh and Uma (2015) reported that the genotypes, which produced higher number of effective tillers per plant and higher number of grains per spike also showed higher grain yield.Singh *et al*. (2012) showed that the yield was significantly higher (5.55.7 t ha^{-1}) for DBW 17, HD 2687, HD 2894, PBW 343, PBW 550 and UP 2338, while it was lower in UP 2425, PBW 509, HI 1544 and DBW 16 (4.64.9 t ha^{-1}).



Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Figure 21. Effect of genotype on grain yield plant^{-1} of wheat

Effect of drought levels

Different drought level significantly influenced grain yield plant^{-1} of wheat (Figure 22). Experimental result showed that, the highest grain yield plant^{-1} (36.18 g) was recorded in D_0. Whereas the lowest grain yield plant^{-1} (23.35 g) was recorded in D_3. Talebi *et al.* (2009) observed that, significant difference among stress conditions for grain yield and suggested that high yield potential under normal conditions does not necessarily results in improved yield under stress conditions.Samara *et al*. (2009) reported that, drought stress during grain filling period reduced grain yield by 73 to 87%, together with all the grain yield components. Barley grain yield under severe drought stress was positively correlated with grain filling duration and gross photosynthetic rate and negatively correlated with leaf water potential.

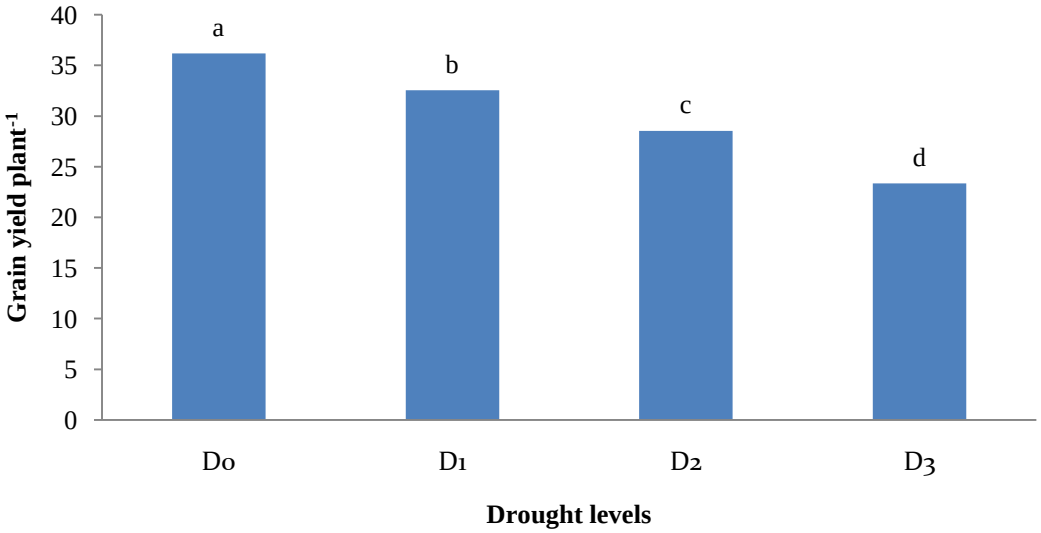


Figure 22. Effect of drought levels on grain yield plant^{-1} of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation.

Interaction effect of genotype and drought levels

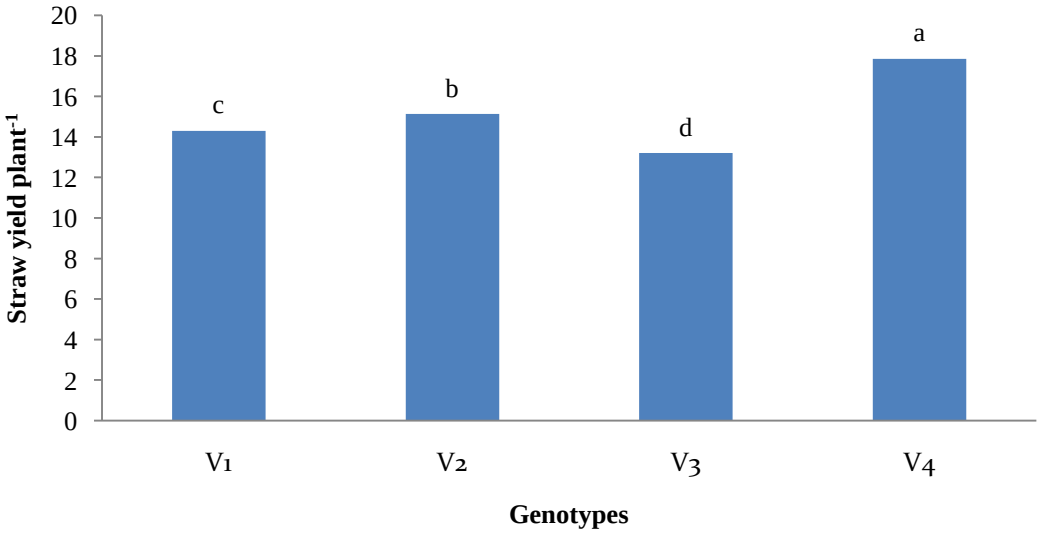
Cultivation of different wheat genotype growing at different drought levels significantly influenced grain yield plant^{-1} of wheat (Table 6).. Experimental result showed that, the highest grain yield plant^{-1} (38.50 g) was recorded in V_3D_0 which was

statistically similar with V_4D_0. Whereas the lowest grain yield plant^{-1} (20.20 g) was recorded in V_1D_3 which was statistically similar with V_2D_3.

4.4.2 Straw yield plant^{-1}

Effect of genotype

Different wheat genotype significantly influenced straw yield plant^{-1} of wheat (Figure 39). Experimental result showed that, the highest straw yield plant^{-1} (17.85 g) was recorded in V_4. Whereas the lowest straw yield plant^{-1} (13.20 g) was recorded in V_3. Chourasiya *et al*. (2013) reported that among the varieties, HI 8498 produced a significant maximum grain yield (60.82 q ha^{-1}) and straw yield (80.63 q ha^{-1}) whereas GW 366 had the lowest grain and straw yield. The higher grain and straw yield with the wheat variety HI 8498 was attributed to more yield attributes, i.e. tillering number m^{-2}, ear head m^{-2}, grain number ear^{-1} and test weight compared to the other varieties



Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Figure 23. Effect of genotype on straw yield plant^{-1} of wheat

Effect of drought levels

Different drought level significantly influenced straw yield plant^{-1} of wheat (Figure 24). Experimental result showed that, the highest straw yield plant^{-1} (20.80 g) was recorded in D_0. Whereas the lowest grain yield plant^{-1} (10.28 g) was recorded in D_3. Increasing drought levels is toxic to plant and itscan disrupt normal functioning of plant metabolism, consequently leading to stunted growth and low crop productivity.

Maralian *et al*. (2010) reported that drought stress at heading stage reduced straw yield more as compare to stress at tillering stage.

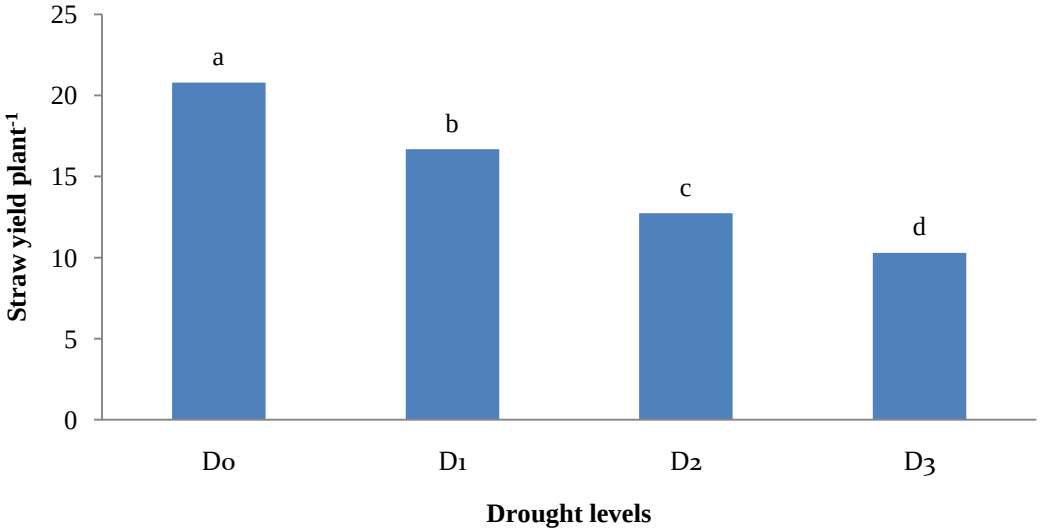


Figure 24. Effect of drought levels on straw yield plant^{-1} of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Cultivation of different wheat genotype growing at different drought levels significantly influenced straw yield plant^{-1} of wheat. Experimental result showed that, the highest straw yield plant^{-1} (24.30 g) was recorded in V_4D_0. Whereas the lowest straw yield plant^{-1} (9.40 g) was recorded in V_3D_3 which was statistically similar with V_2D_3 and V_1D_3.

4.4.3 Biological yield plant^{-1}

Effect of genotype

Different wheat genotype significantly influenced biological yield plant^{-1} of wheat (Figure 25). Experimental result showed that, the highest biological yield plant^{-1} (49.80 g) was recorded in V_4. Whereas the lowest biological yield plant^{-1} (41.95 g) was recorded in V_1.

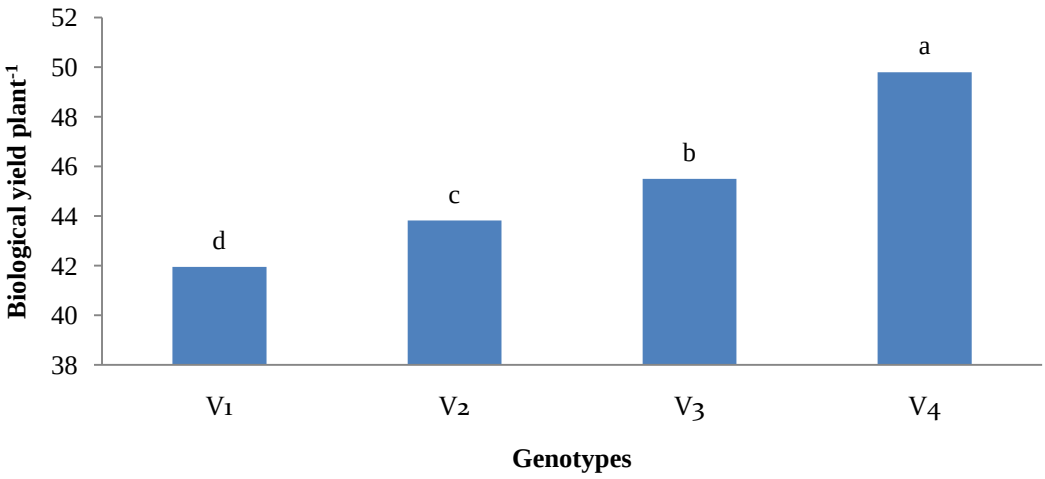


Figure 25. Effect of genotype on biological yield plant^{-1} of wheat

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

Different drought level significantly influenced biological yield plant^{-1} of wheat (Figure 26). Experimental result showed that, the highest biological yield plant^{-1} (56.99 g) was recorded in D_0. Whereas the lowest biological yield plant^{-1} (33.62 g) was recorded in D_3.

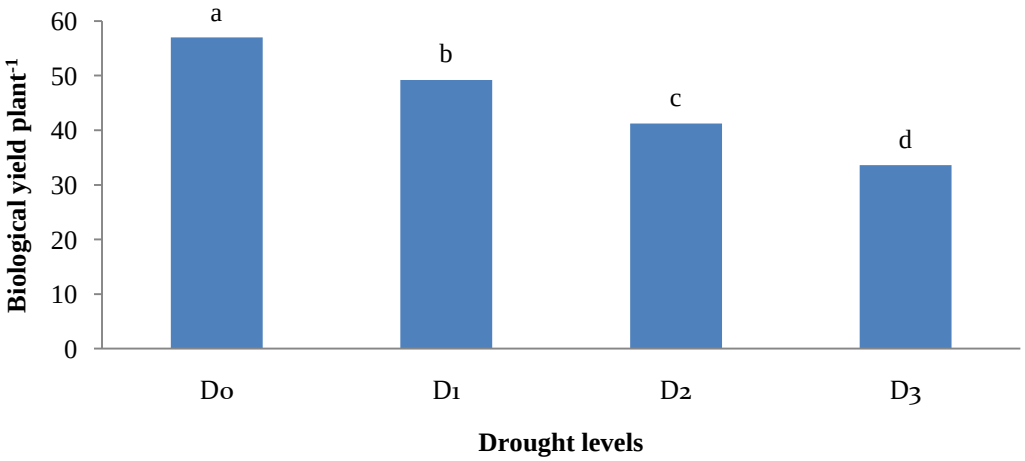


Figure 26. Effect of drought levels on biological yield plant^{-1} of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Cultivation of different wheat genotype growing at different drought levels significantly influenced biological yield plant^{-1} of wheat. Experimental result showed that, the highest biological yield plant^{-1} (61.16 g) was recorded in V_4D_0. Whereas the lowest biological yield plant^{-1} (30.13 g) was recorded in V_1D_3 which was statistically similar with V_2D_3.

4.4.4 Harvest index

Effect of genotype

Cultivation of different wheat genotype significantly influenced harvest index of wheat (Figure 27). Experimental result showed that, the highest harvest index (71.33 %) was recorded in V_3. Whereas the lowest harvest index (64.76 %) was recorded in V_4.Golabadi*et al.* (2008) reported that selection criteria for improving grain yield must include biological yield and 1000 grain weight in non stress environment and harvest index and number of grains per spike in stress environment with the highest direct effect.

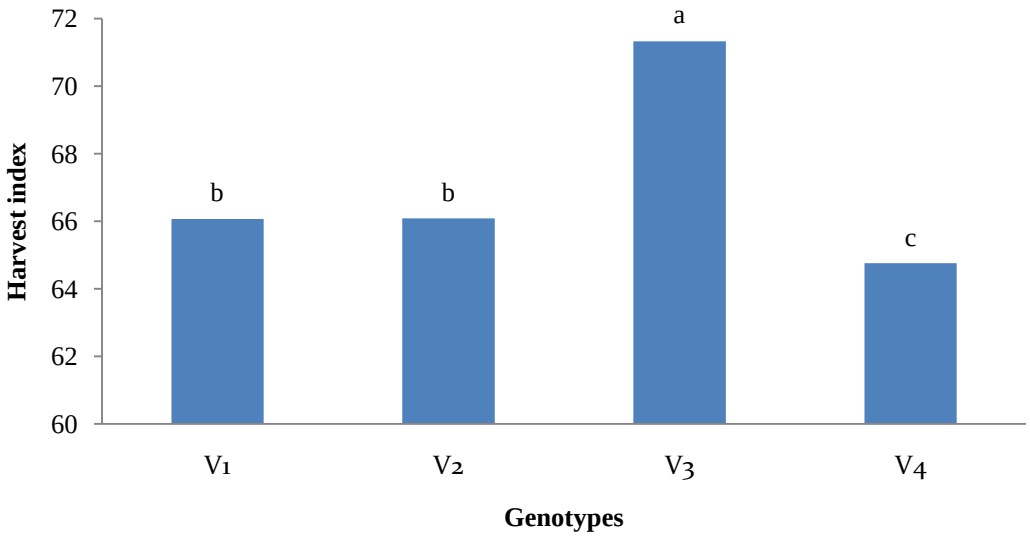


Figure 27. Effect of genotype on harvest index of wheat

Here: V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33.

Effect of drought levels

Different drought level significantly influenced harvest index of wheat (Figure 28). Experimental result showed that, the highest harvest index (69.35 %) was recorded in D_4. Whereas the lowest harvest index (63.58 %) was recorded in $D_{0.}$

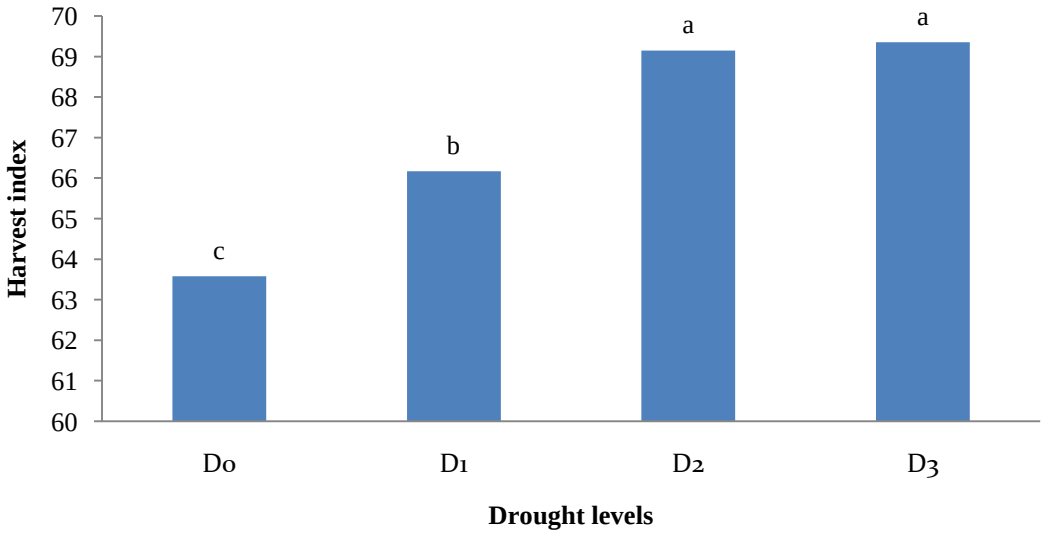


Figure 28. Effect of genotype on harvest index of wheat

Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

Interaction effect of genotype and drought levels

Cultivation of different wheat genotype growing at different drought levels significantly influenced harvest index of wheat (Table 6). Experimental result showed that, the highest harvest index (73.31 %) was recorded in V_3D_3 which was statistically similar with $V_3D_{2.}$ Whereas the lowest harvest index (60.23 %) was recorded in V_4D_0 which was statistically similar with V_2D_0.

Table 6. Interaction effect of variety and drought level on grain yield plant^{-1}, straw yield plant$^{-1,}$ biological yield plant^{-1} and harvest index of wheat

Treatment combinations	Grain yield plant^{-1}	Straw yield plant^{-1}	Biological yield plant^{-1}	Harvest index
V_1D_0	34.80 b	19.60 c	54.42 bc	63.92 gh
V_1D_1	31.00 c	15.30 e	46.33 e	66.91 ef
V_1D_2	24.50 e	12.40 f	36.91 hi	66.41 f
V_1D_3	20.20 f	9.90 h	30.13 j	67.06 ef
V_2D_0	34.60 b	21.60 b	56.20 b	61.63 ij
V_2D_1	30.90 c	16.90 d	47.75 de	64.64 g
V_2D_2	28.20 d	12.20 f	40.35 fg	69.81 bc
V_2D_3	21.20 f	9.80 h	31.00 j	68.28 c-e
V_3D_0	38.50 a	17.70 d	56.21 b	68.55 c-e
V_3D_1	34.50 b	14.50 e	49.06 d	70.39 b
V_3D_2	30.40 c	11.20 g	41.64 f	73.08 a
V_3D_3	25.70 e	9.40 h	35.10 i	73.31 a
V_4D_0	36.80 a	24.30 a	61.16 a	60.23 j
V_4D_1	33.70 b	20.00 c	53.67 c	62.73 hi
V_4D_2	31.00 c	15.10 e	46.12 e	67.29 d-f
V_4D_3	26.30 e	12.00 fg	38.27 gh	68.79 b-d
$LSD_{(0.05)}$	1.81	0.94	2.37	1.73
CV(%)	3.61	3.75	3.15	1.55

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability. V_1: BRRI Gom-29, V_2: BARI Gom-30, V_3: BARI Gom-32 andV_4: BARI Gom-33,Here: D_0: Control-3 times irrigation: crown root initiation (CRI) stage (17-21 DAS), flowering stage (50-55 DAS) and maturity stage (70-80 DAS); D_1: 2 times irrigation: crown root initiation (CRI) stage (17-21 DAS) and flowering stage (50-55 DAS); D_2: 1 time irrigation: crown root initiation (CRI) stage (17-21 DAS); D_3: No irrigation

CHAPTER V

SUMMARY AND CONCLUSION

Our experimental results suggested that increasing drought levels greatly reduced the yield and yield contributing parameters of wheat. The lowest grain yield (23.35 g plant^{-1}) was recorded in D_3 (Water reduction) treated pot (D_3). The highest grain yield (36.18 g plant^{-1}) stover yield (20.80 g plant^{-1}) and biological yield (56.99 g plant^{-1}) was found in D_0 control treatment. Different wheat genotypes have different growth characteristics that influences plant growth. In this experiment among different genotypes, BARI Gom-32 (V_3) performed well and recorded the highest grain yield plant^{-1} (32.28 g). In case of combination cultivation of BARI Gom-32 (V_3) and in absence of drought stress condition recorded the maximum grain yield plant^{-1} (38.50 g) comparable to other treatment combinations. Increasing drought condition disrupt plant growth and development and the lowest grain yield (23.35 g plant^{-1}) was recorded inV_1D_3.

Recommendation

According to the findings of our study we are suggesting the following recommendations:

i. Increasing drought stress gradually reduced plant growth and development
ii. Among the four genotype of wheat (BRRI Gom-29, BARI Gom-30, BARI Gom-32 and BARI Gom-33) BARI Gom-32 is best performed in drought stress condition.
iii. However, more experiment should be conducted at different location of drought prone areas with more varieties of wheat and different amendments.

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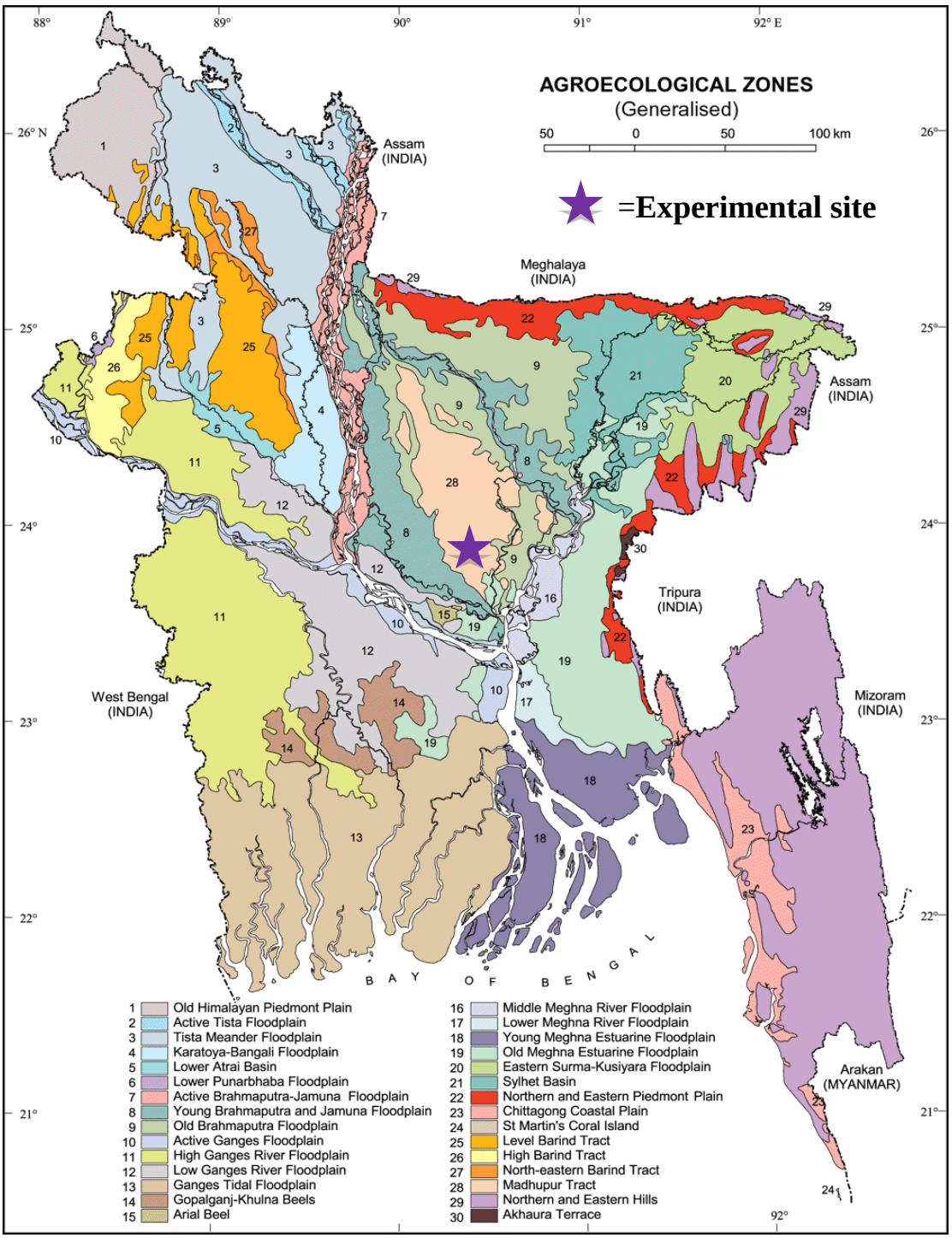
APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. Characteristics of soil of experimental pot

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

Physical characteristics	
Constituents	**Percent**
Sand	26
Silt	45
Clay	29
Textural class	Silty clay
Chemical characteristics	
Soil characteristics	**Value**
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10

Appendix III.Monthly meteorological information during the period from October-2019 to March 2020.

Year	Month	Air temperature (^{0}C)		Relative humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2019	October	27.26	16.30	64	43
	November	29.6	19.8	53	00
	December	28.8	19.1	47	00
2020	January	25.5	13.1	41	00
	February	25.9	14	34	7.7
	March	31.9	20.1	38	71

(Source:Metrological Centre, Agargaon, Dhaka (Climate Division)

Appendix IV. Analysis of variance of the data of plant height wheat at different DAS

Source	**DF**	Mean square of plant height at			
		30 DAS	60 DAS	90 DAS	At harvest
Replication	2	1.000	7.56	4.00	3.06
Genotype (S)	3	19.263*	107.16*	141.47*	111.39*
Drought levels (D)	3	283.202*	1453.80*	1212.59*	1990.24
S × B	9	3.038*	9.43*	15.62*	17.33*
Error	30	0.600	3.56	2.00	1.46
Total	47				

Ns: Non significant

**: Significant at 0.01 level of probability

*: Significant at 0.05 level of probability

Appendix V. Analysis of variance of the data of number of tillers plant^{-1} wheat at different DAS

Source	**DF**	Mean square of number of tillers plant^{-1} at		
		30 DAS	60 DAS	90 DAS
Replication	2	0.02687	0.00813	0.0044
Genotype (S)	3	0.06750*	0.46500*	0.4450*
Drought levels (D)	3	2.32750*	9.37500*	11.2350*
S × B	9	0.01417*	0.39667*	0.1233*
Error	30	0.01354	0.01079	0.0084
Total	47			

*: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data of SPAD value, relative water content and membrane stability index of wheat

Source	**DF**	SPAD **value**		**Relative water content**	**Membrane stability index (MSI)**
		30 DAS	**60 DAS**		
Replication	2	1.563	0.51	1.55	4
Genotype (S)	3	1.563*	0.512*	1.563*	4.00*
Drought levels (D)	3	66.995*	64.582*	10.877*	129.77*
S × B	9	442.615*	441.357*	843.142*	1197.15
Error	30	15.507	10.962	8.139	14.24
Total	47	1.029	0.572	0.762	1.33

*: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data of days to first flowering, days to maturity, filled grains spike^{-1}, unfilled grains spike^{-1} and 1000 grains weight of wheat

Source	**DF**	Mean square of				
		Days to first flowering	Days to maturity	Filled grains spike^{-1}	Unfilled grains spike^{-1}	1000 grains weight
Replication	2	1.00	10.56	4.00	0.25	5.063
Genotype (S)	3	154.16*	143.65*	107.35*	41.56*	48.315*
Drought levels (D)	3	1177.49*	1344.34*	1178.5*	1056.46*	384.570*
S × B	9	7.56*	7.27*	4.16*	5.83*	7.145*
Error	30	1.00	3.36	2.40	0.52	2.663
Total	47					

*: Significant at 0.05 level of probability

Appendix VII. Analysis of variance of the data of grain yield plant^{-1}, straw yield plant$^{-1,}$ biological yield plant^{-1} and harvest index of wheat

Source	**DF**	Mean square of			
		Grain yield plant^{-1}	Straw yield plant^{-1}	Biological yield plant^{-1}	Harvest index
Replication	2	2.250	0.188	2.45	2.209
Genotype (S)	3	64.647*	47.247*	134.84*	101.948*
Drought levels (D)	3	363.287*	255.562*	1219.13*	90.096*
S × B	9	3.495*	2.292*	2.31*	6.619*
Error	30	1.183	0.321	2.04	1.084
Total	47				

*: Significant at 0.05 level of probability