STUDY ON MORPHO-PHYSIOLOGICAL CHARACTERISTICS AND YIELD PERFORMANCE OF WHEAT GENOTYPES UNDER WATER LIMITED DROUGHT CONDITION

A Thesis

By

MD. NAZRUL ISLAM
Student No. 1305028

MASTER OF SCIENCE (MS)
IN
CROP PHYSIOLOGY AND ECOLOGY

DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR

DECEMBER 2014

STUDY ON MORPHO-PHYSIOLOGICAL CHARACTERISTICS AND YIELD PERFORMANCE OF WHEAT GENOTYPES UNDER WATER LIMITED DROUGHT CONDITION

A Thesis

By

MD. NAZRUL ISLAM
Student No. 1305028

Submitted to the
Department of Crop Physiology and Ecology
Hajee Mohammad Danesh Science and Technology University, Dinajpur
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE(MS)
IN
CROP PHYSIOLOGY AND ECOLOGY

DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
DINAJPUR

DECEMBER 2014

STUDY ON MORPHO-PHYSIOLOGICAL CHARACTERISTICS AND YIELD PERFORMANCE OF WHEAT GENOTYPES UNDER WATER LIMITED DROUGHT CONDITION

A Thesis

By

MD. NAZRUL ISLAM
Student No. 1305028

Approved as to the style and content by

....

(Professor Dr. Sripati Sikder)
Supervisor

....

(Professor Dr. Md. Maniruzzaman Bahadur)
Co-supervisor

....

(Professor Dr. Md. Abu Hasan)
Chairman
Examination Committee

DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY

DINAJPUR

DECEMBER 2014

DEDICATED
TO
MY Beloved PARENTS

ACKNOWLEDGEMENTS

The author expresses his deepest sense of gratefulness to the Almighty Allah, Who has enabled his to complete the present research work and to prepare this capacious thesis for the degree of Master of Science (MS) in Crop Physiology and Ecology.

The author expresses his heartfelt gratitude, profound respect and immense indebtedness to her research supervisor Professor Dr. Sripati Sikder, Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur for his cordial guidance, intense supervision, continuous inspiration, invaluable advice, and generous help during the entire period of research work and in preparation of the manuscript. Without his help and supervision it would not be possible to complete the dissertation within the stipulated period. Sincere appreciation is also due to his constructive criticism and meticulous corrections of this manuscript.

The author also express his respect and gratefulness to her co-supervisor, Professor Dr. Md. Maniruzzaman Bahadur, Department of Crop Physiology and Ecology, HSTU, Dinajpur for his encouragements, and suggestions throughout the research work. The author is grateful and indebtedness to his respectful teacher Professor Dr. Md. Abu Hasan, Department of Crop Physiology and Ecology, and Md. Rabiul Islam, Lecturer, Department of Crop Physiology and Ecology, HSTU, Dinajpur for their sympathetic encouragement, affectionate advices and valuable suggestions during the entire course of the study.

Cordial thanks are extended to all laboratory and office staffs of the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur for their helps and co-operations.

At last, from the core of heart, the author feels duty bound to acknowledge the blessing and incentives of his wife Shahana Begum and two children Arnab and Ahona for their moral supports and sacrifice, which encouraged and paved the way of his higher studies.

December 2014 *The author*

ABSTRACT

The experiment was conducted at research field and laboratory in the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur during the period of November 2013 to April 2014. It was laid out in a split plot design with three replications. The treatment factors were A- Main plot treatments two growing conditions viz. i. well watered condition (giving three irrigations) and ii. water limited drought condition (giving one irrigation at 20 DAS for seedling establishment) and B- Sub plot treatments: six wheat genotypes viz. BAW 1170, BAW 1161, BAW 1163, BAW 1151, BARI Gom 26 and BAW 1135. To attain different phenologcal stages, the maximum number of days were required for BAW 1170, BAW 1161 and BAW 1163 followed by BAW 1151 and BARI Gom 26, whereas the minimum number of days were required for BAW 1135 under well watered and water limited drought condition. Higher leaf chlorophyll content and leaf proline content were also showed higher by drought tolerant wheat genotypes compared to other genotypes at both the well watered and water limited condition. At water limited drought condition wheat genotypes BAW 1170, BAW 1161 and BARI Gom 26 showed higher level of plant

height, spike length, floret sipkelet^{-1}, grains sipkelet^{-}1, floret sipke^{-1}, grains sipke$^{-1,}$ 1000 seed weight and lower the floret sterility than the genotypes BAW 1151, BAW 1163 and BAW 1135. BAW 1170 gave the highest grain yield (4.2 t ha^{-1}) and BAW 1135 produced the lowest grain yield (2.8 t ha^{-1}) at well watered condition. At water limited drought condition the highest grain yield was produced by BAW 1170 (3.5 t ha^{-1}) and the lowest grain yield was produced by BAW 1135 (2.0 t ha^{-1}). BAW 1170 and BAW 1135 showed the highest harvest index (40.00%). BARI Gom 26 showed the lowest harvest index (34.11%) under well watered condition. Whereas at water limited drought condition the highest harvest index was given by BARI Gom 26 (38.71%) and the lowest harvest index was showed by BAW 1163 (31.58). Finally, from the DSI (Drought susceptible index) based on grain yield it may be concluded that wheat genotypes BAW 1161, BAW 1170 and BARI Gom 26 were regarded as drought tolerant and genotypes BAW 1151, BAW 1163 and BAW 1135 were considered as drought susceptible.

ABBREVIATION AND ACRONYMS

%	Percentage
@	At the rate of
AEZ	Agro Ecological Zone
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BRRI	Bangladesh Rice Research Institute
cm	Centimeter
CV%	Co-efficient of Variance
DAE	Department of Agricultural Extension
DAT	Days after transplanting
DSI	Drought susceptible index
DMRT	Duncan’s Multiple Range Test

et al.	And others
FAO	Food and Agriculture Organization
g	Gram
HSTU	Hajee Mohammad Danesh Science and Technology University
HYV	High Yielding Varieties
IAA	Indole acetic acid
IRRI	International Rice Research Institute
J.	Journal
K	Potassium
kg	Kilogram
m^{-2}	Per square meter
mg	Milligram
MoP	Muriate of potash
N	Nitrogen
^{o}C	Degree Celsius
P	Phosphorous
P_2O_5	Phosphate
pH	Potential of H^+ concentration
ppm	Parts per million
S	Sulphur
t ha^{-1}	Ton (s) per hectare
TSP	Triple super phosphate
UNDP	United Nations Development Programme
viz.	Such as

CONTENTS

LIST OF TABLES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop of the world ranking first both in acreage and production among seed crops. At least one third of the total population of the world lives on wheat grains. It provides more nourishment for the nations of the world than any other food crops. It is produced under diverse environmental conditions ranging from well irrigated to water stress situations and wheat yield are reduced 50-90% of their irrigated potential by drought on at least 60 Mha in developing world. In Make para Bangladesh Wheat is the second most important cereal crop next to rice (BBS 2005). The area under wheat cultivation is about 0.706 million hectare producing 1.507 million tons of wheat with an average 2.013 ton per hectare (BBS 2005). Therefore, in Bangladesh its average yield is very low (2.13 t ha^{-1}) compared to other advanced countries of the world. One of the major causes for low is shortage of water during the growing season. It is grown in the winter season (usually November to April) which is dry as well as inadequate soil moisture. Although the vast storage of soil moisture resulted from monsoon rain supports the plant growth favourably at the early stages of growth, the plant suffers from water stress at the reproductive stage when the residual soil moisture depletes (Karim *et al*. 2000). Boyer (1982) claimed that water stress limited global productivity more severely than that caused by any other environmental stresses. Therefore, about 42.78% of the total wheat area in the country is irrigated and rest of the area is cultivated under drought condition (BBS 2005). The present situation is not far better than this.

Drought severely limits wheat productivity in many different environments around the world. Some estimation indicates that 50%

of the approximately 230 M ha sown to wheat annually in the world is regularly affected by drought (Pfeiffer *et al*. 2005). Drought induces decrease in leaf water content and increased stomatal closure, it decreases the supply of CO_2 to messophyll tissue and the rate of photosynthesis is decreased. Drought operates the water cycle and increases photorespiration. Water stress adversely affects the plant establishment, and thereafter growth and development. Cell enlargement, gas exchange and assimilates partitioning are hindered by drought stress. Under extreme condition it may severely disturbs several metabolic processes which may results in diminished photosynthesis, check cell enlargement, cell division and finally cell death (Kramer 1983). Water stress at reproductive stage is more harmful to plant process than any other growth stage. This is because water stress at anthesis markedly reduces photosynthesis, reproductive development and finally grain yield (Araus *et al*. 2002). However, this problem will be further increased due to climate change. Due to raise in world temperature soil losses its moisture holding capacity as a result drought effect is accelerated. Thus the best option for yield improvement and yield stability of wheat drought condition is to develop drought tolerant wheat varieties.

Clearly, there is no optimum strategy for developing what cultivars better adapted to drought condition. The existence of large genotype x environment interaction makes it difficult to pinpoint the underlying genetic control of adaptation. The challenges are to combine these different strategies most effectively to produce well adapted wheat germplasm. However, some of the highest yielding genotypes under supplementary irrigation condition can also be among highest yielding under drought condition. Therefore, evaluation under drought condition appears to be necessary to preserve genotypes possessing alleles for drought tolerance. Yield potential (yield under irrigated condition) and traits (yield under drought condition) can be combined in one single genotype. The yield is a complex process. It is a function of interactions among the factors responsible for wheat growth and depends on the environmental factors for expression of yield potential. So, in Bangladesh selection of drought tolerant genotypes by screening advance lines through evaluate their performance in growth and yield attributes at water limited drought condition in Bangladesh environments would be an important step to develop heat tolerant genotype and also achieving high yield potential of wheat under drought condition. Therefore, the present investigation was done with the following objectives.

I. To evaluate the wheat genotypes for different growth and morphological traits in relation to drought tolerance.
II. To evaluate the performance of wheat genotypes on the basis of selected traits at field condition and identify the relative drought tolerant genotypes.
III. To find out the comparative drought tolerent wheat genotype(s).

CHAPTER II

REVIEW OF LITERATURE

Water deficit stress on what has a profound effect on growth and yield of the Crop. In this regards many researches throughout the world have several observations on the effect of water deficit Stress on wheat. But there is very little information on it is available in Bangladesh. However, some of the information on the morpho-physiological characters affected by water Stress is given below.

2.1. Phenology and Physiological characters in relation to water Stress.

Improvement of drought tolerance in crop plants requires identification of relevant drought resistance mechanisms and development of a suitable methodology for their measurement in large breeding populations. Drought tolerance is manifested by the relative ability to the plant tissue to sustain a smaller reduction in physiological or metabolic activity as its water potentials decreases (Blum and Ebercon 1981).

Stress exposed plants immediately lower down relative water content of their leaves, the decrease in leaf water potential and osmotic potential is also reported (Grover *et al*. 2004).

Osmotic adjustment i.e. the active lowering of osmotic potential in response to water stress is regarded as the mechanism which significantly contributes to increase water stress resistance (Morgan 1984; Blum and Sullivan 1986; Khan *et al*. 1993).

Large differences in kernels/spikelet and kernel weight indicated that these two variably were responsible for yield adjustments to stress during spikelet and kernel development phase (Duggan and Fowler 2006).

Baser *et al*. (2004) studied the effect of water stress on the yield and yield components of winter wheat and found a decrease of about 40% in yield under water stressed conditions as compared to control.

Weight of grains per spike was reported by many researchers as the most closely linked variable related to grain yield per unit area and was often used in selecting high yielding wheat strains (Kumbhar *et al.,* 1983).

The 1000-grain weight had also been shown as the main yield component accounting for 20% of variation in wheat grain yield (Collaku, 1989).

2.2. Yield and yield component under water Stress

Photosynthesis, which is the basic process influencing crop productivity, is inhibited by water stress (Chaves and Oliveira, 2004). The reduction in photosynthesis as a result of water stress can be attributed to both stomatal and non-stomatal limitations (Graan and Boyer, 1990).

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

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

Arabinda and Dolgodvorov (1994) studied the different stages of growth of two newly developed high yielding spring wheat varieties, namely Moskovskaya 35 and Minovoskya spring. They divided the growth cycle into three major developmental phases viz., vegetative, panicle development and grain filling and ripening phase. They observed that the vegetative phase started with the emergence of seedlings upto the point of panicle initiation and needed 36, 36, and 39 days after sowing in Moskovskaya 35 and 37, 36, and 38 for Minovoskya spring in 1983, 1984 and 1985, respectively. The panicle developmental phase included the heading and flowering stages and required 56, 60, 67 days after sowing for Moskovskaya 35 and 58, 60 and 68 days after sowing for Minovoskya spring in the first, second and third year year respectively. The third growth phase began with the fertilization of florets in the panicle and continued upto maturity of the plant and required 107, 108 and 112 days after sowing for Moskovskaya 35 and 108, 110 and 113 for Minovoskya spring in 1983, 1984 and 1985, respectively.

Rahman *et al*. (2000) to study the effect of irrigation and nitrogen fertilization on the leaf photosynthesis (LPn), Crop grow rate (CGR), leaf area index (LAI) and dry matter (DM) production of wheat and reported that both irrigation and N application created a significant impact on LPn, LAI, CGR and DM production of wheat. Irrigation scheduling which included irrigation at grain filling stage (80 DAS) coupled with N application up to 120 kg/ ha significantly increased LPn, LAI, CGR and DM production.

Abdorrahmani *et al*. (2005) found that drought stress reduced dry matter production, crop growth rate and relative growth rate.

Singh and Patel (1996) subjected two wheat cv WH-283 and WH-331 in a pot experiment to water stress by withholding water until wilting occured at tillering, flowering or grain filling stages and observed that leaf water potential, osmotic potential, relative water content and photosynthesis decreased in both the cultivars and at all the growth stages respiration rate and accumulation of proline increased with water stress. The effect was more pronounced in WH-283 than the WH-331. Water stress reduced grain yield at flowering more than water stress at tillering or grain filling stage.

Proline accumulation capacity in plant is closely related with plant-antidrought, specially under soil water deficits. Many reports from wheat and other crops have proved this (Wang and Li 2000, Wang *et al*. 2003, Errabii *et al*. 2006)

Vendruscolo *et al*. (2007) found that proline is involved in tolerance mechanism against oxidative stress and this is the main strategy of plants to avoid detrimental effects of water deficit Stress.

Maiti *et al*. (2000) reported that proline accumulation is a stress tolerance mechanism of resistant plants against various abiotic stresses such as drought, high temperature and salinity.

Maralian *et al*. (2010) conducted a field study to evaluate the effect of water stress on proline accumulation rate and wheat grain yield. A bred wheat line (N84-12) was evaluated by contrasting irrigation regimes i.e., well watered and water deficit stress before tillering stage (T1) and after heading stage (T2). To impose water deficit stress plant was not irrigate before T1 and T2. The analysis of variance showed that water deficit stress significantly affected proline accumulation rate and harvest index in $P \leq 0.01$. The highest proline accumulation rate was observed under T2 condition and grain yield was decreased by water deficit stress compared to well watered condition.

Ashraf *et al.* (1994) evaluate four wheat genotypes (two tolerant: Chakwal-86 and DS-4, two susceptible: DS-17 and Pavon) to drought induced by PEG-6000 solutions. Water stress reduced chlorophyll (a, b, and total) contents and reduction was more pronounced in drought susceptible genotypes. Total phenol, peroxidase activity and cholophyll a/b ratio increased under drought conditions.

Podsiado (1999) grew four spring wheat cultivars on sandy soil with or without irrigation. Irrigation generally increased the chlorophyll and carotinoid contents but decreased nitrate reductase activity and increased acid and alkaline phosphate activities of flag leaf.

Blum *et al.* (1994) reported that grain filling of wheat is seriously impaired by heat stress due to reducing in current leaf and ear photosynthesis at high temperatures. An alternative source of carbon for grain filling is stored stem reserves. They evaluated the hypothesis that the mobilization of stored stem reserves into growing grain is an important source of carbon for supporting grain filling under heat stress through two experiments with two spring wheat cultivars (V_5 and V_{2183}) of very similar phenology and plant stature, which had previously been found to differ in grain shrivelling under drought and heat stress conditions in the field. Variety V_5 was more heat susceptible than V_{2183}. The rates of stem dry weight (DM) loss was monitored under optimum (control) and high (stress) temperatures in glass house (Expt 1) and growth chamber (Expt 2). In Expt 1, irrespective of the environment, stem DM reserves may have accounted for about half of grain weight per ear in V_5, while it was less than quarter in V_{2183}. The contribution of stem reserves to grain mass was consistently higher in V_5 than in V_{2183} under both stress and non-stress conditions. In Expt 2, stem weight loss in the controls could account for 62.3% and 40.2% of grain weight per ear, in V_5 and V_{2183} respectively. However, under heat stress these values increased to greater than 100%.

Rahman (1997) conducted an experiment with 8 wheat cultivars under irrigated and drought condition. He reported that moisture retention capacity (MRC) and relative leaf water content (RLWC) were higher in irrigated plants than the drought plants. He found variation in MRC and RLWCamong the cultivars in different magnitude.

Prakash and Ramchandran (2000) indicated leaf water potential as a tool to measure the water stress condition was reduced in moisture deficit brinjal plant.

Canopy temperature (CT) has been expected to be a useful physiological parameter to screen wheat genotypes for tolerance of water stress and yield potential but it is strongly influenced by environmental conditions (Blum *et al*. 1989).

Inagaki and Nachit (2007) conducted a study on wheat under water deficit stress. Infrared thermograph was used to monitor the changes in the leaf temperature. CT of 11 wheat genotypes was also compared under moderate water stress in the field. They suggested that leaf and canopy temperature was a reliable indicator of thermal changes in wheat foliage under water deficit.

Siddique *et al*. (1999) conducted an experiment on drought effects on four wheat cultivars (Kanchan, Sonalika, Kalyansona and C306). These cultivars were grown in pots and subjected to four levels of water stress at vegetative or anthesis stage or both. Exposure of plant to drought led to noticeable decreases in leaf water potential and relative water content with a concurrent increase in leaf temperature. The higher leaf water potential and relative water content as well as lower leaf temperature was associated with a higher photosynthesis rate. Drought stress plant displayed a higher CT than well watered plant in both vegetative growth and anthesis growth stages. Successive stresses at both developmental stages raised the canopy temperature much higher than in plants stressed once.

Water stress adversely affects the plant establishment, and thereafter growth and development. Cell enlargement, gas exchange and assimilates partitioning are hindered by drought stress. Under extreme condition it may severely disturbs several metabolic processes which may results in diminished photosynthesis, check cell enlargement, cell division and finally cell death (Kramer 1983).

Siddique *et al.* (1999) found reduce spikelet per spike, grain per spike and grain yield at drought stress. They reported that the reduction of spikelet per spike was more severe at vegetative drought than at anthesis drought of wheat plant. They indicated that ecological condition at vegetative stage played an important role in determining the number of spikelet per spike.

Karim *et al.* (2000) stated that water stress reduced grain yield by reducing productive tillers per plant, fertile spikelet per plant, number of grains per plant and individual grain weight. They also mentioned that water stress at reproductive stage is more harmful to plant processes than that of any other growth stages. This is because of water stress at anthesis markedly reduces photosynthesis, reproductive development and finally grain yield.

Sikder *et al.* (2011) tested four wheat varieties (Prodip, Sufi, Bijoy and Pavon-76) under well watered and non-irrigated water stress condition to evaluate their morphological and yield performance in relation to water stress. They found that plant height, ear bearing tiller number, grain number per spike, seed size and grain yield were significantly affected by combined effect of growing conditions (water level) and varieties. Under water stress condition all the varieties showed reduced value of those parameters at different magnitude compared to well water condition. Varieties Prodip, Sufi and Bijoy had showed relatively better performance and lower reduction under non-irrigated water stress condition in those characters compared to Pavon-76.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at research field and laboratory of the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during the Rabi (winter) season of 2013-2014. Details of the methodology of the experiment followed during the research period are presented in this chapter.

3.1 Experimental site and soil

The location of the experimental site was at 25º38´ N latitude and 88º41´ longitude and at the elevation of 34.4 m above the sea level. The experimental site was medium high land and belonging to the Agro-ecological Zone-1 (AEZ-1) named Old Himalayan Piedmont Plain (FAO and UNDP 1988). The soil characteristic was given at appendix I and II.

3.2 Weather in experimental period

The field experiment was performed during the period of November 2013 to April 2014. The weather information was shown in appendix III.

3.3 Germplasm Collection

Six wheat genotypes (Five advanced lines and one cultivated variety) collected from Wheat Research Centre, BARI, Dinajpur.

3.4 Experiment

The experiment was carried out at the research farm of Crop Physiology and Ecology Department, HSTU, Dinajpur. It was laid out in a split plot design with three replications. The unit plot size will be 3m x 2m having a plot to plot and block to block distance of 0.75m and 1.0 m, respectively. For crop cultivation the management practice recommended by WRC was followed.

The treatment factors A and B were

A. Main plot treatment: Two growing conditions

i. Well watered condition (Giving three irrigations) and
ii. Water limited drought condition (Giving one-1 irrigation at 20 DAS for seedling establishment).

B. Sub plot treatment: Six wheat genotypes viz.

i. BAW 1170
ii. BAW 1161
iii. BAW 1163
iv. BAW 1151
v. BARI Gom 26 and
vi. BAW 1135

3.5 Physiological parameters

3.5.1 Phenological stages

The following phenological stages were recorded at the days when 50% plants of each plot reached a definite stage as the representative of that stage. Duration of anthesis and grain filling (days) were also recorded.

i. Crown root initiation – When 50% plants of the plot produced crown root.
ii. Tillering- When 50% plants of the plot produced maximum tiller.
iii. Booting - When 50% plants of the plot reached to booting condition.
iv. Heading - When 50% plants of the plot emerged spike.
v. Anthesis - When 50% plants of the plot gave flowering.
vi. Physiological maturity - When 50% plants of the plot produced matured soft grain.

vii. Maturity. - When 50% plants of the plot produced hard grain and ready for harvesting.

3.5.2 Chlorophyll estimation

Chlorophyll was estimated on fresh weight basis extracting with 80% acetone by using spectrophotometer (Model: SPECTRO UV-VIS RS, Labomed Inc, USA) according to Witham *et al.* (1986) using the following formulae:

mg chlorophyll a/g tissue = [12.7(D663 – 2.69(D645)] x [v/(1000 x w)]

mg chlorophyll b/g tissue = [22.9(D645 – 4.68(D663)] x [v/(1000 x w)]

mg chlorophyll (a+b)/g tissue = [20.2(D645 + 8.02(D663)] x [v/(1000 x w)]

3.5.3 Proline estimation

Proline contents of the flag leaf at 8 DAA in all the wheat cultivars grown in two different growing conditions were estimated. At 8 DAA, the flag leaves from each replication of each cultivar were collected and immediately kept in the ice-bag and were brought to Crop Physiology and Ecology Laboratory of HSTU for proline estimation. One gram fresh weight of the flag leaf was taken for proline estimation. Subsequently proline was estimated as Troll and Lindsley (1955).

At first ninhydrin reagent was prepared in such a way so that it was utilized for proline estimation within two hours of preparation. For preparing ninhydrin reagent, addition of 30 ml glacial acetic acid and 30 ml 6M orthophosphoric acid were mixed with 1.25 g of ninhydrin. It was subsequently heated and stirred gently to dissolve but the temperature was not allowed to exceed 70^0C. Proline standards were prepared for 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 ppm with distilled water.

The fresh samples were crushed in mortar and pestle and homogenized the material in 10 ml 3% sulphosalicylic acid until no large segments of plant material remained. Homogenate was filtered through Whatman No. 2 filter paper and washed with 3% sulphosalicylic acid and the volume was set to 25 ml. Two ml of the filtrate and each standard proline solutions were then reacted with 2 ml of ninhydrin reagent and 2 ml of glacial acetic acid in a pyrex test tube and boiled for one hour at 100^0C in water bath covering the tube with aluminium foil to prevent excess evaporation. Subsequently, it was cooled in ice bath and 4 ml of toluene was added to each tube using a dispensor. Each tube was then shaken vigorously for 15 to 20 seconds in an electrical shaker and allowed the layer to separate for 30 minutes. The absorbance of layer was measured through spectrophotometer at 520 nm with pure toluene as a blank. Proline content was expressed on a fresh weight basis from the standard curve, using standard L-proline according to the method developed by to Troll and Lindsley (1955).

3.6 Morphological and yield parameters

3.6.1 Plant height

Plant height was measured from the base of the plant to the tip of the spike. Five plant samples from each plot were taken and means were calculated.

3.6.2 Spike length

Spike length was measured from the base of the spike to the tip of the spike excluding the own. Five spikes from each plot were taken and means were calculated.

3.6.3 Spikes per plant

Spikes of five plant samples from each plot were taken and means were calculated.

3.6.4 Florets per spike and spikelet

Floret number per spike and spikelet was counted from five spikes of each plot and means were calculated.

3.6.5 Grain per spike and spikelet

Grain number per spike and spikelet was counted from five spikes of each plot and means were calculated.

3.6.6 Floret sterility

Floret sterility was measured on the basis of following equation-
Floret sterility (%)

= (1- Number of kernel per spike/Number of floret per spike) ×100

3.6.7 1000 seeds weight

1000 cleaned sun dried grains were counted from the seed stock obtained from each treatment combination and weighted using electronic balance.

3.6.8 Grain weight and biological weight

Grain and straw yield per plot was calculated first then converted to ton per hectare. Biological yield also measured.

3.6.9 Harvest index

Harvest index was calculated by dividing economic yield by biological yield of plant in each pot by multiplying with 100 and expressed in percentage.

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

3.6.10 Drought susceptibility index

Drought susceptibility index (DSI) was calculated for different parameters as described by Fischer and Maurer (1976).

$S = (1 - Y/Y_p) / (1 - X/X_p)$

Where, Y = Variable of a cultivar in a stress environment

Y_p = Variable of a cultivar in a stress-free environment

X = Mean of Y of all the cultivars

X_p = Mean of Y_p of all the cultivars.

($S < 1.0$, stress tolerant and $S > 1.0$, stress susceptible)

3.7 Statistical analysis

The recorded data was analyzed by partitioning the total variance with the help of computer by using MSTAT program. The treatment means compared using Duncun's Multiple Range Test (DMRT).

CHAPTER IV

RESULTS AND DISCUSSSION

4.1 Physiological parameters

4.1.1 Phenological stages

The interaction effect of growing conditions and wheat genotypes on various phenological stages was significant which is presented in Table 1. From the results, it was found that the crown root initiation (CRI) stage required lower number of days than that of the other successive stages like tillering, booting, heading, anthesis, physiological maturity and harvesting maturity. In case of CRI stage, the maximum number of days (21 days) required for BAW 1170, BAW 1161 and BAW 1163 followed by BAW 1151 (18 days) and BARI Gom 26 (17 days), where as the minimum number of days required for BAW 1135 (16 days) under well watered condition. The requirement of days was decreased for all the genotypes for attaining the CRI stage under water limited drought condition. In this condition, maximum number of days needed to attain CRI stage by BAW 1170 (20 days) followed by BAW 1161 and BAW 1163 (18 and 19 days, respectively), where as the minimum number of days (15 days) required for BAW 1135 and BARI Gom 26 followed by BAW 1151 (17 days).

In case of tillering stage, the maximum number of days (35 days) required for BAW 1170, followed by BAW 1161, BAW 1163 and BAW 1151 (33, 30 and 30 days, respectively), where as the minimum number of days required for BAW 1135 (25 days) followed by BARI Gom 26 (27 days) under well watered condition. At water limited drought condition, the requirement of days was decreased by all the genotypes for attaining the tillering stage. In this case, maximum number of days needed to attain tillering stage by BAW 1170 (33 days) followed by BAW 1161 (31 days), where as the minimum number of days (31 days) required for BAW 1135 followed by BAW 63, BAW 1151 and BARI Gom 26 (28, 29 and 25 days, respectively).

At well watered condition, the maximum number of days required for attaining booting stage by BAW 1170 (45 days) followed by BAW 1161 and BAW 1163 (44 and 42 days, respectively), where as the minimum number of days (35 days) required for BAW 1135 and BARI Gom 26. The requirement of days was decreased for all the genotypes for attaining the tillering stage under water limited drought condition. In this condition, the highest number of days needed to attain booting stage by BAW 1170 (43 days) followed by BAW 1161 and BAW 1163 (40 and 39 days, respectively), where as the lowest number of days required for BAW 1135(32 days) followed by BARI Gom 26 and BAW 1151 (34 and 35 days, respectively).

For attaining heading stage, BAW 1170 required the maximum number of days (65 days) followed by BAW 1161 and BAW 1163 (62 and 60 days, respectively), where as BAW 1135 required the minimum number of days (55 days) followed by BARI Gom 26 and BAW 1151 (57 and 58 days, respectively) under well watered condition. At water limited drought condition, the requirement of days was decreased by all the genotypes for attaining the heading stage. In this condition, maximum number of days needed to attain heading stage by BAW 1170 (61 days) followed by BAW 1161 and BAW 63 (59 and 57 days, respectively), where as the minimum number of days required by BAW 1135 (50 days) followed by BARI Gom 26 and BAW 1151 (52 and 53 days, respectively).

At well watered condition, BAW 1170 required the maximum number of days (69 days) for attaining the anthesis stage followed by BAW 1161 and BAW 1163 (67 and 65 days, respectively), where as BAW 1135 required the minimum number of days (58 days) followed by BARI Gom 26 and BAW 1151 (59 and 60 days, respectively). At water limited drought condition, the requirement of days was decreased by all the genotypes for attaining the anthesis stage. In this condition, maximum number of days needed to attain anthesis stage by BAW 1170 (66 days) followed by BAW 1161 and BAW 63 (63 and 62 days, respectively), where as the minimum number of days required by BAW 1135 (55 days) followed by BARI Gom 26 and BAW 1151 (56 and 57 days, respectively).

Table 1. Days required for attaining crown root initiation and tillering of wheat genotypes as affected by water limited drought condition.

Wheat genotypes	Crown root initiation		Tillering	
	Well watered	Water limited drought	Well watered	Water limited drought
BAW 1170	21 a	20 ab	35 a	33 ab
BAW 1161	21 a	18 bcd	33 ab	31 bc
BAW 1163	21 a	19 abc	30 cd	28 de
BAW 1151	18 bcd	17 cde	30 cd	29 cde
BARI Gom 26	17 cde	15 e	27 ef	25 f
BAW 1135	16 de	15 e	25 f	21 g
CV (%)	6.39		5.28	

Wheat genotypes	Booting		Heading	
	Well watered	Water limited drought	Well watered	Water limited drought
BAW 1170	45 a	43 ab	65 a	61 bc
BAW 1161	44 ab	40 cd	62 ab	59 bcd
BAW 1163	42 bc	39 de	60 bcd	57 de
BAW 1151	37 ef	35 fg	58 cde	53 fg
BARI Gom 26	35 fg	34 gh	57 de	52 fg
BAW 1135	35 fg	32 h	55 ef	50 g
CV (%)	3.82		3.34	

Wheat genotypes	Anthesis		Physiological maturity		Harvesting maturity	
	Well watered	Water limited drought	Well watered	Water limited drought	Well watered	Water limited drought
BAW 1170	69 a	66 abc	105 a	100 b	115 a	110 bc
BAW 1161	67 ab	63 bcd	103 a	98 bc	113 ab	108 cd
BAW 1163	65 abc	62 cde	100 b	95 de	110 bc	105 def
BAW 1151	60 def	57 fg	96 cd	90 f	106 cde	100 gh
BARI Gom 26	59 defg	56 fg	93 e	88 f	103 efg	96 hi

BAW 1135	58 efg	55 g	90 f	85 g	101 fg	93 i
CV (%)	3.93		1.96		2.20	

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

BAW 1170 required the maximum number of days (105 days) for attaining the physiological maturity stage followed by BAW 1161 and BAW 1163 (103 and 100 days, respectively), where as BAW 1135 required the minimum number of days (90 days) followed by BARI Gom 26 and BAW 1151 (93 and 96 days, respectively) under well watered condition., At water limited drought condition, the requirement of days was decreased by all the genotypes for attaining the physiological maturity stage. In this condition, maximum number of days needed to attain physiological maturity stage by BAW 1170 (100 days) followed by BAW 1161 and BAW 63 (98 and 95 days, respectively), where as the minimum number of days required by BAW 1135 (85 days) followed by BARI Gom 26 and BAW 1151 (88 and 90 days, respectively).

In case of harvesting maturity stage, BAW 1170 required the maximum number of days (115 days) followed by BAW 1161 and BAW 1163 (113 and 110 days, respectively), where as BAW 1135 required the minimum number of days (101 days) followed by BARI Gom 26 and BAW 1151 (103 and 106 days, respectively) under well watered condition. At water limited drought condition, the requirement of days was decreased by all the genotypes for attaining the harvesting maturity stage. In this condition, maximum number of days needed to attain harvesting maturity stage by BAW 1170 (110 days) followed by BAW 1161 and BAW 63 (108 and 105 days, respectively), whereas the minimum number of days required by BAW 1135 (93 days) followed by BARI Gom 26 and BAW 1151 (96 and 100 days, respectively). In the present study, it was found that drought has profound effect on wheat genotypes to attaining different phenological stages. Results from other studies Sikder *et al.* (2011) found that the drought significantly reduced the number of days to attain different phenological stages of various wheat cultivars. Varietal differences in phenological stages of wheat under well watered and drought condition also found by Rahman *et al.* (1997) and Sikder *et al.* (2011).

4.1.2 Chlorophyll content of flag leaf

The combined effect of growing conditions and wheat genotypes on chlorophyll content of flag leaf during anthesis stage was significant which is presented in Table 2. The chlorophyll content was decreased in all wheat genotypes under water limited drought condition than the well watered condition. From the results it was also found that BAW 1170 gave the highest amount of total chlorophyll (2.80 mg/g fresh weight) which was at par with BAW 1161 (2.60 mg/g fresh weight) under well watered condition. BAW 1163 and BAW 1151 showed the intermediate chlorophyll content (2.35 and 2.00 mg/g fresh weight, respectively). Besides this BAW 1135 and BARI Gom 26 showed comparatively lower amount of chlorophyll content (1.60 and 1.90 mg/g fresh weight, respectively) at well watered condition.

At water limited drought condition the highest amount of chlorophyll content was found in BAW 1163 (2.10 mg/g fresh weight) followed by BAW 1170 (2.00 mg/g fresh weight), whereas the lowest chlorophyll content was produced by BAW 1135 (1.40 mg/g fresh weight) followed by BARI Gom 26 and BAW 1151 (1.50 and 1.80 mg/g fresh weight, respectively). The highest relative performance found in BAW 1151 (90.00%) and lowest relative performance found in BAW 1161 (71.15%). Results from other studies Asraf *et al.* (1998) found that water stress water stress produced chlorophyll a, b and total chlorophyll content and the reduction was more pronounced in drought susceptible genotypes.

Table 2. Chlorophyll and proline content of leaf of wheat genotypes as influenced by water limited drought condition

Wheat genotypes	Chlorophyll content of flag leaf (mg/g fresh weight)			Proline content of flag (µmole/g fresh weight)		
	Well watered	Water limited drought	Relative performance (%)	Well watered	Water limited drought	Relative performance (%)
BAW 1170	2.80 a	2.00 cd	71.43	1.71 c	2.30 a	134.50
BAW 1161	2.60 a	1.85 d	71.15	1.65 cd	2.15 ab	130.30
BAW 1163	2.35 b	2.10 c	89.36	1.50 de	2.00 b	133.33
BAW 1151	2.00 cd	1.80 de	90.00	1.25 f	1.74 c	139.20
BARI Gom 26	1.90 cd	1.50 f	78.95	0.79 g	1.60 cd	202.53
BAW 1135	1.60 ef	1.40 f	87.50	0.77 g	1.40 ef	181.82
CV (%)	5.66		-	6.76		-

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

4.1.3 Proline content of leaf

The combined effect of growing conditions and wheat genotypes on proline content of flag leaf during anthesis stage was significant which is presented in Table 2. The proline content was increased by all wheat genotypes in water limited drought condition than the well watered condition. From the results it was found that BAW 1170 gave the highest amount of proline (1.71 µmole/g fresh weight) followed by BAW 1161 (1.65 µmole/g fresh weight), whereas BAW 1135 produced the lowest proline content (0.77 µmole/g fresh weight) which was statistically similar with BARI Gom 26 (0.79 µmole/g fresh weight) and the genotypes BAW 1163 and BAW 1151 showed the intermediate proline content (1.50 and 1.25 µmole/g fresh weight, respectively) at well watered condition.

On the other hand, at water limited drought condition the highest amount of proline content was found in BAW 1170 (2.30 µmole/g fresh weight) followed by BAW 1161 and BAW 1163 (2.15 and 2.00 µmole/g fresh weight, respectively), whereas the lowest proline content was produced by BAW 1135 (1.40 µmole/g fresh weight) followed by BARI Gom 26 and BAW 1151 (1.60 and 1.74 µmole/g fresh weight, respectively). The highest relative performance found in BARI Gom 26 (202.53%) and lowest relative performance found in BAW 1161 (130.30%). Similar results also reported by some researcher that proline accumulation rate is higher at drought condition than the well watered condition (Wang and Li 2000, Wang *et al.* 2003 and Errabii *et al.* 2006). In the present study, there existed wide variation in proline content among studied wheat genotypes in both the well watered and water stress condition. Perhaps this was genotypes inherent characteristics. Fujita *et al.* (1998) reported that plant species differ considerably un the amount of proline that accumulated upon stress. Different researchers also found varietals differences in proline accumulation under heat or water stress like Sikder *et al.* (2011) in wheat.

4.2 Morphological and yield attributes

4.2.1 Plant height (cm)

The combined effect of growing conditions and wheat genotypes on plant height was significant which is presented in Table 3. From the results it was found that BAW 1170 attained the highest plant height (105 cm) followed by BAW 1161 and BAW 1163 (103 and 102 cm, respectively), where as BAW 1135 showed the lowest plant height (95 cm) followed by BARI Gom 26 and BAW 1151 (97 and 98 cm, respectively) under well watered condition. At water limited drought condition all the wheat genotypes showed decreasing trend of plant height. In this water stress condition, the highest plant height produced by BAW 1170 (104 cm) followed by BAW 1161 and BAW 1163 (100 and 101 days, respectively), whereas the lowest plant height produced by BAW 1135 (95) followed by BARI Gom 26 and BAW 1151 (97 and 98 cm, respectively). The highest relative performance found in BAW 1170 (99.04%) and lowest relative performance found in BAW 1151 (91.84%). Reduced plant height under water stress was also reported by Siddique *et al.* (1999) and Sikder *et al.* (2011).

4.2.2 Spike length (cm)

The significant interaction of growing conditions and wheat genotypes on spike length is presented in Table 3. From the results it was found that BAW 1170 showed the highest spike length (11.5 cm) which was at par with BAW 1161 (11.0 cm), whereas BAW 1135 produced the lowest spike length (8.9 cm) followed by BARI Gom 26 and BAW 1151 (9.0 and 9.8 cm, respectively) under well watered condition. At water limited drought condition all the wheat genotypes showed reduced spike length compared to well watered condition. In this condition, the highest spike length produced by BAW 1170 (11.3 cm) followed by BAW 1161 and BAW 1151 (10.8 and 9.5 cm, respectively), whereas the lowest spike length produced by BAW 1135 (8.3) which was statistically similar with BARI Gom 26 (8.5 cm). The highest relative performance found in BAW 1170 (87.65%) and lowest relative performance found in BAW 1135 (81.23%). Baque (2003) reported that ear length significantly reduced due to water stress. The reduction of ear length was well distinct under severe water stress condition. Similar results were reported by Sikder *et al.* (2011) and Rahman (2004).

Table 3. Plant height and spike length of wheat genotypes as influenced by water limited drought condition.

Wheat genotypes	Plant height (cm)			Spike length (cm)		
	Well watered	Water limited drought	Relative performance (%)	Well watered	Water limited drought	Relative performance (%)
BAW 1170	105 a	104 ab	99.04	11.5 a	11.3 a	98.26
BAW 1161	103 ab	100 bcd	97.08	11.0 a	10.8 a	98.18
BAW 1163	102 abc	101 a-d	99.02	10.0 b	9.0 cd	90.00
BAW 1151	98 cde	90 g	91.84	9.8 b	9.5 bc	96.94
BARI Gom 26	97 def	93 fg	95.87	9.0 cd	8.5 d	94.44
BAW 1135	95 ef	89 g	93.68	8.9 cd	8.3 d	93.25
CV (%)	2.64		-	3.82		-

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

Table 4. Spike number plant^{-1} and floret number sipkelet^{-1} of wheat genotypes as influenced by water limited drought condition.

Wheat genotypes	Spike plant^{-1}			Floret sipkelet^{-1}		
	Well watered	Water limited drought	Relative performance (%)	Well watered	Water limited drought	Relative performance (%)
BAW 1170	7.53 a	6.60 a-d	87.65	5.0	4.8	96.00

BAW 1161	7.12 a	5.90 b-e	82.86	4.9	4.5	91.84
BAW 1163	7.05 ab	5.85 b-d	82.98	4.5	4.3	95.55
BAW 1151	7.00 abc	5.80 cde	82.86	4.4	4.2	95.45
BARI Gom 26	6.70 a-d	5.58 de	83.28	4.1	4.0	97.56
BAW 1135	6.50 a-d	5.28 e	81.23	4.0	3.9	97.50
CV (%)	9.47		-	10.58		-

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

4.2.3 Spike plant^{-1}

The combined effect of growing conditions and wheat genotypes on plant height was significant which is presented in Table 4. From the results it was found that BAW 1170 produced the highest spike plant^{-1} (7.53) followed by BAW 1161, BAW 1163 and BAW 1151 (7.12, 7.05 and 7.00, respectively), whereas BAW 1135 showed the lowest spike plant^{-1} (6.50) followed by BARI Gom 26 (6.70) under well watered condition. At water limited drought condition all the wheat genotypes showed lower number of spike plant^{-1} than well watered condition. Under water limited drought condition the highest number of spike plant^{-1} was produced by BAW 1170 (6.60) followed by BAW 1161 and BAW 1163 (5.90 and 5.85, respectively), whereas the lowest number of spike plant^{-1} produced by BAW 1135 (5.28) followed by BARI Gom 26 and BAW 1151 (5.58 and 5.80, respectively).). The highest relative performance found in BAW 1170 (98.26%) and lowest relative performance found in BAW 1163 (90.00%). Similar results also found in wheat by Handy *et al.* (2003) and Sikder *et al.* (2011). Afzal *et al.* (2006) found that number of spikes per m^2 increased with the increase of irrigation frequency.

4.2.4 Floret sipkelet^{-1}

The interaction effect of growing conditions and wheat genotypes on floret sipkelet^{-1} was insignificant and it is presented in Table 4. From the results it was found that BAW 1170 gave the highest number of floret sipkelet^{-1} (5.0) followed by BAW 1161 and BAW 1163 (4.9 and 4.5, respectively), where as BAW 1135 showed the lowest number of floret sipkelet^{-1} (4.0) followed by BARI Gom 26 and BAW 1151 (4.1 and 4.4, respectively) under well watered condition. At water limited drought condition all the wheat genotypes showed decreasing trend of floret sipkelet^{-1} compared to well watered condition. At this stress condition, the highest number of floret sipkelet^{-1} produced by BAW 1170 (4.8) followed by BAW 1161 and BAW 1163 (4.5 and 4.3, respectively), whereas the lowest number of floret sipkelet^{-1} produced by BAW 1135 (3.9) followed by BARI Gom 26 and BAW 1151 (4.0 and 4.2, respectively). The highest relative performance found in BARI Gom 26 (97.56%) and lowest relative performance found in BAW 1161 (91.84%). Similar results also found in wheat by Bhuiya and Kamal (1994), Maksud *et al.* (2002) and Sikder *et al.* (2011).

4.2.5 Grains sipkelet^{-1}

The combined effect of growing conditions and wheat genotypes on grains sipkelet^{-1} was significant and it is presented in Table 5. The number of grains sipkelet^{-1} was decreased in water limited drought condition than well watered condition. From the results it was found that BAW 1170 showed the highest number of grains sipkelet^{-1} (4.5) followed by BAW 1161 (4.0) and BAW 1163 (3.8), where as BAW 1135 showed the lowest number of grains sipkelet^{-1} (2.9) followed by BARI Gom 26 (3.0) and BAW 1151 (3.2) under well watered condition. Under water limited drought condition the highest number of grains sipkelet^{-1} was produced by BAW 1170 (3.9) followed by BAW 1161 and BAW 1163 (3.5 and 3.3, respectively), whereas the lowest number of grains sipkelet^{-1} produced by BAW 1135 (2.5) followed by BARI Gom 26 and BAW 1151 (2.7 and 2.8, respectively). The highest relative performance found in BARI Gom 26 (90.00%) and lowest relative performance found in BAW 1135 (86.20%). In the present study, it was cleared that all the wheat genotypes showed reduced number of grain per spikelet and there was distinct genotypic variation among studied wheat genotype. Sikder *et al.* (2011) reported that drought condition reduced the grain number per spikelet of wheat compared to well watered conditions. They also found varietal differences among wheat varieties under well watered and drought condition. Siaram *et al.* (1990) also found that the number of grains per spikelet of wheat was generally reduced by moisture stress.

4.2.6 Floret sipke^{-1}

The interaction effect of growing conditions and wheat genotypes on number of floret sipke^{-1} was significant and it is presented in Table 5. The studied wheat genotypes showed decreasing trend in the number of floret sipke^{-1} in water limited drought condition than the well watered condition. From the results it was found that BAW 1170 showed the highest number of floret sipke^{-1} (90.5) followed by BAW

1161 (87.0) and BAW 1163 (86.5), whereas BAW 1135 showed the lowest number of floret sipke^{-1} (75.0) followed by BARI Gom 26 (79.0) and BAW 1151 (80.0) under well watered condition. At water limited drought condition the highest number of floret sipke^{-1} was produced by BAW 1170 (85.0) followed by BAW 1161 and BAW 1163 (83.5 and 81.0, respectively), whereas the lowest number of floret sipke^{-1} produced by BAW 1135 (65.0) followed by BARI Gom 26 and BAW 1151 (70.0 and 73.5, respectively).). The highest relative performance found in BAW 1161 (95.98%) and lowest relative performance found in BAW 1135 (86.67%). In the present study, it was found that all the wheat genotypes showed reduced number of floret per spike at drought condition compared to well watered conditions. Similar results also found by Sikder *et al.* (2011). Number of floret per spike was gradually higher in irrigated condition compared to drought condition (Hanson *et al.* 1982).

Table 5. Number of grains sipkelet^{-1} and florets sipke^{-1} of wheat genotypes as influenced by water limited drought condition

Wheat genotypes	Grains sipkelet^{-1}			Floret sipke^{-1}		
	Well watered	Water limited drought	Relative performance (%)	Well watered	Water limited drought	Relative performance (%)
BAW 1170	4.5 a	3.9 abc	86.67	90.5 a	85.0 bc	93.92
BAW 1161	4.0 ab	3.5 bcd	87.50	87.0 ab	83.5 bcd	95.98
BAW 1163	3.8 abc	3.3 b-e	86.84	86.5 ab	81.0 cd	93.64
BAW 1151	3.2 c-f	2.8 def	87.50	80.0 d	73.5 fg	91.88
BARI Gom 26	3.0 def	2.7 ef	90.00	79.0 de	70.0 g	88.60
BAW 1135	2.9 def	2.5 f	86.20	75.0 ef	65.0 h	86.67
CV (%)	11.03		-	3.16		-

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

Table 6. Grains sipke^{-1} and floret sterility of wheat genotypes as influenced by water limited drought condition

Wheat genotypes	Grains sipke^{-1}			Floret sterility (%)		
	Well watered	Water limited drought	Relative performance (%)	Well watered	Water limited drought	Relative performance (%)
BAW 1170	65.0 a	57.5 bcd	88.46	28.18 e	32.35 bcd	114.80

BAW 1161	59.5 b	55.0 cde	92.43	31.60 bcd	34.13 ab	108.00
BAW 1163	58.0 bc	54.4 de	93.79	32.94 bcd	32.83 bcd	99.66
BAW 1151	53.0 ef	50.0 fg	94.33	33.75 abc	31.37 cd	92.95
BARI Gom 26	51.0 fg	50.5 fg	99.01	35.44 a	27.85 e	78.58
BAW 1135	48.0 gh	45.0 h	93.75	36.00 a	30.76 d	85.44
CV (%)	3.30		-	4.00		-

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

4.2.7 Grains sipke^{-1}

The interaction effect of growing conditions and wheat genotypes on grains sipke^{-1} was significant which is presented in Table 6. The number of grains sipke^{-1} was decreased by all wheat genotypes in water limited drought condition than well watered condition. From the results it was found that BAW 1170 produced the highest number of grains sipke^{-1} (65.0) followed by BAW 1161 and BAW 1163 (59.5 and 58.0, respectively), whereas BAW 1135 showed the lowest number of grains sipke^{-1} (48.0). BARI Gom 26 and BAW 1151 produced intermediate number of grains sipke^{-1} (51.0 and (53.0) under well watered condition. On the other hand, at water limited drought condition the highest number of grains sipke was produced by BAW 1170 (57.5) followed by BAW 1161 and BAW 1163 (55.0 and 54.4, respectively), whereas the lowest number of grains sipke^{-1} produced by BAW 1135 (45.0) followed by BARI Gom 26 and BAW 1151 (50.5 and 50.0, respectively).). The highest relative performance found in BARI Gom 26 (99.01%) and lowest relative performance found in BAW 1170 (88.46%). Results from other studies in wheat BARI (1993) reported that maximum grain number per spike was gradually increased in well watered condition compared to drought condition which was also agreed by Sikder *et al.* (2011).

4.2.8 Floret sterility

The interaction effect of growing conditions and wheat genotypes on floret sterility was significant and it is presented in Table 6. From the results it was found that BAW 1170 showed the lowest floret sterility (28.18%) followed by BAW 1161 (31.60%) and BAW 1163 (32.94%), whereas BAW 1135 showed the highest floret sterility (36.00%) followed by BARI Gom 26 (35.44%) and BAW 1151 (33.75%) under well watered condition. At water limited drought condition the lowest floret sterility was showed by BARI Gom 26 (27.85%) followed by BAW 1135 and BAW 1151 (30.76 and 31.37%, respectively), whereas the highest floret sterility found by BAW 1161 (34.13%). In the present study, drought stress significantly increased the floret sterikity of studied wheat genotypes compared to well watered conditions. The highest relative performance found in BAW 1170 (114.80%) and lowest relative performance found in BARI Gom 26 1163 (78.58%). Sikder and Paul (2010) also found heat stress significantly increased the floret sterility of wheat cultivars compared non-stress condition.

4.2.9 Thousand seed weight

The interaction effect of growing conditions and wheat genotypes on 1000 seed weight was significant which is presented in Table 7. Thousand seed weight was decreased in all wheat genotypes in water limited drought condition than the well watered condition. From the results it was found that BAW 1170 gave the heaviest seed (55.0 g) followed by BAW 1161 and BAW 1163 (50.0 and 48.5 g, respectively), whereas BAW 1135 showed the lightest 1000 seed weight (43.8 g) followed by BARI Gom 26 and BAW 1151 (44.5 and 45.0 g, respectively) under well watered condition. On the other hand, at water limited drought condition the heaviest seed was produced by BAW 1170 (54.6 g) followed by BAW 1161 and BAW 1163 (49.0 and 48.0 g, respectively), whereas the lightest 1000 seed weight produced by BAW 1135 (43.5) followed by BARI Gom 26 and BAW 1151 (44.0 and 44.3 g, respectively). Similar result also found by Collaku (1989) who told that about 20% variations found in 1000 grain weight at well watered condition than drought condition. The highest relative performance found in BAW 11735 (99.31%) and lowest relative performance found in BAW 1161 (98.00%). Results from other studies in wheat Sikder *et al.* (2011) observed that 1000 grain weight increased in the well watered condition than the drought condition. Narosima Rao and Shiv Raj (1988) also reported that irrigated sorghum plant had higher individual seed weight compared to rainfed plants.

4.2.10 Grain yield

The combined effect of growing conditions and wheat genotypes on grain yield was significant which is presented in Table 7. The grain yield was decreased by all wheat genotypes in water limited drought condition than well watered condition. From the results it was found that BAW 1170 gave the highest grain yield (4.2 t ha^{-1}) followed by BAW 1161 and BAW 1163 (3.9 and 3.8 t ha^{-1}, respectively), whereas BAW 1135 produced the lowest grain yield (2.8 t ha^{-1}) under well watered condition. BARI Gom 26 and BAW 1151 (2.9 and 3.1 t ha^{-1}, respectively) produced the intermediate yield at well watered condition. On the other hand, at water limited drought condition the highest grain yield was produced by BAW 1170 (3.5 t ha^{-1}) followed by BAW 1161 and BAW 1163 (3.3 and 3.0 t ha^{-1}, respectively), whereas the lowest grain yield was produced by BAW 1135 (2.0 t ha^{-1}) followed by BARI Gom 26 and BAW 1151 (2.4 and 2.5 t ha^{-1}, respectively). The highest relative performance found in BAW 1161

(84.62%) and lowest relative performance found in BAW 1135 (71.47%). This result agreed with Baser *et al.* (2004) who found that 40% grain yield reduced due to water stress drought condition. Results from other researchers in wheat reported that water stress significantly inhibited the grain yield compared to well watered condition (Sairam *et al.* 1990, Sarker 1996, Zhai *et al.* (2003) and Sikder *et al.* (2011).

4.2.11 Drought susceptibility index (DSI)

Drought susceptible index (DSI) based on grain yield is presented in Table 7. From the results it was found that the highest DSI (1.48) showed by BAW 1135 followed by BAW 1163 and BAW 1151 (1.09 and 1.00), whereas, the lowest DSI found in BAW 1161 (0.80) followed by BAW 1170 and BARI Gom 26 (0.86 and 0.89, respectively). Due to lower DSI based on grain yield (DSI < 1.00) genotype BAW 1161, BAW 1170 and BARI Gom 26 were considered as drought tolerant wheat genotypes and BAW 1151, BAW 1163 and BAW 1135 were treated as drought susceptible wheat genotypes (DSI ≥ 1.00). Results from other studies in wheat Sikder *et al.* (2011) used DSI for grain yield to grading wheat varieties as drought tolerent (DSI < 1.00) and drought susceptible (DSI > 1.00).

4.2.12 Biological yield

The interaction effect of growing conditions and wheat genotypes on biological yield was significant which is presented in Table 8. The biological yield was decreased by all wheat genotypes in water limited drought condition than the well watered condition. From the results it was found that BAW 1161 gave the highest biological yield (11.0 t ha^{-1}) followed by BAW 1170 and BAW 1163 (10.5 and 10.4 t ha^{-1}, respectively), whereas BAW 1135 produced the lowest biological yield (2.8 t ha^{-1}) under well watered condition. BARI Gom 26 and BAW 1151 produced the intermediate yield (8.5 and 9.0 t ha^{-1}, respectively) at well watered condition. On the other hand, at water limited drought condition the highest biological yield was produced by BAW 1170 (10.0 t ha^{-1}) followed by BAW 1161 and BAW 1163 (8.9 and 9.5 t ha^{-1}, respectively), whereas the lowest

Table 7. Thousand seed weight, grain yield and DSI based in grain yield of wheat genotypes as influenced by water limited drought condition.

Wheat genotypes	1000 seed weight (g)			Grain yield (t ha^{-1})			DSI based on grain yield
	Well watered	Water limited drought	Relative performance (%)	Well watered	Water limited drought	Relative performance (%)	
BAW 1170	55.0 a	54.6 a	99.27	4.2 a	3.5 bcd	83.33	0.86
BAW 1161	50.0 b	49.0 b	98.00	3.9 ab	3.3 cde	84.62	0.80
BAW 1163	48.5 b	48.0 bc	98.97	3.8 abc	3.0 def	78.95	1.09
BAW 1151	45.0 cd	44.3 d	98.44	3.1 de	2.5 fgh	80.65	1.00
BARI Gom 26	44.5 d	44.0 d	98.88	2.9 efg	2.4 gh	82.76	0.89
BAW 1135	43.8 d	43.5 d	99.31	2.8 efg	2.0 h	71.47	1.48
CV (%)	3.71		-		9.49	-	-

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

Table 8. Biological yield and harvest index of wheat genotypes as influenced by water limited drought condition.

Wheat genotypes	Biological yield (t ha^{-1})			Harvest Index (%)		
	Well watered	Water limited drought	Relative performance (%)	Well watered	Water limited drought	Relative performance (%)
BAW 1170	10.5 ab	10.0 ab	95.24	40.00 a	35.00 c	87.50
BAW 1161	11.0 a	8.9 abc	80.90	35.45 c	37.07	104.59

					abc	
BAW 1163	10.4 ab	9.5 ab	91.35	36.53 bc	31.58 d	86.45
BAW 1151	9.0 abc	7.0 cd	77.78	34.44 cd	35.71 bc	103.69
BARI Gom 26	8.5 bc	6.2 d	72.94	34.11 cd	38.71 ab	113.48
BAW 1135	7.0 cd	5.9 d	84.28	40.00 a	33.89 cd	84.73
CV (%)	13.65		-	4.53		-

Values followed by the different letter(s) are significantly different from each other by DMRT at 5% level.

biological yield was produced by BAW 1135 (5.9 t ha^{-1}) followed by BARI Gom 26 and BAW 1151 (6.2 and 7.0 t ha^{-1}, respectively). The highest relative performance found in BAW 1170 (95.24%) and lowest relative performance found in BARI Gom 26 (72.94%). Similar results was found in other studiesin wheat that greater biological yield under well watered condition compared to water stress condition (Saren and Janna 2001, and Sikder *et al.* 2011)

4.2.13 Harvest index

The interaction effect of growing conditions and wheat genotypes on harvest index was significant and it is presented in Table 8. From the results it was found that BAW 1170 and BAW 1135 showed the highest harvest index (40.00%) followed by BAW 1163 (36.53%), whereas BARI Gom 26 showed the lowest harvest index (34.11%) which was statistically similar with BAW 1151 (34.44%) under well watered condition. On the other hand, at water limited drought condition the highest harvest index was given by BARI Gom 26 (38.71%) followed by BAW 1161 (37.07%), whereas the lowest harvest index was showed by BAW 1163 (31.58%) followed by BAW 1135 and BAW 1151 (33.89 and 35.71%, respectively). The highest relative performance found in BARI Gom 26 (113.48%) and lowest relative performance found in BAW 11635 (84.73%). In the present study, all the wheat genotypes showed reduced HI at drought condition compared to well watered condition. There were distinct genotypic variations among wheat genotypes under well watered and drought condition. Similar results also found by Sikder *et al.* (2011). Maqsood *et al.* (2002) reported that higher HI was observed in irrigated treatment compared to non-irrigated condition.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at research field and laboratory of the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur during the period of Nov 2013 to April 2014. It was laid out in a split plot design with three replications. The treatment factors were “A- Main plot treatment: two growing conditions viz. i. well water growing condition (giving three irrigations) and ii. water limited drought condition (giving one-1 irrigation at 20 DAS for seedling establishment) and B- Sub plot treatment: six wheat genotypes viz. BAW 1170, BAW 1161, BAW 1163, BAW 1151, BARI Gom 26 and BAW 1135.

In phenologcal stages, the maximum number of days required for BAW 1170, BAW 1161 and BAW 1163 followed by BAW 1151 and BARI Gom 26, whereas the minimum number of days required for BAW 1135 under well watered and water limited drought condition. At water limited drought condition the highest amount of chlorophyll content was found in BAW 1163 (2.10 mg/g fresh weight) followed by BAW 1170 (2.00 mg/g fresh weight), where as the lowest chlorophyll content was produced by BAW 1135 (1.40 mg/g fresh weight) followed by BARI Gom 26 and BAW 1151 (1.50 and 1.80 mg/g fresh weight, respectively). The proline content of all the six wheat genotypes in water limited drought condition compared to well watered condition. At water limited drought condition the highest amount of proline content was found in BAW 1170 (2.30 µmole/g fresh weight) and the lowest proline content was produced by BAW 1135 (1.40 µmole/g fresh weight) followed by BARI Gom 26 and BAW 1151 (1.60 and 1.74 µmole/g fresh weight, respectively).

At water limited drought condition all the wheat genotypes showed decreasing trend of plant height. At water limited drought condition all the wheat genotypes showed decreasing trend of spike length. In this condition, the highest spike length produced by BAW 1170 (11.3 cm) followed by BAW 1161 and BAW 1151 (10.8 and 9.5 cm, respectively), where as the lowest spike length produced by BAW 1135. Under water limited drought condition the highest number of spike plant^{-1} was produced by BAW 1170 (6.60) and the lowest number of spike plant^{-1} produced by BAW 1135 (5.28). At water limited drought condition all the wheat genotypes showed decreasing trend of floret sipkelet^{-1}, grains sipkelet^{-}1, floret sipke^{-1}, grains sipke^{-1} and increasing the floret sterility. At both the well watered and drought condition BAW 1170 gave the heaviest 1000 seed weight (55.0 and 54.6 g, respectively) and BAW 1135 showed the lightest 1000 seed weight (43.8 and 43.5 g, respectively). The grain yield was decreased by all wheat genotypes at water limited drought condition than the well watered condition. BAW 1170 gave the highest grain yield (4.2 t ha^{-1}), whereas BAW 1135 produced the lowest grain yield (2.8 t ha^{-1}) and BARI Gom 26 and BAW 1151 (2.9 and 3.1 t ha^{-1}, respectively) produced the intermediate yield at well watered condition. At water limited drought condition the highest grain yield was produced by BAW 1170 (3.5 t ha^{-1}) and the lowest grain yield was produced by BAW 1135 (2.0 t ha^{-1}). Due to lower DSI based on grain yield (DSI < 1.00) genotype BAW 1161, BAW 1170 and BARI Gom 26 were considered as drought tolerant wheat genotypes and BAW 1151, BAW 1163 and BAW 1135 were treated as drought susceptible wheat genotypes (DSI ≥ 1.00). The biological yield of all the studied wheat genotypes was decreased by all wheat genotypes at water limited drought condition compared to well watered condition. BAW 1170 and BAW 1135 showed the highest harvest index (40.00%) and BARI Gom 26 showed the lowest harvest index (34.11%) under well watered condition, whereas t water limited drought condition the highest harvest index was given by BARI Gom 26 (38.71%) and the lowest harvest index was showed by BAW 1163 (31.58).

From the overall results it was observed that water limited drought condition nagatively affected different morphological and yield traits of wheat genotypes. It was also found that the genotypes BAW 1170 showed better performances in phenology, chlorophyll content, proline content and different yield parameters. Finally, from the DSI based on grain yield it may be concluded that wheat genotypes BAW 1161, BAW 1170 and BARI Gom 26 were regarded as drought tolerant and genotypes BAW 1151, BAW 1163 and BAW 1135 were considered as drought susceptible.

REFERENCES

Abdorrahmani B., K.G. Gholosani and M. Esfahani. 2005. The effect of supplementary irrigation on the growth index and yield components of wheat. Agric. Sci. Tabriz. 15(1): 51-67.

Afzal A., S. Ahmed, A. Khan and M. Amin. 2006. Comparison of wheat and barley for yield and yield components under different irrigation patterns. Sarhad J. Agric. 22(1): 7-11.

Arabinda S. and V.F. Dolgodvorov. 1994. Study of the growth phases of spring wheat. Bangladesh J. Agril. Sci. 21: 167- 173.

Araus J. L., G. A. Slafer, M. P. Reynolds and C. Royo. 2002. Plant breeding and drought in C_3 cereals: what should we breed for? Annals Bot. 89: 925-940.

Arus J.L., G.A. Slafer, M.P. Reynolds and C. Royo. 2002. Plant Breeding and drought in C_3 ereals: what should we breed for? Ann. Bot. 89: 925-940.

Ashraf M.Y. and A.S. Bhatii. 1998. Effect of dealy sowing on some parameters of photosynthesis in wheat (*Triticum aestivum* L.). Wheat info. Ser., 86: 46-48.

Ashraf M.Y., A.R. Azmi, A.H. Khan and S.A. Ala. 1994. Effect of water stress on total phenols, peroxidase activity and chlorophyll content in wheat (*Triticum aestivum* L.). Acta Physiol. Planta. 16(3): 185-195.

Ashraf M. and M.R. Foolad. 2007. Roles of glycinebetaine and proline in improving plant abiotic stress tolerance. Environ. Exp. Bot. 59: 206-216.

Baque M. A. 2003. Potassium induced changes in the physiology of wheat plants (*Triticum aestivum* L.) under water stress conditions. M.Sc.(Ag.) thesis, Dept Agron., Bangabandhu Sheikh Mujibur Rahman Agril. Univ., Gazipur.

BARI (Bangladesh Agricultural Research Institute). 1993. Study on irrigation and Nitrogen requirement for late sown wheat. Annual Report (1992-1993). BARI Joydebpur, Gazipur.

Baser I., S. Sehirali, H. Orta, T. Erdem, Y. Erdem and O. Yorgancilar. 2004. Effect of different water stresses on the yield and yield components of winter wheat. Cereal Res. 32(2): 217-223.

BBS 2005. Statistical Year Book of Bangladesh. Statistics Division, Ministry of Planning. Govt. of the Peoples' Republic of Bangladesh, Dhaka.

Bewley J.D. 1979. Physiological aspects of desiccation tolerance. Ann. Rev. of Plant Physio. 30: 195-238.

Bhuiya, M.S.H. and A.M.A. Kamal. 1994. Development stages grain yield components of wheat. Bangladesh J. Agric. Sci. 21: 335-341.

Blum A. and A. Ebercon.1981. Cell membrane stability as a measure of drought and heat tolerance in wheat. Crop Science 21:43-48.

Blum A., B. Sinmena, J. Mayer, G. Golan and L. Shpilar. 1994. Stem reserve mobilization supports wheat grain filling under heat stress. Aust. J. Plant Physiol. 13: 771-781

Blum A., L. Shpiler, G. Golan and J. Mayer. 1989. Yield stability and canopy temperature of wheat genotypes under drought stress. Field Crops Res. 22: 289-296.

Blum, A. and C.Y. Sullivan. 1986. The comparative drought resistance of landraces of sorghum and millet from dry and humid regions. Ann. Bot. 57: 838–846.

Bojovic B. and J. Stojanovic. 2005. Chlorophyll and carotenoid content in wheat cultivars as a function of mineral nutrition. Arch. Biol. Sci. 57(4): 283-290.

Boyer J.S. 1982. Plant productivity and environment. Science 48(3): 38-42 Cereal Res. Comm. 28: 101-107.

Chaves M.M. and M.M. Oliveira. 2004. Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. J. Exp. Bot. 55: 2365-2384.

Collaku A. 1989. Analysis of the structure of correlations between yield and some quantitative traits in bread wheat. Buletini i Shkencave Bujqe¨ sore. 28: 137–144.

Duggan B.L. and D.B. Fowler. 2006. Yield structure and kernel potential of winter wheat on canadian prairies. Crop Sci. 46: 1479-1487.

Errabii T., C. B. Gandonou, H. Essalmani, J. Abrini, M. Idaomar, N. Skali- Senhaji. 2006. Growth, Proline and ion accumulation in Sugarcane callus cultures under drought-induced osmotic stress and its subsequent relief. Afr. J. Biotechnol. 5(6): 1488-1493.

FAO (Food and Agriculture Organization) and UNDP (United Nations Development Programme). 1988. Land Resources Appraisal of Bangladesh for Agricultural Development. Report No. 2. Agro-ecological Regions of Bangladesh. FAO, Rome, Italy. pp. 212-221.

Fischer R. A. and R. Maurer. 1976. Drought resistance in spring wheat cultivars. I. Grain yield response. Aust. J. Agric. Res. 29: 897-907.

Fujita T., A. Maggio, M. Garcia-Rios, R. A. Bressan, and L. N. Csonka. 1998. Comparative analysis of regulation of genes for Δ’-pyroline-5 carboxylate synthetase from tomato. Plant Physiol. 188: 661-674.

Gallagher J. N., P. V. Biscoe and R. K. Scott. 1975. Barley and its environment. V. Stability of grain weight. J. Appl. Ecol. 21: 319-336.

Graan T. and J.S Boyer. 1990. Very high CO2 partially restores photosynthesis in sunflower at low leaf water potentials. Planta 181: 378-384.

Grover A., A. Kapoor, D. Kumar, H.E. Shashidhar and S. Hittalmani. 2004. Genetic improvement for abiotic stress responses. In: *Plant Breeding-Mendelian to* Mole*cular Approaches* Ed. H.K. Jain and M.C. Kharkwal pp. 167-193. Narosa Pblishing House, New Delhi, India.

Handy A., V. Sardo and K.A.F. Ghanem. 2005. Saline water in supplemental irrigation of wheat and barley under rainfed agriculture. Agri. Water Manag. 78(1/2): 122-127.

Handy T.C., Grafton, S.T., Shroff, N.M., Ketay, S., Gazzaniga, M.S., 2003. Graspable object grab attention when the potential for action is recognized. Nat. Neurosci. 6, 421–427.

Hanson H., N.E. Bolavg and R.G. Anderson. 1982. Wheat in the third world.West View Press.Inc.Boulder Colarado, USA. p.13

Inagaki M.N. and M.M. Nachit. 2007. Visual monitoring of water deficit stress using infrared thermography in wheat. ICARDA, PO Box 5466, Aleppo, Synia.

Karim M.A., A. Hamid and S. Rahman. 2000. Grain growth and yield performance of wheat under subtropical conditions. II. Effect of water stress at reproductive stress.

Khan A.H., M.Y. Ashraf and A.R. Azmi. 1993. Osmotic adjustment in wheat: A response to water stress. Pak. J. Sci. Ind. Res. 36 (4): 151-155.

Kramer P.J. 1983. Water relation of plants. Academic Press, Orlando. Pp. 342-389.

Kumbhar, M.B., A.S Larik, H.M. Hafiz and M.J. Rind. 1983. Wheat Information Services 57: 42–45.

Maiti R.K., L.S. Moreno and E.P. Wische. 2000. Responses of some crops to various abiotic stress factors and its physiological and biochemical basis of resistances: A review. Agri. Rev. Pubela, Mexico 21(3): 155-167.

Maksud M., A. Ali, A. Zubair, M. Saeed and S. Ahmed. 2002. Effects of irrigation and nitrogen levels on grain yield and quality of wheat (Triticum aestivum L). Int. J. Agric. Biol. 4(1): 164-165.

Maralian F., A. Ebadi, T.R. Didar and B.H. Eghrari. 2010. Influence of water stress on wheat grain yield and proline accumulation rate. African J. Agric. Res. 5(4): 286-289.

Morgan J.M. 1984. Osmoregulation and water stress in higher plants. Ann. Rev. Plant Physiol*. 3*5: 299-319.

Narasima Rao, C. L. and A. Shiv Raj. 1988. Effect of water stress on grain growth of glossy and non-glossy varieties of grain sorghum (*Sorghum hiclor*). Indian J. Agril. Sci. 58: 770-773.

Podsiado, C., Koszanski, Z. and I.I. Zbiec. 1999. Response of some spring barley cultivars to irrigation and mineral fertilization. Part 2.Canopy architecture and yield structure. Folia Univ. Agric. Stetinensis, Agricultura. (73): 131-137.

Podsiado C., Z. Koszanski and I.I. Zbiec. 1999. Response of some wheat cultivars to irrigation and mineral fertilization. Part II: Canopy architecture and yield structure. Folia Univ. Agric. Stetinesis, Agric. 73:131-137.

Prakas M. and K. Ramchandra. 2000. Effect of chemical ameliorants on stomal frequency and water relation in brinjal (*Solanum melongena* L.) under moisture stress conditions. J. Agron and Crop Sci. 185: 237-239.

Radford P.J. 1967. Growth analysis formulae- their use and abuse. Crop Sci. 7: 171-175

Rahman M. M. 1997. Effect of different levels of irrigation and nitrogen on yield and yield contributing characters of foxtail millet. M.Sc (Ag). Thesis, Dept Agron. Bangladesh Agril. Univ., Mymensingh.

Rahman M.A., A.J.M.S. Karim, M.M. Hoque and K. Eqashira. 2000. Effect of irrigation and nitrogen fertilization on photosynthesis, leaf area index and dry matter production of wheat on a clay terrace soil of Bangladesh. J. Agric., Kyushu University 45(1): 289-300.

Rahman M.S. 1997. Variation in morpho-physiological characters and yield of wheat (*Triticufm aestivum* L.) cultivars under irrigated and drought condition. PhD Thesis, Department of Botany, University of Rajshahi, Bangladesh.

Sairam R.K., P.S. Deshmukh, D.S. Shukla and Sitaram. 1990. Metabolic activity and grain yield under moisture stress in wheat genotypes. Indian J. Plant Physol. 33: 226-231

Saren B.K. and A.K. Jana. 2001. Effect of depth irrigation and level and time of nitrogen application on growth yield and nutrient uptake by wheat (*Triticum aestivum*). Indian J. Agron. 46(2): 227-232.

Sarker A.M. 1996. Grain production and water use of wheat (Triticum aestivum L) as affected by water stress. Ph.D. Thesis. University of Rajshahi, Bangladesh.

Siddique M.R.B., A. Hamid and M.S. Islam. 1999. Drought stress effect on yield and yield attributes of wheat. Bangladesh J. Agril. Res. 24(4): 621-628.

Sikder S, F. Begum, M.A. Baquy, M.R. Islam and K.K. Kundu. 2011. Influence of non-irrigated water stress on morphological and yield performance of wheat. J. Bangladesh Soc. Agric. Sci. Technol. 8 (3&4):45-50.

Sikder S. and N.K. Paul. 2010. Effect of post anthesis heat stress on stem reserves mobilization, canopy temperature depression and floret sterility of wheat cultivars. Bangladesh J. Bot. 39(1): 65-69.

Singh J. and A.L. Patel. 1996. Water status, gaseous exchage proline accumulation and yield of wheat in response to water stress. Ann. Biol. Ludhinana. 12(1): 26-28.

Skovmand, B., Lopez, C., Sanchez, H., Herrera, R., Vicarte, V., Fox, P.N., Trethowan, R., Gomez, M.L., Magana, R.I., Gonzalez, S., van Ginkel, M., Pfeiffer, W. & Mackay, M.C. 2005. The international wheat information system (IWIS), version 3. *In* B. Skovmand, M.C. Mackay, C. Lopez & A. McNab, eds. *2000. Tools for the new millennium*. On CD. Mexico, DF, CIMMYT.

Troll W. and J. Lindley. 1955. A photometric method for determination of proline. J. Biol. Chem. 215: 655- 660.

Vendruscolo A.C.G., I. Schuster, M. Pileggi, C.A. Scapim, H.B.C. Molinari, C.J. Marur and L.G.C. Vieira. 2007. Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat. J. Plant physiol. 164(10): 1367-1376.

Wang J.R. and S.X. Li. 2000. Effect of water limited deficit stress in different growth stages on winter wheat grain yield and their constituents. Acta Bot. Boreal-Occident Sin. 20(2): 193-200.

Wang W. X., P. Vinocur and A. Altman. 2003. Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. Planta 218(1): 1–14.

Witham F.W., D.F. Blydes and R. H. Devlin. 1986. Exercises in plant physiology (2nd edition). PWS publishers, Bonton, U.S.A. pp 128-131.

Zhai B.N., S.X. Li, B.N. Zhai and S.X. Li. 2003. Combined effects of water and nitrogen fertilizer on yield and quality of winter wheat. Plant nitrogen and fertilizer Sci. 9(1): 26-32.

APPENDICES

Appendix I: Morphological and Physiological characteristics of soil

Morphology	Characteristics
Location	Crop Physiology and Ecology research field, HSTU, Dinajpur
AEZ	Old Himalayan Piedmont Plain (AEZ-1)
General Soil type	Non-Calcareous Brown Floodplain Soil
Parent material	Piedmont alluvium
Soil series	Ranishankail
Drainage	Moderately well drained
Flood level	Above flood level
Topography	High land
Physical Characteristics	Value
sand (2-0.02mm)	60.0
silt (0.02-0.002mm)	27.0
clay (< 0.002mm)	13.0
Textural class	Sandy loam

Source: The Morphological and physical characteristics of soil samples were done by SRDI, Dinajpur, Bangladesh

Appendix II: Chemical characteristics of initial soil samples

Characteristics	Content	Interpretation
pH	5.40-5.50	Moderately acidic
Organic carbon (%)	0.69	Low
Organic matter (%)	1.19	Low
Bulk density (g cm-3)	1.30-1.57	Medium
CEC (meq/100g soil)	5.60	Low
Total N (%)	0.07	Very low
Available P (ppm)	16.75	Medium
Exchangeable K (meq/100g soil)	0.17	Medium low

Source: The chemical analysis of initial soil samples were done in SRDI, Dinajpur, Bangladesh

Appendix III: Weather data for growing season of wheat, 2013-2014

Month	Relative humidity (%)	Temperature		Total rainfall (mm)
		Minimum (^oC)	Maximum (^oC)	
November/13	90	15.5	29.0	0.0
December/13	83	11.9	24.8	0.0
January/14	86	10.5	22.0	0.0
February/14	86	11.5	24.1	28.0
March/14	85	16.6	30.7	1.0
April/14	86	18.8	29.5	20.0

Source: Wheat Research Centre, Dinajpur