PERFORMANCE OF DIFFERENT RICE GENOTYPES UNDER WATER STRESS CONDITIONS

HALIMA SAYEED JASMINE

DEPARTMENT OF AGRICULTURAL BOTANY
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

DECEMBER, 2015

PERFORMANCE OF DIFFERENT AUS RICE GENOTYPES UNDER WATER DEFICIT CONDITIONS

By

HALIMA SAYEED JASMINE
Registration No. 11-04-690

A Thesis
Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
IN
AGRICULTURAL BOTANY
SEMESTER: July-December 2015

Approved by:

Prof. Dr. Kamal Uddin Ahamed
Chairman of the Advisory
Committee

Prof. A.M.M. Shamsuzzaman
Member of the Advisory
Committee

Dr. Jiban Krishna Biswas
Member of the Advisory
Committee

Prof. Dr. Parimal Kanti Biswas
Member of the Advisory
Committee

Dr. Kamal Uddin Ahamed
Professor
Department of Agricultural Botany
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh
Tel: 88-02-9116637
Cell: +8801552601173
E-mail: kuahmed@yahoo.com

CERTIFICATE

This is to certify that the thesis entitled, "PERFORMANCE OF DIFFERENT AUS RICE GENOTYPES UNDER WATER DEFICIT CONDITIONS" submitted to the faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY IN AGRICULTURAL BOTANY, embodies the result of a piece of bona fide research work carried out by HALIMA SAYEED JASMINE Registration No. 11-04690 under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: December, 2015
Place: Dhaka, Bangladesh

(Prof. Dr. Kamal Uddin Ahamed)
Supervisor

DEDICATED

TO

MY BELOVED PARENTS

ACKNOWLEDGMENTS

In the name of “Almighty Allah “the most kind and merciful, Who indebted the author to complete the Ph.D. courses and research. Therefore all praises belong to Him. The author likes to express her heartiest respect and pray to Allah for her father Md. Syedullah’s departed soul, who encouraged the author to perform Ph. D study and achieve every success of life.

The author would like to express her indebtedness, heartiest respect and deep sense of gratitude to the chairman of Advisory Committee, Dr. Kamal Uddin Ahamed, Professor, Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka, for his continuous guidance and inspiration, valuable suggestion, extending generous help, scholastic supervision throughout the course, research and in preparation of manuscript of the thesis and made it possible to complete the degree in a peaceful state of mind which would possible to complete the study and research work.

The author sincerely express her gratitude to the respected members of the Advisory committee Prof. A.M.M. Shamsuzzaman, Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Prof. Dr. Parimal kanti Biswas, Department of Agronomy, Sher-e-Bangla Agricultural University, Dr. Jiban Krishna Biswas, Director General (DG), Bangladesh Rice Research Institute (BRRI) for their co-operation and constructive suggestions to conduct the course and research work as well as preparation of the thesis.

The author would like to express her respect to convey the profound thanks and gratitude to the Ex Director of SAURES, SAU Prof. Dr. Mohammed Ali, Department of Entomology, SAU, Dhaka for permission to pursue higher studies leading to Ph.D. The author is also grateful to SAU authority for allowing leave on deputation for completing the same.

The author is thankful to her respected course teacher Prof. Dr. Jalal Uddin Ahmed, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) for his valuable course and advice in studying literature and encouragement toward increasing

the depth of knowledge. The author would like to express her boundless gratitude to all the teachers of the Ph.D. courses of Sher-e-Bangla Agricultural University for their valuable courses.

The author feels much pleasure to express her thanks to Prof. Dr. Naheed Jeba, Department of Genetics and Plant Breeding and Prof. Dr. Md. Razzab Ali, Department of Entomology, SAU for their co-operation in multiple aspects in Ph.D. study. The author also thankful to Mohammad Mohidur Rahman and Nasima Akhter for their help and Pretom kumar Hore, AEO for his co-operation in data analysis.

The author also expresses her gratitude to the Higher Education Quality Enhancement Project (HEQEP) for providing financial support to conduct the research work.

The author pleased and feels to remember all staff, worker and farm labours of Sher-e-Bangla Agricultural University (SAU) for their sincere help in carrying out the research work.

Finally the author feels much pleasure to express her thanks for her family members, son Khondaker Salman Sayeed (Ishtee) and husband Khondker Selim Reza for their all kind of help and co-operation. The author would like to express her indebtedness to her mother Amena Khatun and very happy to mention her beloved sister Sufia Sayeed Nazma and her brother A.I S. Mufti for encouraging her to complete her Ph.D. study .The author would like to remember her respected and beloved elder sister Late Rokeya Akhter.

December, 2015 The Author

SAU, Dhaka

PERFORMANCE OF DIFFERENT AUS RICE GENOTYPES UNDER WATER DEFICIT CONDITIONS

ABSTRACT

Water deficit encountered by rice plant is a common feature in Bangladesh especially in dry season for which rice is grown by supplying irrigation water. Aus rice is a dry season crop dependent on rain or irrigation. In Bangladesh, the Aus rice faces drought problem at vegetative stage. So, it is necessary to develop or introduce drought tolerant high yielding *Aus* rice varieties. Different rice research institutes like BRRI, BINA have released some drought tolerant rice varieties. Further improvement of those and other rice varieties are required in order to meet up the future rice demand. Considering the above statements four pot experiments were carried out during September 2012 to July 2014 at Agricultural Botany field of Sher-e-Bangla Agricultural University, Dhaka. Plants were grown in the rain protected polyethylene shelter to avoid rain under natural light conditions. The first experiment was conducted with eleven BRRI rice varieties (BR21, BR24, BRRI dhan42, BRRI dhan43, BRRI dhan48, BRRI dhan55) and other lines BR6976-11-1, OM1490, BR6976-2B-15 along with the tolerant check varieties Hashikalmi and Dharial. These rice varieties were used to find out their response of roots to water deficit in the soil of root elongation tubes. Due to water stress shoot height decreased and root length increased. And other three experiments were conducted with four drought treatments such as 0 days (control), 7, 10 and 15 days and drought imposed in different age of the plants in the earthen pots. The morpho-physiological and biochemical changes reduced plant growth rate due to water deficit affecting decline in leaf area, specific leaf area, shoot dry weight, panicle dry weight, panicle number, panicle length, number of effective tillers, total dry matter content, stomatal conductance, proline content and grain yield etc. After anthesis, the SPAD value gradually decreased towards maturity. Among the genotypes, BRRI dhan55 produced the highest number of tillers and grain yield per plant. It revealed that Hashikalmi showed significantly taller plant throughout the growing period and developed more tillers. The sensitive genotypes showed reduction in leaf area, number of leaf, dry matter, tiller number and took much longer time to recover and develop new organs. The grain sterility percentage was much higher in BR6976-2B-15 due to water stress treatment compared to other genotypes. The grain yield per plant recorded was the highest at control treatment and gradually decreased with the increasing water deficit duration in all the genotypes. But the grain yield was less affected in BRRI dhan55 and Hashikalmi due to water deficit treatment. Anthocyanin, and proline were increased, sugar and starch were decreased under water deficit conditions. Leaf accumulates anthocyanins under drought conditions and the red colour increased as the intensity of water deficit was increased. Under water stress condition RWC was significantly reduced. RWC declined with the increase of water deficit condition. Stomatal conductance was higher at early drought condition (1st to 3rd drought stress) and gradually decreased towards maturity at late water deficit condition (4th to 6th drought stress) in all the genotypes. Stomatal conductance was higher in BRRI dhan55 and Hashikallmi and lower in BR 6976-2B-15. The tolerant genotypes BRRI dhan55 and Hashikalmi were less affected under water deficit treatment compared to susceptible genotypes. Among the genotypes, BRRI dhan55 and Hashikalmi were tolerant and BR6976-2B-15, BR6976-11-1 was sensitive or susceptible to water stress considering the different parameters.

LIST OF CONTENTS

Experiment - 4

N0. OF TABLE	LIST OF TABLE	PAGE NO.

N0. OF TABLE	LIST OF TABLE	PAGE NO.

SOME COMMONLY USED ABBREVIATIONS

Anonymous	A
At the rate of	@
Degree Centigrade	^{0}C
Agro-Ecological Zone	AEZ
Bangladesh Agricultural University	BAU
Bangladesh Bureau of Statistics	BBS
Bangladesh Rice Research Institute	BRRI
Centi-bar	cb
Centi-meter	cm
Coefficient of Variance	CV
Cultivar (s)	cv.
Cumulative root length	CRL
Days after transplanting	DAT
Degree of freedom	df
Dry matter	DM
East	E
Error mean sum of square	EMS
And others	*et al.*
Food and Agriculture Organization	FAO
Gram (s)	g
Harvest Index	HI
Journal	*J.*

Kilogram	kg
Leaf area Index	LAI
Least Significant Difference	LSD
Leaf water potential	LWP
Meter	m
Milliliter	ml
Millimeter	mm
North	N
Number	No
Percentage	%
Non significant	NS
Non-structural carbohydrate	NSC
Randomized Complete Block Design	RCBD
Relative water content	RWC
South	S
Shere-e-Bangla Agriculture University	SAU
Specific leaf area	SLA
Specific leaf weight	SLW
Total dry matter	TDM
variety	var.
Namely	viz.
West	W

Chapter-1

INTRODUCTION

CHAPTER 1

INTRODUCTION

Drought is a major problem of growing rice it affects directly the growth and development of rice, especially in low rainfall season (Usman *et al*., 2013). According to the IRRI (2005), drought stress is one of the major constraints to rice (*Oryza sativa* L.) cultivation and production. Rice is more susceptible to drought than any other crops. Drought is one of the biggest enemies of Bangladeshi farmers. In 1999, Bangladesh suffered the longest drought in 50 years, with more than four months without rain and in 2010 the country recorded its lowest rainfall since 1995.

Drought affects 20% of the total rice growing area in Asia (Pandey and Bhandari, 2008). Usman *et al*. (2013) stated that drought affected the growth and reduced the fresh shoot and root weights, root and shoot lengths and also physiological processes. Drought can be caused by too little precipitation (rain and snow) over an extended period, but drought can also be caused by increased demand for the available supply of usable water even during periods of average or above average precipitation. Morphological characters were massively affected by drought with the dry mass production and consequently with the drought tolerance of the upland rice varieties (Lum*,* 2014).

In Bangladesh usually no rain occurs during January to March. Rice is mostly grown in well-puddled and irrigated conditions and requires two to three times more water than other cereal crops such as wheat or maize. Even if there is little amount of rain the total rainfall in three months is irregular and often inadequate which fails to meet the evapotranspirational demand of plant, consequently water stress develops and affects translocation of assimilates and grain development in plant. Many aspects of plant growth are affected by drought stress (Hsiao, 1973); these include leaf expansion, production and promote senescence and abscission (Karamanos, 1980). Drought can affect rice plant in any growth stage like vegetative and reproductive stage resulting poor yield. Lum (2014), reported that eight local upland rice (*Oryza sativa* L.) varieties that were drought affected, Kusam (drought-sensitive variety) was markedly affected than the drought tolerant varieties in the activities of shoot length, root length and dry matter.

Root size, structure, morphology, depth, length, density and branching or distributions in soil horizons are important in maintaining high leaf water potential against evapotranspiration demand under water deficit (Passioura 1982; Blum 1982). When water deficit occurs, the most effective resistance mechanism available to the rice plant is a deep root system consisting of mostly thick roots that enables the plant to avoid the adverse effects of internal water deficit (Chang *et al.*, 1972). Root uptakes water from the lower layers where it is expected to be available, this would help to maintain a good plant water potential which has a demonstrated positive effect on yield under stress (Mumbani and Lal, 1983). Kanbar (1999) found the relationship between roots and yield morphological characters in rainfed low land rice.

Biochemical processes were massively affected by drought and the activities of antioxidant enzymes and proline accumulation were associated with the dry mass production and consequently with the drought tolerance of the upland rice varieties (Lum, 2014). Drought also reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism and growth promoters (Jaleel *et al.,* 2008a-d; Farooq *et al*., 2008). Under low-moisture stress, traits those help the plant to gain access additional reserves are more important than traits associated with reducing moisture losses (Fukai and Cooper, 1995). Reduction of photosynthetic activity, accumulation of organic acids and osmolytes and changes in carbohydrate metabolism, are typical physiological and biochemical responses to drought stress (Tabaeizadeh, 1998). Shao et al. (2008) observed that metabolic changes during drought affect reduction of nutrients such as carbohydrates, nitrates, potassium concentration. One of the basic mechanisms for reducing the impact of drought is early stomatal closure at the beginning of a period of water deficit. Stomatal closure reduces water loss, but also reduces the gas exchange between the plant and the ambient air. The reduced CO_2 intake then results in reduced photosynthesis (Chaves *et al*., 2002). This mechanism is therefore useful to improve plant survival under drought stress, but also associated with yield reduction. Water stress may damage oxygen evolving complex of photosystem II and PSII reaction centers (Subrahmanyam *et al*., 2006). The osmotic adjustment during the water stress, the proline accumulation is also considered to be involved in the protection of the enzymes and cellular structure and to act as a free radical scavenger (Vijrabhaya *et al.,* 2000). The osmotic adjustment has been observed in stem, leaves, roots and fruits (Unyayar *et al*., 2004). Shao et al. (2008), also observed that physiological and biochemical changes reduce growth rate by effecting decline in net photosynthesis, internal CO_2 concentration increase, reduces leaf water potential, respiratory hazard due to reduction of gas exchange (CO_2 & O_2), loss of turgar, osmotic adjustment, decrease in efficiency of photochemical and Rubisco, accumulation of proline, glutathione, glybet, MDHA, alfa-tocopherol, increase antioxidative enzymes accumulation, anthocyanin and relative water contents (RWC) content, chlorophyll content, decrease stomata conductance, nutrient metabolism and growth promoters, protein synthesis, soluble sugar accumulation translocation, ion uptake, enzyme and protein synthesis decreases, protein breakdown, ABA increase, viscosity of protoplasm and NH_3 increases toxicity due to acidity of chloroplast. One of the most important changes under drought stress is the decrease in the total chlorophyll content (Begum and Paul, 1992 and Levitt, 1980).

The performance of rice genotypes varies under water stress conditions at different growth stages. Islam *et al.* (1994) observed that yield losses resulting from water deficit are particularly severe when drought strikes at booting stage. Water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which results in low grain weight and increases empty grains (RRDI, 1999). Bangladesh has three main rice crop seasons namely Aus, Aman and Boro. Rain-fed ecosystem is mainly assigned for Aus and Aman rice. Aus rice is grown from April to July and T. Aman (Transplanted Aman) rice from July to November. Boro rice is a dry season crop mainly dependent on irrigation. Most of our traditional Aus varieties possess quite a good grade of resistance to both the problems. But their yield is not satisfactory. That is why farmers are switching over to grow Boro crop in some Aus fields wherever irrigation facilities are available. So, it is quite logical to develop/introduce drought tolerant high yielding rice varieties. Among the rice growing seasons, Aus are the most vulnerable one and offers low yield per unit of land. The Aus rice faces drought problem at the beginning stage (vegetative stage) but may face flash flood at the flowering time.

For a drought prone condition, the rain-fed upland and lowland varieties are suitable options. The upland rice varieties are mostly of land race origin cultivated as Aus rice, directly dry seeded in a well-plowed field. The soil should have some moisture to support seedling establishment. This could be a residual moisture from the rain in April might occur along with the Kal-Boishakhi (strong gale occurring in April). If there is no rain, Aus rice could be dry seeded in a cultivated field and kept underneath the soil for a month or so, just for waiting for the rain. This is a traditional practice called "Khorani" in Bangla. This Aus rice has some tolerance to drought and could withstand a jolt of drought during the month of Jaisthay (May). If it rains in June the crop could recover soon to yield a reasonable harvest. The yield potentiality of these varieties is quite low. Therefore, the BRRI scientists were in the process of developing some varieties like BR20, BR21, BR24, BRRI dhan27, BRRI dhan42 and BRRI dhan43 for the last 20 years. These varieties have some ability to avoid water stress through elongated roots.

In Bangladesh rice ecotype is characterized as rainfed, mostly dry seeded upland conditions (unbunded rice culture) and drought at the vegetative stage and no drought at the reproductive stage. The season is characterized by early drought even after the seedling establishment. Under long term water stress, plants might permanently wilt or stop growing. Plants may eventually die. Drought can be chronic in climatic regions with low water availability or random and unpredictable due to changes in weather conditions during the period of plant growth. In agriculture, mild to severe drought has been one of the major production limiting factors. In severe cases, 100% yield loss can be experienced due solely to abiotic stresses, such as drought. Severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of plant (Jaleel *et al.,* 2008c). It is estimated that the world needs to produce 40% more rice to feed the population by 2025 (FAO 2002). Hence, there is an urgent need to increase rice production to meet global demand. Also water stress management strategies need to be taken for better yield and improved varieties that are more resilient to abiotic stresses. Agricultural technology related to crop production has to be developed according to specific location. Considering the above mentioned facts the present research work was undertaken to achieve the following objectives:

1. To find out the responses of morpho-physiological and biochemical characters of Aus rice genotypes under drought stress.
2. To find out the performance of better yielding rice genotypes under drought conditions, and
3. To measure the mechanism of drought resistance in a few Aus rice genotypes.

CHAPTER 2

REVIEW OF LITERATURE

Drought stress is one of the most important manifestations of abiotic stress in plants and environmental stresses affecting agricultural productivity around the world and may result in considerable yield reductions (Farahani *et al.*, 2009). Water deficit are global issues to ensure survival of agricultural crops and sustainable food production reported by Nakayama *et al.*, (2007). Zubaer (2007) reported that it is observed that the natural calamities are the main barriers to increase yield of rice. It is estimated that the world needs to produce 40% more rice to feed the population by 2025 (FAO 2002). Because of increases in population and income in major rice-consuming countries, demand for rice has been steadily increasing over the years. Anon (2004) stated that about half of the total world rice area is rainfed where drought is major production constraint. Shaw (1988) stated that drought is moisture deficit sufficient to have an adverse effect on rice. Plant growth and productivity is adversely affected by natural wrath in the form of various biotic and abiotic stress factors reported by Rahdari and Hoseini, (2012).

Major problems in rice ecosystem of abiotic stresses are environmental, non-biological, climate change, temperature (high / low), water (high / low), salt, high tide, radiation, poor soil fertility. Chemical and biotic stresses caused by living organisms are fungi, bacteria, viruses, insects, herbivores, weed, other plants/competitor and socioeconomics resource constraints and yield gap. At a glance the abiotic stresses are classified that environmental stress are two types abiotic and biotic. Abiotic stresses are temperature (high, low) water (drought, flood), radiation, chemical (salt, ion or gases, herbicides and insecticides) and winds (Anonymous, 2015). Akram and Ashraf, (2013) reported that drought can be defined as the absence of rainfall or irrigation for a period of time. It is one of the major abiotic stresses those severely affect and reduce the yield and productivity of food crops worldwide up to 70%. Drought has been identified as the key factor for low productivity in the rainfed ecosystem reported by Zeigler and Puckridge, (1995). Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration and evaporation.

Pinheiron and Chaves (2011) reported that the timing of water deficits during the season (e.g. sowing, crop establishment, flowering, or grain filling) may have a much larger impact on yield than the intensity of drought. Water-deficit may occur early in the growing season or any time from flowering to grain filling and the intensity of the stress depends on the duration and frequency of water-deficit reported by Wade *et al.,* (1999). Boyer (1982) found that drought limits the productivity of many crops and affects both quality and quantity of the yield. Sairam and Srivastava (2001) stated that reduction of plant growth is the most typical symptom of drought stress. A collection of terms was used to describe the different types of drought stress responses that allow a plant to produce grains under stress reported by O'Toole *et al*. (1978). The first term is, escape (e.g., early flowering, or matching crop duration and development to the rainy season length), the second, avoidance (e.g., deep root growth to allow continued water uptake), the third, drought tolerance (e.g., the ability to withstand very negative soil water potentials), and the last one, drought resistance, an overall term for the ability to produce grains through any of the above mechanisms. Drought resistance also refers to a plant ability to grow and reproduce satisfactorily under drought conditions reported by Popp *et al.,* (2002). Jaleel *et al*. (2008b) advocated that the reactions of plants to water stress differ significantly at various organizational levels depending upon intensity and duration of stress as well as plant species and its stage of growth. This review describes some aspects of drought induced changes in morphological, physiological and biochemical in rice. Drought reduces plant growth by affecting various morphological, physiological and metabolic changes. The response of plants to drought stress is complex and involves changes in their morphology, physiology, bio-chemical and metabolism. Reddy *et al*., (2004), Zhao *et al*.(2008), stated that understanding plant responses to drought is of great importance and also a fundamental part for making the crops stress tolerant stated.

2.1 Effects of water stress on plants

Drought, as an abiotic stress, is multidimensional in nature and it affects plants at various levels of their organization. In fact, under prolonged drought, many plants will dehydrate and die. Water stress in plants reduces the plant-cell's water potential and turgor, which elevate the solutes' concentrations in the cytosol and extracellular matrices. As a result, cell enlargement decreases leading to growth inhibition and reproductive failure. This is followed by accumulation of abscisic acid (ABA) and compatible osmolytes like proline, which cause wilting. At this stage, overproduction of reactive oxygen species (ROS) and formation of radical scavenging compounds such as ascorbate and glutathione further aggravate the adverse influence. Drought not only affects plant water relations through the reduction of water content, turgor and total water, it also affects stomatal closure, limits gaseous exchange, reduces transpiration and arrests carbon assimilation (photosynthesis) rates. Negative effects on mineral nutrition (uptake and transport of nutrients) and metabolism leads to a decrease in the leaf area and alteration in assimilate partitioning among the organs. Alteration in plant cell wall elasticity and disruption of homeostasis and ion distribution in the cell has also been reported. Synthesis of new protein and mRNAs associated with the drought response is another outcome of water stress on plants. Under the water stress cell expansion slows down or ceases, and plant growth is retarded. However, water stress influences cell enlargement more than cell division. Plant growth under drought is influenced by altered photosynthesis, respiration, translocation, ion uptake, carbohydrates and nutrient metabolism.

2.2 Effects and mechanism under drought stress condition

At the whole plant level the effect of stress is usually perceived as a decrease in photosynthesis and growth, and is associated with alteration in carbon and nitrogen metabolism (Cornic and Massacci, 1996; Mwanamwenge *et al.,* 1999). The plant response is complex because it reflects over space and time the integration of stress effects and responses at all underlying levels of organization (Blum, 1996). In the natural environment plants are well adapted to minimize damages which only occur under extreme conditions. In the frame of "physiological window" mild drought induces in plants regulation of water loss and uptake allowing maintenance of their leaf relative water content within the limits where the photosynthetic capacity shows no or little changes. But severe drought induces in plants unfavourable changes leading to inhibition of photosynthesis and growth. The most severe drought stress is desiccation. On the basis of presence or absence of bulk water, the mechanisms of protection are different. While the mechanisms conferring drought tolerance are mainly based on structural stabilization by preferential hydration, desiccation tolerance mechanisms are based on the replacement of water by molecules that form hydrogen bonds.

Plants display a variety of physiological and biochemical responses at cellular and whole-organism levels towards prevailing drought stress, thus making it a complex phenomenon. CO_2 assimilation by leaves is reduced mainly by stomatal closure, membrane damage and disturbed activity of various enzymes, especially those of CO_2 fixation and adenosine triphosphate synthesis. Enhanced metabolite flux through the photo respiratory pathway increases the oxidative load on the tissues as both processes generate reactive oxygen species. Injury caused by reactive oxygen species to biological macromolecules under drought stress is among the major deterrents to growth. Plants display a range of mechanisms to withstand drought stress. The major mechanisms include curtailed water loss by increased diffusive resistance, enhanced water uptake with prolific and deep root systems and its efficient use, and smaller and succulent leaves to reduce the transpiration loss. Among the nutrients, potassium ions help in osmotic adjustment; silicon increases root endodermis silicification and improves the cell water balance. Low-molecular-weight osmolytes, including glycine betaine, proline and other amino acids, organic acids, and polyols, are crucial to sustain cellular functions under drought. Plant growth substances such as salicylic acid, auxins, gibberellins, cytokinin and abscisic acid modulate the plant responses towards drought. Polyamines, citrulline and several enzymes act as antioxidants and reduce the adverse effects of water deficit. At molecular levels several drought-responsive genes and transcription factors have been identified, such as the dehydration-responsive element-binding gene, aquaporin, late embryogenesis abundant proteins and dehydrins.

Some of the effects of a rapidly imposed water deficit might be common to those when the deficit is imposed slowly, reproduction of slowly imposed water deficits under field conditions is required when considering a crop’s response to drought. This type of study will allow the evaluation of acclimation processes in mature plants as well as plant resistance to a multi stress situation that often is the cause of dramatic losses in agricultural production. Recent studies revealed that molecular and metabolic responses of plants to a combination of stresses are unique and cannot be extrapolated from the separate study of individual stresses (Mittler, 2006). Moreover, Alteration of growth patterns in plants contributes to survival under water depletion conditions. An increase in root to shoot ratio is found commonly in physiological studies on the effects of drought on plants. Growth arrest can be considered as a medium by which plants can preserve carbohydrates for sustained metabolism, prolong energy supply and recovery faster after stress relief. On the other hand, continuation of root growth increases the exploratory capacity of plants in deeper more humid soil layers. Reduction of photosynthesis under restricted. Scarcity of water is a severe environmental constraint to plant productivity. Drought-induced loss in crop yield probably exceeds losses from all other causes, since both the severity and duration of the stress are critical. The effects of drought stress on the growth, phenology, water and nutrient relations, photosynthesis, assimilate partitioning, and respiration in plants.

C.A.Jaleel *et al* (2009) stated that plant growth and productivity is adversely affected by nature's wrath in the form of various biotic and abiotic stress factors. Water deficit is one of the major abiotic stresses, which adversely affects crop growth and yield. These changes are mainly related to altered metabolic functions, one of those is either loss of or reduced synthesis of photosynthetic pigments. This results in declined light harvesting and generation of reducing powers, which are a source of energy for dark reactions of photosynthesis. These changes in the amounts of photosynthetic pigments are closely associated to plant biomass yield.

2.3 Effects of drought stress on morpho-physiological processes

It has been established that drought stress is a very important limiting factor at the initial phase of plant growth and establishment. It affects both elongation and expansion growth reported by Anjum *et al. (*2003) and Shao *et al*. (2008). Among the crops, rice as a submerged crop, is probably more susceptible to drought stress than most other plant species. In soybean, the stem length was decreased under water deficit conditions (Specht *et al*., 2001). The plant height was reduced up to 25% in water stressed citrus seedlings (Wu *et al*., 2008). Stem length was significantly affected under water stress in potato (Heuer & Nadler, 1995), *Abelmoschus esculentus* (Sankar *et al*., 2007 & 08); *Vigna unguiculata* (Manivannan *et al*., 2007); soybean (Zhang *et al*., 2004) and parsley (*Petroselinum crispum*) (Petropoulos *et al*., 2008). Water 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 to assist plant growth under severe drought conditions in pearl millet (Shao *et al*., 2008). The reduction in plant height was associated with a decline in the cell enlargement and more leaf senescence in *A. esculentus* under water stress (Bhatt & Srinivasa Rao, 2005). 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 inter-specific differences between two sympatric *Populus* species were found in total number of leaves, total leaf area and total leaf biomass under drought stress (Wullschleger *et al*., 2005). The leaf growth was more sensitive to water stress in wheat than in maize (Sacks *et al*., 1997); *Vigna unguiculata* (Manivannan *et al*., 2007) and sunflower (Manivannan *et al*., 2007). Roduction of ramified root system under drought is important to above ground dry mass and the plant species or varieties of a species show great differences in the production of roots. The importance of root systems in acquiring water has long been recognized. A prolific root system can confer the advantage to support accelerated plant growth during the early crop growth stage and extract water from shallow soil layers that is otherwise easily lost by evaporation in legumes (Johansen *et al*., 1992). The development of root system increases the water uptake and maintains requisite osmotic pressure through higher proline levels in *Phoenix dactylifera* (Djibril *et al*., 2005). An increased root growth due to water stress was reported in sunflower (Tahir *et al*., 2002) and *Catharanthus roseus* (Jaleel *et al*., 2008a & c). The root dry weight was decreased under mild and severe water stress in *Populus* species (Wullschleger *et al*., 2005). An increase in root to shoot ratio under drought conditions was related to ABA content of roots and shoots (Manivannan *et al*., 2007b). The root growth was not significantly reduced under water deficits in maize and wheat (Sacks *et al*., 1997). Greater plant fresh and dry weights under water limited conditions are desirable characters. A common adverse effect of water stress on crop plants is the reduction in fresh and dry biomass production (Farooq *et al*., 2009). Plant productivity under drought stress is strongly related to the processes of dry matter partitioning and temporal biomass distribution (Kage *et al*., 2004). However, some genotypes showed better stress tolerance than the others. Mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes (Mohammadian *et al*., 2005). Reduced biomass was seen in water stressed soybean (Specht *et al*., 2001), *Poncirus trifoliatae* seedlings (Wu *et al*., 2008), common bean and green gram (Webber *et al*., 2006) and *Petroselinum crispum* (Petropoulos *et al*., 2008). A moderate stress tolerance in terms of shoot dry mass plants was noticed in rice (Lafitte *et al*., 2007).

Different environmental stresses to a plant may result in similar responses at the cellular and molecular level. This is due to the fact that the impacts of the stressors trigger similar strains and downstream signal transduction chains. A good example for an unspecific response is the reaction to stressors which induce water deficiency e.g. drought, salinity and cold, especially frost. The stabilizing effect of liquid water on the membrane bilayer can be supported by compatible solutes and special proteins. At the metabolic level, osmotic adjustment by synthesis of low-molecular osmolytes (carbohydrates, betains and proline) can counteract cellular dehydration and turgor loss. Taking the example of *Pinus sylvestris*, changes at the level of membrane composition, and concomitantly of photosynthetic capacity during frost hardening is shown. Additionally the effect of photoperiod as measured via the phytochrome system and the effect of subfreezing temperatures on the incidence of frost hardening is discussed. Extremely hydrophilic proteins such as dehydrins are common products protecting not only the biomembranes in ripening seeds (late embryogenesis abundant proteins) but accumulate also in the shoots and roots during cold adaptation, especially in drought tolerant plants. Dehydrins are characterized by conserved amino acid motifs, called the K-, Y- or S-segments. Accumulation of dehydrins can be induced not only by drought, but also by cold, salinity, treatment with abscisic acid and methyl jasmonate. Positive effects of the over expression of a wild chickpea (Cicer pinnatifi dum) dehydrin in tobacco plants on the dehydration tolerance is shown.

Morphological responses are leaf tip burning, leaf rolling, yellowish leaf, shrinkage of leaves, increase root length to absorbed water from deep soil, increase root shoot ratio. There are three basic drought patterns affecting rice production: Fukai and Cooper (1995) found that there were three basic drought patterns affecting the life of rice plant production that were i) early drought stresses, ii) intermittent drought stresses and iii) late drought stresses. Fukai and Cooper (1995), also observed that early droughts often result in delayed sowing or transplanting in case of rice. Boonjung and Fukai (1996) observed that early drought may reduce tiller numbers and reductions were often minimal yield. Fukai and Cooper (1995), also stated that Intermittent or continuous droughts (occurring between the tillering and flowering stages) may greatly reduce yields despite no apparent drought symptoms (eg. leaf rolling) mainly as a result of reduced leaf expansion and photosynthesis. Fischer and Turner (1978), observed that drought could significantly influenced plant performance and survival and could lead to major constraints in plant functioning, including a series of morphological, physiological and metabolic changes (Ludlow and Muchow, 1990). Lum (2014), reported that among of eight local upland rice (*Oryza sativa* L.) varieties affected by drought-sensitive variety, Kusam was markedly affected than the drought tolerant varieties in the activities of shoot length, root length and dry matter yield and biochemical parameters; proline and antioxidant enzymes and proline accumulation. It also affects Boro and Aman rice. Water stress greatly suppresses cell expansion and cell growth due to the low turgor pressure. Shao *et al*. (2008) found that osmotic regulation can enable the maintenance of cell turgor for survival or to assist plant growth under severe drought conditions in pearl millet. Farooq *et al*. (2009) reported that development of optimal leaf area is important for photosynthesis and dry matter yield. Water deficit stress mostly reduced leaf growth and in turns the leaf areas. The leaf growth was more sensitive to water stress in wheat than in maize (Sacks *et al*., 1997).

The physiological responses are recognition of root signals, Loss of turgor and osmotic adjustment, reduced leaf water potential, decrease in stomatal conductance of CO2 reduced internal CO2 concentration, Decreased efficiency of rubisco biochemical responses are and molecular responses are stress responsive gene expression (Shao *et al*., 2008). Jaleel *et al.* (2009) stated that plant growth and productivity is adversely affected by nature's wrath in the form of various biotic and abiotic stress factors. Water deficit is one of the major abiotic stresses, which adversely affects crop growth and yield. Drought symptoms can be very confusing, and can vary with different types of plants. In case of rice under drought stress can have many symptoms including leaf yellowing, leaf rolling and willting. Leaves of rice become v-shape, u-shape and o-shape. With mild water deficiency, plants are usually slow growing and stunted. The most common symptom of plant water stress is wilt which reduces growth.

Taiz and Zieger (1998) found that drought reduced plant productivity by inhibiting growth and photosynthesis. Drought resistance is a complex trait involving several interacting morpho-physiological mechanisms by which plants are able to cope with water deficit conditions, such mechanisms include escape, avoidance, tolerance and recovery reported by Hussain, (2006). Drought can affect rice plant in any growth stage at vegetative and reproductive stage resulting poor yield. Early droughts often result in delayed sowing or transplanting. Yield reductions from early droughts (occurring during vegetative growth, after establishment but before maximum tillering) are often minimal and result from a reduction in tiller numbers observed by Boonjung and Fukai, (1996). At vegetative stage of rice also reduced plant growth, yield and it varies with the severity of the stress and age of the crop. Drought affects Aus crops at vegetative phase. Rice is more susceptible to drought. Drought at vegetative stage of rice also reduces plant height, number of tillers per hill, number of leaves per hill, leaf area per hill, total dry matter per hill and it varies with the severity of the stress and age of the crop. Long duration varieties face less yield damage in vegetative stage than short duration varieties. Shao *et al*. (2008), stated that it had been established that drought stress was very important limiting factor at the initial phase of plant growth and establishment. It effects elongation and expansion growth, some genotypes showed better stress tolerance than the others. At reproductive stage drought reduces number of filled grains per panicle, number of unfilled grains per panicle, grain weight, harvest index, grain yield and it varies with the severity of the stress and age of the crop. Yoshida (1981) reported that rice plant is most sensitive to water stress from panicle initiation to heading stage.

Liu *et al. (*2006), found that drought occurs during later growing stages for which spikelet fertility was reduced and this influences to yield loss. Drought can affect in any growth stage of rice plant like vegetative and reproductive stage resulting poor yield. Water sress at vegetative stage of rice also reduced plant growth, yield and it varies with the severity of the stress and age of the crop. According to RRDI (1999), water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which results low in grain weight and increases empty grains. Drought can affect in any growth stage of rice plant at vegetative and reproductive stage resulting poor yield. Drought also reduced potential spike number and decreased translocation of assimilates to the grains at or before panicle initiation. Islam *et al.* (1994), observed that drought at booting stage resulting yield losses when it was severe. Zubaer *et al*. (2007) reported that the interaction effect of different soil moisture levels and rice genotypes at booting, flowering and maturity stages reduced on plant height due to water stress condition.

i. Drought effect on root growth

Usman *et al*. (2013) that the root length of upland rice varieties exhibited significant reduction at highest drought level as compare to control. They also stated that drought affected the growth and reduced the fresh shoot and root weights, root and shoot lengths. Reduction of ramified root system under drought is important to above ground dry mass and the plant species or varieties of a species show great differences in the production of roots. The importance of root systems in acquiring water has long been recognized. An increased root growth due to water stress was reported by Jaleel *et al*., (2008a). Wullschleger *et al*. (2005) advocated that the root dry weight was decreased under mild and severe water stress in *Populus* species. Sacks *et al*. (1997), observed that the root growth was not significantly reduced under water deficits in maize and wheat. Sikuku *et al.* (2010) reported that drought tolerant cultivars have deep and thick roots. The thick roots are positively correlated with xylem vessel area, which are vital to the conductance of water from soil to the upper parts of the plants to meet the evaporative demand. The shallower root distribution in the field was thought to be due to genetic predetermination, lack of oxygen, or the presence of a hardpan. There had still not explained exactly why roots grow deeper in cylinders than in the field, even at similar soil bulk densities. Other studies revealed root growth in root boxes to be well correlated with soil water extraction in a field line-source irrigation trial, detected by neutron probe readings (Puckridge and O'Toole, 1981).Comparisons of root growth in containers with scoring/performance in the field included comparisons of root mass distribution with depth between root boxes and field studies (Henry, 2013; IRRI 1977). Among the several factors contributing to enhance stress tolerance, root characters are considered to be a vital component of dehydration postponement mechanism since they contribute to regulation of plant growth and extraction of water and nutrients from deeper layers. Several components of root morphology contributed to drought tolerance (Ekanayake *et al*., 1985). Deep rooted system allows to extract deep soil moisture during drought and thick root are correlated with xylem vessel area which are vital to the conductance of water from soil to the upper parts of the plants to meet evaporative demand. Lateral roots capture small amount of intermittent rainfall. When water deficit occurs, the most effective resistance mechanism available to the rice plant is a deep root system consisting of mostly thick roots that enables the plant to avoid the adverse effects of internal water deficit. The root length of upland rice varieties exhibited significant reduction at highest drought level as compare to control. Fraser *et al.* (1990), observed that reduction of root length under stress conditions may due to an impediment of cell division and elongation leading kinds of tuberization. Kramer (1982), and Blum (1982), reported that under water deficit condition root size, structure, morphology, depth, length, density and branching or distribution in soil horizons are important in maintaining high leaf water potential against evapotranspiration demand. Ekanayake *et al.* (1985) stated that several components of root morphology contributing to drought tolerance have been identified. Russell (1959) reported that root development has long been recognized as an important factor in determining a plant species adaptability to water stress conditions. The complexities of interrelationships that exist between root morphological characters and yield components have not been unfolded so far, little research has been carried out to understand the responsibility of root traits to drought resistance. O' Toole (1982), classifies the drought resistance mechanisms of rice into root-related traits, shoot-related traits and reproductive stage specific traits. Several studies documented very small or no influence of the primary or secondary components of drought resistance, including root system, on grain yield and its attributes. While the effects under well-watered conditions were small, they were minuscule under moisture stress conditions (Blum *et al*. 1999). Root studies are arduous under actual field conditions. Henry *et al.* (2011), also stated that genetic variation for deep root growth in drought-stressed rice was observed.

Drought resistance identified by plant breeders in the 1970s was largely dependent on avoidance reported by IRRI (1976). As such, research efforts on roots were focused on linking root growth in con-tainers with drought scoring in the field. Combination of showing deep root growth but low drought tolerance when root depth was restricted, and was even used as a drought-susceptible check in some screenings (IRRI 1979). Kinandang Patong was highlighted in the root/drought sections of IRRI annual reports in the 1970s for showing deep root. During the 1970s, physiologists were screening root growth of large numbers of genotypes, as required by the breeding program. Using the root box technique, 200 varieties were screened for root depth in 1975 (IRRI 1976); 768 were screened for root depth in 1977, of which 256 were classified as deep, mostly upland varieties (IRRI 1978); and 1081 were screened for deep root: shoot ratio in 1979 (IRRI 1980). A number of traits were explored that were hypothesized to be representative of deep root growth, including root pulling force in flooded paddies and time to flowering, for which shorter time to flowering was reported to be correlated with deep root: shoot ratio. Comparisons of root growth in containers with scoring/performance in the field included compari-sons of root mass distribution with depth between root boxes and field studies (IRRI, 1977). The shallower root distribution in the field was thought to be due to genetic predetermination, lack of oxygen, or the presence of a hardpan. Greenhouse root studies during the 1970s included the use of tanks (hydroponic systems) and soil-filled boxes, and a unique greenhouse setup for maintaining constant soil water potential. Containers were also used to conduct large-scale screenings on drought tolerance under limited rooting depth (IRRI, 1979).

ii. Plant height

Zubaer *et al*. (2007), reported that that plant height decreased with increasing soil moisture stress. It might be due to inhibition of cell division or cell enlargement under water stress. Variation in plant height among the genotypes also indicates that different genotypes had different water requirement. In soybean, the stem length was decreased under water deficit conditions found by Specht, (2001). The plant height was reduced up to 25% in water stressed citrus seedlings found by Wu *et al*., (2008). Stem length was significantly affected under water stress in potato (Heuer & Nadler, 1995), *Abelmoschus esculentus* found by Sankar *et al*., (2008); *Vigna unguiculata* found by Manivannan *et al*., (2007a); soybean found by Zhang *et al*., (2004) and parsley (*Petroselinum crispum*). Bhatt & Srinivasa Rao (2005) stated that the reduction in plant height was associated with a decline in the cell enlargement and more leaf senescence in *A. esculentus* under water stress.

Mohammad khani and Heidari (2008) who showed that all the upland rice varieties displayed significant reduction in shoot length at the most drought levels as compared with control. This reduction in growth might be due to low osmotic potential as well as a decrease in wall extensibility and cellular expansion. Zubaer *et al*. (2007) also reported that the interaction effect of different soil moisture levels and rice genotypes at booting, flowering and maturity stages reduced on plant height due to water stress condition. Amin *et.al* (2009) reported that shoot length reduction is occurring due to the lower turgor pressure in the water stress conditions.

iii. Root shoot ratio

A number of traits were explored that were hypothesized to be representative of deep root growth, including root pulling force in flooded paddies and time to flowering, for which shorter time to flowering was reported to be correlated with deep root: shoot ratio.

Kulkarni *et al.* (2008) reported that the root shoot ratio was reduced when the soil was subjected to drought condition (water stress) for all the rice varieties. Under the well-watered treatment, the root shoot ratio was higher than under water stress treatment for all the varieties and MR220 showed a lower root shoot ratio than the other varieties. Based on the observation, the Jawi Lanjut varieties showed high root shoot ratio than the other varieties under the water stress treatment. Mohammadian *et al*. (2005) reported that mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes. Water stress induced increased in root shoot ratio was observed in maize (Sharp *et al.*2004). Under the well-watered treatment, the root shoot ratio is higher than under water stress treatment for all the varieties. Higher root to shoot ratio under the drought conditions has been linked to the ABA content.

Wullschleger *et al*. (2005) advocated that the root dry weight was decreased under mild and severe water stress in *Populus* species. Sacks *et al*. (1997), observed that the root growth was not significantly reduced under water deficits in maize and wheat. Greater plant fresh and dry weights under water limiting conditions are desirable characters. Farooq *et al*. (2009), stated that a common adverse effect of water stress on crop plants was the reduction in fresh and dry biomass production. However, some genotypes showed better stress tolerance than the others. Mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes (Mohammadian *et al*., 2005). Reduced biomass was seen in water stressed common bean and green gram (Webber *et al*., 2006) and *Petroselinum crispum* (Petropoulos *et al*., 2008). A moderate stress tolerance in terms of shoot dry mass was noticed in rice (Lafitte *et al*., 2007).

IRRI (1977) reported that in terms of traits that were studied during the 1970s in addition to maximum root depth, large diversity for deep root: shoot ratio (based on roots below 30 cm) was observed in relation to drought response. During the 1970s, physiologists were screening root growth of large numbers of genotypes, as required by the breeding program. Using the root box technique, 200 varieties were screened for root depth in 1975 (IRRI, 1976); 768 were screened for root depth in 1977, of which 256 were classified as deep, mostly upland varieties (IRRI, 1978); and 1081 were screened for deep root: shoot ratio in 1979 (IRRI, 1980).

iv. Leaf growth

Sacks *et al*. (1997) reported that water deficit stress mostly reduced leaf growth and in turn the leaf areas in many species of plant. It has been established that drought stress is a very important limiting factor at the initial phase of plant growth and establishment. It affects both elongation and expansion growth (Anjum *et al.,* 2003, Shao *et al*., 2008). Water deficit stress mostly reduced leaf growth and in turn the leaf areas in many species of plant. Reduced soil moisture levels produced lower leaf area; it might be due to inhibition of cell division of meristematic tissue under water starved condition. Leaf expansion is most sensitive to water stress (Acevedo *et. al*. 1971) and leaf growth can be drastically reduced (Eastham *et. al*., 1984). Kramer and Boyer (1995) reported that drought stress suppresses leaf expansion, tillering and midday photosynthesis and reduces photosynthetic rate and leaf area due to early senescence. As a result, leaf area index development is the most affected physiological process during this stage. Reduction of root length under stress conditions may due to an impediment of cell division and elongation leading kinds of tuberization (Fraser *et al*., 1990). Farooq *et al. (*2009) stated that water deficit stress decreases the leaf area which results in the decreases in the shoot length in many crops. In wheat the reduction in leaf area was more than the maize. It has been reported that smaller leaf area may be described to acceleration of leaf senescence and abscission or to the sensitivity of leaf expansion to water stress (Boyer, 1970; Whiteman and Wilson, 1965).

Anjum *et al. (*2003); Bhatt & Srinivasa Rao (2005) and Kusaka *et al*. (2005) stated that 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). In this present study leaf area varied significantly under water stress condition. The results of the experiment are in agreement with Aggarwall and Kodundal (1988), and Hossain (2001). Reduced soil moisture levels produced lower leaf area, it might be due to inhibition of cell division of meristematic tissue under water starved condition. Acosta-Gallegos *et al*. (1991) reported that leaf expansion rate and crop growth rate at mid-pod-filling were greatly reduced by drought stress. Farooq *et al*. (2009) reported that development of optimal leaf area is important for photosynthesis and dry matter yield. Water deficit stress mostly reduced leaf growth and in turn the leaf areas. The leaf growth was more sensitive to water stress in wheat than in maize (Sacks *et al*., 1997).

v. Number of leaves

Zubaer *et al*. (2007) who stated that the number of leaves per hill varied significantly under different moisture levels, the highest number of leaves was found in 100% FC. The number decreased gradually with increasing soil moisture stress and produced the lowest number of leaves per hill in all growing stages. 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 inter-specific differences between two sympatric *Populus* species were found in total number of leaves, total leaf area and total leaf biomass under drought stress. The leaf growth was more sensitive to water stress in wheat than in maize (Sacks *et al*. 1997) and sunflower (Manivannan *et al*. 2007). Water stress might inhibit photosynthesis and produce less amount of assimilates which resulted in lower number of leaves. Hossain (2001) reported that the results also indicate that different genotypes had different requirements for leaf production.

vi. Days to flowering and maturity

Zubaer *et al*. (2007) showed that water stress affects more at flower stage than that at booting stages. The results also showed that the flowering stage more critical than other stages. Begum (1992) conducted that water stress effect on flowering decreased the individual grain weight. Water deficit just before flower initiation may also decrease the number of spikelet primordial at this stage (Oosteruis and Cartwright, 1983). Delay in flowering due to drought stress was negatively associated with grain yield, and seemed to be governed by a lower plant water status reported by Kumar *et al.,* (2006). A number of traits were explored that were hypothesized to be representative of deep root growth, including root pulling force in flooded paddies and time to flowering, for which shorter time to flowering was reported to be correlated with deep root: shoot ratio.

Early senescence causes low yield which causes drought. Zubaer *et al*. (2007) showed that water stress affects more at maturity stages than that at booting stages. At flowering and maturity stages, similar trend were found for producing leaf area per hill. Levitt (1980) stated that crop maturity period was shortened by environmental stresses, which was mainly due to limited source caused by leaf senescence for the sink. Drought stress suppresses leaf expansion and midday photosynthesis and reduces photosynthesis rate and leaf area due to early senescence (Kramer and Boyer, 1995).

vii. Number of tillers

Boonjung and Fukai (1996) observed that early drought may reduce tiller number and reductions were often minimal yield. Kramer and Boyer (1995) stated that drought stress suppresses tillering and midday photosynthesis and reduces photosynthetic rate due to early senescence.

Number of effective tiller means number of panicle per plant cannot increase due to early senescence. Plants were not able to produce enough assimilates for inhibited photosynthesis. It might be also happened for less amount of water uptake to prepare sufficient food and inhibition of cell division of meristematic tissue. For this reason, no of tiller production reduced might be the facts that under water stress condition.

viii. Leaf rolling

The leaf rolling under water stress condition was observed by Zulkarnain *et al.*(2009) who found that the sensitive rice varieties showed higher leaf rolling score and the tolerant cultivars showed lower leaf rolling. It was also reported that after a long time drought condition the leaves of all rice varities (tolerant and sensitive) were rolled at midday. Fukai and Cooper (1995) observed that intermittent or continuous droughts may greatly reduce yields despite no apparent drought symptoms eg. Leaf rolling mainly as a result of reduced leaf expansion and photosynthesis reductions was often minimal yield. Both stomatal closure and leaf rolling improved water use efficiency at moderate stress while non stomatal inhibition of photosynthesis reduced water use efficiency. Drought symptoms can be very confusing, and can vary with different types of plants. In case of rice under drought stress can have many symptoms including leaf yellowing, leaf rolling and leaves of rice become v-shape, u-shape and o-shape With mild water deficiency, plants are usually slow growing and stunted. The most common symptom of plant water stress is wilt which reduces growth. Under long term water stress, plants might permanently wilt or stop growing. Under water stress condition many drought signs in a plant incude leaf yellowing, wilt, leaf rolling. It was also reported that after a long time drought condition the leaves of all rice varities (tolerant and sensitive) were rolled at midday. Delayed leaf rolling was considered as a desirable character in rice (Maji, 1994). It was also reported that the leaf rolling is one of the acclimation responses of rice and is used as a criterion for scoring drought tolerance (Pandey and Shukla, 2015). Leaf rolling is hydronasty that lead to reduced light interception,transpiratio and leaf dehydration (Kadioglu and Terzi (2007). Leaf rolling may help in maintaining internal plant water status (Turner *et al.,* 1986; Abd Allah, 2009, Gana, 2011; Ha, 2014).

2.4 Effects of drought stress on physiological characteristics

Usman *et al*. (2013), stated that drought affected rate of photosynthesis, accumulation of total soluble sugars and the photosynthetic pigments also carotenoids and biochemical processes.

Physiological responses are a deficit of water include leaf wilting, a reduction in leaf area, leaf abscission and thereby reducing water loss through transpiration and increasing the rate of photosynthesis in relation to drought, closure of stomata, transpiration and photosynthesis are affected due to water stress. It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism and growth promoters reported by Jaleel *et al., (*2008a-d), Farooq *et al*. (2008). Drought reduces plant growth by affecting various physiological and metabolic changes. Physiological and metabolic changes reduce growth rate by effecting decline in net photosynthesis, internal CO_2 concentration increase, reduces leaf water potential, respiratory hazard due to reduction of gas exchange (CO_2 &O_2), recognition of root characteristics. Jaleel *et al. (*2008a-d), and Farooq *et al*. (2008), stated that drought also reduced plant growth by affecting various physiological and biochemical processes.

i. Photosynthesis

Photosynthesis is particularly sensitive to the effects of water deficiency. Plants resistance to water deficiency yields metabolic changes along with functional and structural rearrangements of photosynthesizing apparatus. Photosynthesis of higher plants decreases with the reduction in the relative water content (RWC) and leaf water potential. Effects and responses photosynthesis rate is a usual effect of water stress in plants and has been attributed primarily to stomata limitation and secondarily to metabolic impairment. However, metabolic impairment is the more complex phenomenon than the stomatal limitation though the relative importance of stomatal or metabolic inhibitions is unclear. Some studies blamed stomatal closure for the inhibition of C4 photosynthesis under water stress while others concluded that non-stomatal factors play the major role. The photosynthesis rate of leaves in both C3 and C4 plants decrease under the drought conditions. Evidence indicates that C4 photosynthesis is more sensitive to water stress and C4 plants, such as corn (*Zea mays* L.) are more susceptible to water deficiency than C3 plants, such as wheat. It explains the predominance of C4 plants in hot, arid regions - areas prone to frequent drought. C3 and C4 plants are alike in the basic process of photosynthesis like Calvin cycle and electron transport chain components, yet significant differences exist between them, which make their responses to water stress differ at a number of levels. There are some co-factors, which decrease plants' photosynthesis under water stress. Of them, qualitative and quantitative changes in the pool of photosynthesizing pigments, low CO2 uptake due to stomatal closure and resistance, poor assimilation rates in photosynthetic leaves are prominent. Assimilation rates in photosynthetic leaves decreases due to reduced photosynthetic metabolites and enzymes activity, low carboxylation efficiency and inhibition of chloroplast activity at low water potential. Among other co-factors of water stress, the damage of the photosynthetic apparatus through the production of ROS such as superoxide and hydroxyl radicals, worth special mention. Decrease in chlorophyll content of leaves under water stress is well known. Water stress inhibits chlorophyll synthesis at four consecutive stages: (I) the formation of 5-aminolevuliniuc acid (ALA); (II) ALA condensation into porphobilinogen and primary tetrapyrrol, which is transformed into protochlorophyllide; (III) light-dependent conversion of protochlorophyllide into chlorophyllide; and (IV) synthesis of chlorophylls a and b along with their inclusion into developing pigment–protein complexes of the photosynthetic apparatus. In the majority of cases, carotenoids are less sensitive to water stress than chlorophyll, which has been demonstrated for several species of agricultural plants. However, unlike chlorophyll, increase in xanthophyll pigments such as zeaxanthin and antheraxanthin in plants under water stress have been reported. Xanthophyll pigments have a protective role on plants under stress, and some of these pigments are involved in the xanthophyll cycle which has inhibitory role on ROS production. RuBisCO, the key enzyme for carbon metabolism in leaves, acts as a carboxylase in the Calvin cycle and as an oxygenase in the photorespiration which, however, frequently is viewed as an adverse process. RuBisCO is the most critical player influencing the physiology of plants under water-stressed conditions. Under the conditions of water stress, a rapid decrease in the amount of RubisCO takes place in most plants which in turn leads to lower activity of the enzyme. This effect is evident in all plants studied though the extent is species-dependent. Water deficiency reduces the supply of carbon dioxide from the environment due to the closure of stomata. Consequently, photorespiration increases which ensure partial substrate replenishment and maintain the carboxylating function of RuBisCO. The end result is the utilization of excess reducing equivalents in chloroplast that causes a reduction in the oxygen-free radicals' production leading to the oxidative damage in chloroplasts. The reduction in chloroplast volume can also be linked to the desiccation within the chloroplast that leads to the conformational changes in RuBisCO. Moreover, drought stress conditions acidify the chloroplast stroma causing inhibition to the RuBisCO activity. In addition, decline in RuBisCO activity is also caused by the lack of the substrate for carboxylation, reduction in the amount and/or activity of the coupling factor - ATPase, loss of RBP recognition sites in RuBisco, structural alterations of chloroplasts and RuBisCO, and release of RuBisCO from damaged plastids. In addition to RuBisCO, water stress can reduce activity of other photosynthetic enzymes to different extents such as NADPdependent glyceraldehyde phosphate dehydrogenase, phosphoenolpyruvate carboxylase, NAD-dependent malate dehydrogenase, phosphoribulos kinase, fructose-1,6-bisphosphatase and sucrose phosphate synthase. In addition to its negative effects on dark reactions of photosynthesis, water stress also disrupts the cyclic and non-cyclic types of electron transport during the light reaction of photosynthesis. The disruption is clearer in the oxygen-releasing complex and electron transfer from protochlorophyllide to P700. Lower electron transport rate negatively affects photophosphorylation process and decrease ATP synthesis as well as NADP+ reduction. ATPase inhibition under water deficiency is also responsible for the reduction in ATP levels in chloroplasts. All these factors cumulatively affect the intensity of photo-assimilation and the stability of the photosynthetic apparatus under the conditions of water stress. Both of the PSs in chloroplasts are affected by water deficiency, however, PS I of some plants are more severely damaged compared to PS II, though there is an opposite conclusion as well. Water stress may damage oxygen evolving complex of photosystem II and PSII reaction centers reported that Subrahmanyam *et al*. (2006). Taiz and Zieger (1998) found that drought reduced plant productivity by inhibiting growth and photosynthesis. The physiological changes reduce plant growth rate by affecting decline in net photosynthesis, decrease stomata conductance, internal CO_2 concentration increase, reduces leaf water potential, respiratory hazard due to reduction of gas exchange (CO_2, O_2), hamper of root characteristics, loss of turgar, osmotic adjustment.

Lawlor & Cornic (2002) stated that the foliar photosynthetic rate of higher plants is known to decrease as the relative water content and leaf water potential decreases. However, the debate continues as, whether drought mainly limits photosynthesis through stomatal closure or through metabolic impairment reported by Lawson *et al*. (2003); Anjum *et al.* (2003). Farooq *et al*. (2009) found that both stomatal and non-stomatal limitation was generally accepted to be the main determinant of reduced photosynthesis under drought stress. Reddy *et al*. (2004), the limitation of photosynthesis under drought through metabolic impairment is more complex phenomenon than stomatal limitation and mainly it is through reduced photosynthetic pigment contents in sunflower. Kramer and Boyer (1995) reported that drought stress suppresses leaf expansion, tillering and midday photosynthesis and reduces photosynthetic rate and leaf area due to early senescence. At the whole plant level the effect of stress is usually perceived as a decrease in photosynthesis and growth, and is associated with alteration in carbon and nitrogen metabolism reported by Yordanov *et al.* (2003).

Osmotic adjustment has been reported to be an important drought adaptation mechanism in many crop plants (Subbarao *et al*., 1995). Vijrabhaya *et al.* (2000), reported that osmotic adjustment during the water stress, the proline accumulation is also considered to be involved in the protection of the enzymes and cellular structure and to act as a free radical scavenger. Subrahmanyam *et al*. (2006) found that water stress may damage oxygen evolving complex of photosystem II and PSII reaction centers. Jaleel et al. (2008a-e) and Farooq *et al*. (2008) stated that drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Smirnoff (1993) and Jaleel *et al.,* (2007d), stated that desiccation was much more extensive loss of water, which can potentially lead to gross disruption of metabolism and cell structure and eventually to the cessation of enzyme catalyzed reactions. Fukai and Cooper (1995) reported that under low-moisture stress, traits those help the plant to gain access additional reserves were more important than traits associated with reducing moisture losses.

ii. Chlorophylls content

Anjum *et al*. (2011) advocated that chlorophyll is one of the major chloroplast components for photosynthesis. The decrease in chlorophyll content under drought stress has been considered a typical symptom of pigment photo-oxidation and chlorophyll degradation. The chlorophyll content decreased to a significant level at higher water deficits in sunflower plants reported by Kiani *et al.* (2008) and in *Vaccinium myrtillus* by Tahkokorpi *et al*. (2007). The foliar photosynthetic rate of higher plants is known to decrease as the relative water content and leaf water potential decreases (Lawlor & Cornic, 2002). However, the debate continues as, whether drought mainly limits photosynthesis through stomatal closure or through metabolic impairment (Lawson *et al*., 2003; Anjum *et al.,* 2003). Both stomatal and non-stomatal limitation was generally accepted to be the main determinant of reduced photosynthesis under drought stress (Farooq *et al*., 2009). The limitation of photosynthesis under drought through metabolic impairment is more complex phenomenon than stomatal limitation and mainly it is through reduced photosynthetic pigment contents in sunflower (Reddy *et al*., 2004). Chlorophy ll b content increased in two lines of okra, whereas chlorophyll a remained unaffected resulting in a significant reduction in Chl a: b ratio in both cultivars under water limiting regimes (Estill *et al.*, 1991; Ashraf *et al.*, 1994). Zhang and Kirkham (1996) advocate that decreased of chlorophyll content during drought stress depending on the duration and severity of drought level. A decrease of total chlorophyll content with drought stress implies a lowered capacity for light harvesting. Synerri *et al.* (1993) reported that drought effect on chlorophyll a and b in leaf, drought is due to chloroplastic proteins hydrolysis, decreasing of leaf pigments and chlorophyll destruction as a primary stage in degradation of proteins. Abaaszadeh *et al.* (2007) reported that chlorophyll concentration decreases under condition of stress by chlorophylase, peroxidase enzymes and phenolic components production. Decreasing of chlorophyll content in plants such as *Paulownia imperialis* (Astorga, 2010) bean (Beinsan *et al*. 2003) was reported under drought stress.

One of the most important changes under drought stress is the decrease in the total chlorophyll content reported by Begum and Paul (1992) and Levitt (1980). But non-reduction of chlorophyll under condition of environmental stress expresses bearing of plant proportional to light damage to chloroplast, while anti-oxidant enzymes action and antioxidant component that conserve chlorophyll have direct relationship reported by Yang (2006). In fact, the reason for increase in chlorophyll level under condition of environmental stress can be proportional to increase in leaf chloroplast in stress leaf where photosynthesis occurs. This is one of the resistant symbols in plants that are proportional to stress. Both the chlorophyll a and b are prone to soil drying reported by Farooq *et al*. (2009). However, carotenoids have additional roles and partially help the plants to withstand adversaries of drought. A reduction in chlorophyll content was reported in drought stressed *Catharanthus roseus* reported by Jaleel *et al*. (2008a-d). Chlorophyll is one of the major chloroplast components for photosynthesis reported by Rahdari and Hseini (2012). The decrease in chlorophyll content under drought stress has been considered a typical symptom of pigment photo-oxidation and chlorophyll degradation reported by Anjum *et al*. (2011). Since the production of reactive oxygen species is mainly driven by excess energy absorption in the photosynthetic apparatus, this might be avoided by degrading the absorbing pigments (Mafakheri *et al*., 2010). Estill *et al.* (1991), and Ashraf *et al.* (1994) reported that chlorophyll b content increased in two lines of okra, whereas chlorophyll a remained unaffected resulting in a significant reduction in Chl a: b ratio in both cultivars under water limiting regimes. Drought stress produced changes in the ratio of chlorophyll 'a' and 'b' and carotenoids (Anjum *et al.,* 2003; Farooq *et al*., 2009).

iii. Carotenoids

Carotenoids are a large class of isoprenoid molecules, which are *de novo* synthesized by all photosynthetic and many non-photosynthetic organisms (Andrew *et al*., 2008). They are divided into the hydrocarbon carotenes, such as lycopene and β-carotene or Oxidative damage generated by drought stress in the plant tissue is alleviated by a concerted action of both enzymatic and non-enzymatic antioxidant systems. These include β- carotenes, ascorbate (AA), α-tocopherol (α-toc), reduced glutathione (GSH) and enzymes including superoxide dismutase (SOD), peroxidase (POD), ascorbate peroxidase (APX), catalase (CAT), polyphenol oxidase (PPO) and glutathione reductase (GR; Prochazkova *et al.*, 2001). Carotenes form a key part of the plant antioxidant defense system, but they are very susceptible to oxidative destruction. β-carotene, present in the chloroplasts of all green plants is exclusively bound to the core complexes of PSI and PSII (Havaux, 1998). Protection against damaging effects of ROS at this site is essential for chloroplast functioning. Here β-carotene, in addition to function as an accessory pigment, acts as an effective antioxidant and plays a unique role in protecting photochemical processes and sustaining them (Havaux, 1998). A major protective role of β-carotene in photosynthetic tissue may be through direct quenching of triplet chlorophyll, which prevents the generation of singlet oxygen and protects from oxidative damage (Farooq *et al*., 2009).

iv. Protein synthesis

Drought conditions bring about quantitative and qualitative changes in plant proteins. In general, proteins in the plant leave decrease during water deficiency due to the suppressed synthesis, more pronouncedly in C3 than in C4 plants. Water stress alters gene expression and consequently, the synthesis of new proteins and mRNAs. The main proteins those synthesized in response to water stress are LEA, desiccation stress protein, proteins those respond to ABA, dehydrins, cold regulation proteins, proteases, enzymes required for the biosynthesis of various osmoprotectants, the detoxification enzymes (SOD, CAT, APX, POD, GR). In addition, protein factors involved in the regulation of signal transduction and gene expression, such as protein kinases and transcription factors are also synthesized. The majority of these stress response proteins are dehydrin-like proteins, which accumulate during seed production and embryo maturation of many higher plants as well as in water stressed seedlings. These proteins have highly conserved domain that linked to hydrophobic interactions needed for macromolecular stabilization.Heat-shock proteins (Hsps) and late embryogenesis abundant (LEA)-type proteins are two major types of stress-induced proteins during different stresses including water stress. Protection of macromolecules such as enzymes, lipids and mRNAs from dehydration are well known functions of these proteins. LEA proteins accumulate mainly in the embryo. The exact functions and physiological roles of these proteins are unknown. Hsps act as molecular chaperones and are responsible for protein synthesis, targeting, maturation and degradation in many cellular processes.They also have important roles in stabilization of proteins and membranes and in assisting protein refolding under stress conditions. Expression of LEA-type genes under osmotic stress is regulated by both ABA-dependent and independent signaling pathways. Genes encoding LEA-type proteins are diverse - RD (responsive to dehydration), ERD (early response to dehydration), KIN (cold inducible), COR (cold regulated), and RAB (responsive to ABA) genes.

v. Lipids

Water stress can lead to a disturbance of the association between membrane lipids and proteins as well as enzymes activity and transport capacity of membranes. Drought results in the variation of fatty acid composition, for example, an increase in fatty acids having less than 16 carbons in chloroplasts. Lipid peroxidation is the well-known effect of drought and many other environmental stresses via oxidative damage.

vi. Proline accumulation

One of the physiological responses that plants use against drought is proline accumulation reported by Girousse *et al*. (1996). Under drought stress condition organisms other than plants also accumulate compatible solutes; for example, glycerol in yeast. Compatible solutes are divided into three major groups- amino acids (e.g. proline), polyamins and quaternary amines (e.g. glycinebetaine, dimethyl sulfonio propionate), polyol (e.g. mannitol, trehalose) and sugars like sucrose and oligosacharids. Free proline is believed to play a key role in cytoplasmic tolerance in many species and, therefore, in the resistance of the whole plant to severe drought. Sugars can play a role in osmoregulation under a drought condition in many plants such as alfalfa and Ziziphus mauritiana. Many studies indicated that solute accumulation under water stress contributes to inhibition of shoot growth. It is clear because compatible solute synthesis and accumulation need high energy level. In many plant species, free proline accumulates in response to vast range of stresses such as drought and salt.

It is reported that one of the most important reasons why free proline level increases is because of abscises acid hormone effect on light processes during proline metabolism. Existing of energetic components resulted from photosynthesis due to proline synthesis simulation. Bandurska and Jozwiak (2010) stated that in studying the effect of imposing drought in *Lolium Perenne*, *Festucarubral* species synchronized with decreasing relative water content, observed more accumulation from proline, while in blank, proline content in stress duration had no changes. Girousse *et al.* (1996) also stated that decreasing of turgor pressure is the first reason for proline accumulation under drought stress. Amino acid proline resulted from proteins degradation whose response to drought stress due to its compatibility with osmosis. Many researchers reported that its accumulation is during drought experience. Under condition of stress, plant cells have the ability to prohibit decreasing of water. Usually, plants resist these stresses by accumulation of compatible solution such as proline reaction, which can bear environmental stress. These solutions can aggregate in concentrations without damaging the metabolism. In many plant species, free proline accumulates in response to vast range of stresses such as drought and salt. There exist a lot of relationships between proline accumulation and resistance to stress. The level of increase in the proline concentration in response to water stress varied between the rice varieties.In proline accumulates under stress also supplies energy for survivor and growth and thereby helps the plants to tolerate stress. Anjum *et al.* (2011) reported that proline accumulation was the first response of plants exposed to water-deficit stress in order to reduce injury to cells. Progressive drought stress induced a considerable accumulation of proline in water stressed maize plants. There exist a lot of relationships between proline accumulation and resistance to stress (Yokota *et al.*, 2006) ccumulation of proline content under water stress indicates accumulated proline might act as a compatible solute regulating and reducing water loss from the plant cell during water deficit and play important role in osmosis balance (Fedina *et al.*, 2002). Thus, the proline content is a good indicator for screening drought tolerant varieties in water stress condition (Bayoumi *et al*., 2008; Rahdari and Hoseini 2012).

Vijrabhaya *et al. (*2000) stated that the osmotic adjustment during the water stress, the proline accumulation is also considered to be involved in the protection of the enzymes and cellular structure and to act as a free radical scavenger. Proline accumulates under stress also supplies energy for survivor and growth and thereby helps the plants to tolerate stress condition. Thus, the proline content is a good indicator for screening drought tolerant varieties in water stress condition (Bayoumi *et al*., 2008, Rahdari and Hoseini, 2012). Barsa (1997) reported that plants in response to environmental stresses had synthesis or accumulation materials such as enzymes, proteins, mineral material and amino acid.

vii. Morphological, anatomical and cytological changes

In the majority of the plant species, water stress is linked to changes in leaf anatomy and ultrastructure. Shrinkage in the size of leaves, decrease in the number of stomata; thickening of leaf cell walls, cutinization of leaf surface, and underdevelopment of the conductive system - increase in the number of large vessels, submersion of stomata in succulent plants and in xerophytes, formation of tube leaves in cereals and induction of early senescence are the other reported morphological changes. The root-to-shoot ratio increases under water-stress conditions to facilitate water absorption and to maintain osmotic pressure, although the root dry weight and length decrease as reported in some plants like sugar beet and Populus. Higher root-to-shoot ratio under the drought conditions has been linked to the ABA content of roots and shoots. Water stress is linked to decrease in stem length in plants such as Albizzia, Erythrina, Eucalyptus and Populus with up to 25% decrease in plant height in citrus seedling. Decreased leaf growth, total leaf area and leaf-area plasticity were observed under the drought conditions in many plant species, such as peanut and Oryza *sativa*. Although water saving is the important outcome of lower leaf area, it causes reduced crop yield through reduction in photosynthesis. Decrease in plant biomass consequences from the water deficit in crop. plants, mainly due to low photosynthesis and plant growth and leaf senescence during the stress conditions. However, in some plants, higher yield was reported under-water deficit condition.

Viii. Improving pigments synthesis.

Water stress, among other changes, has the ability to reduce the tissue concentrations of chlorophylls and carotenoids (Havaux, 1998; Kiani *et al.,* 2008), primarily with the production of ROS in the thylakoids (Niyogi, 1999; Reddy *et al.*, 2004). However, reports dealing with the strategies to improve the pigments contents under water stress are entirely scarce. The available reports show that exogenous application of brassinolide, uniconazole and methyl jasmonate improved the drought tolerance with increased activities of SOD, CAT and APX, ABA and total improved carotenoid contents in maize, while methyl jasmonate brought about a threefold increase in the β-carotene synthesis as well as degradation of the cholorophyll contents in the epidermal peels. Likewise, an important role of tocopherols, lipid-soluble antioxidant in chloroplasts, has been envisioned in improved pigments contents under stress conditions in the photosynthetic organisms including tobacco (Tanaka *et al*., 1999) and *Arabidopsis thaliana* and *Synechocystis* sp. PCC6803 (DellaPenna & Pogson, 2006). These data warrant concerted efforts on the either the induction of pigment synthesis or modification of pigment biosynthesis pathways for enhanced drought tolerance in plants.

Kuixian *et al*. (2012) stated that water status is the main factor affecting rice production. In order to understand rice strategies in response to drought condition in the field, the drought-responsive mechanisms at the physiological and molecular levelswere studied in two rice genotypeswith contrasting susceptibility to drought stress at reproductive stage. In case of rice water-deficit may occur early in the growing season or any time from flowering to grain filling and the intensity of the stress depends on the duration and frequency of water-deficit (Wade et al., 1999). Drought stress suppresses leaf expansion,tillering andmidday photosynthesis (Kramer and Boyer, 1995) and reduces photosynthetic rate and leaf area due to early senescence. Rice-growing areas span the tropics, subtropics, semi-arid tropics and temperate regions of the world. More than 90% of the world's rice is grown and consumed in Asia. The predominantly rice-growing areas in Asia are often threatened by severe abiotic stresses, of which the most common is drought. a reduction in grain yield under drought condition. The phenology, particularly at the reproductive stage, is a major determinant of grain yield in rain fed lowland rice, and any attempt to screen for drought resistance needs to consider variation at reproductive stage (Pantuwan et al., 2002). Therefore, to identify traits that confer drought resistance from the different genotypes with contrasting drought tolerance will bring us novel insights for future breeding of rice. Rice is most susceptible to drought stress at the reproductive stage (Pantuwan et al., 2002). Dramatic reduction of grain yield occurs when drought stress coincides with the irreversible reproductive processes (Pantuwan *et al.,* 2002). Meanwhile, fundamental research has provided significantinsights in the understanding of the physiological and molecular responses of plants to water deficits, but there is still a large gap between yields in optimal and stress conditions (Park *et al.,* 2011). Minimizing the 'yield gap' and increasing yield stability under different stress conditions are of strategic importance in guaranteeing food for the future. Rice is a notoriously drought-susceptible crop due in part to its small root system, rapid stomatal closure and little circular wax during mild water stress (Hirasawa, 1999). Reduction of photosynthetic activity, accumulation of organic acids and osmolytes and changes in carbohydrate metabolism, are typical physiological and biochemical responses to drought stress (Tabaeizadeh, 1998).

Water deficit also increases the formation of reactive oxygen species (ROS) resulting in lipid peroxidation, protein denaturation and nucleic acid damage with severe consequences on overallmetabolism (Hansen *et al.,* 2006). The comparison of upland rice and lowland rice appears to be a paradigm for studying the molecular mechanisms in drought resistance. The understanding of the biological function of the novel genes is a more difficult proposition than obtaining just the sequences. This challenge is because the amount of information on amino acid sequences of known proteins in the database does not match the wealth of information on nucleotide sequences being generated through genome projects. Hence, an understanding of gene expression on a global scale would lend considerable insight into the molecular mechanisms of plant development. Comparative analysis of drought-responsive mechanisms between drought-tolerant and drought-sensitive rice cultivars will unravel novel regulatory mechanisms involved in stress tolerance.

2.5 Effects of drought stress on biochemical characteristics

i. Anthocyanin cotent

Photosynthetic pigments are important to plants mainly for harvesting light and production production of reducing powers. Drought effects on plant and pigment decreased under pre-anthesis drought stress treatment in wheat reported by Edward and Wright (2008).

Schwinn and Davies (2004), Andersen and Jordheim (2006), Hatier and Gould (2007) found that anthocyanins usually appear red in leaf cells, but depending on their chemical nature and concentration, the vacuolar pH, and interactions with other pigments, they can result in pink, purple, blue, orange, brown, and even black leaf colours. Davies (2004) many of the published articles on plant defensive colouration have assumed red foliage to be the outcome of the production of anthocyanins, this despite the fact that other pigments carotenoids, betalains, apocarotenoids, condensed tannins, quinones and phytomelanins – can also contribute to plant vermilion . Scott (1999) stated that anthocyanin were water soluble pigments found in all plant tissues. Krol *et al*. (1995), Burger and Edwards (1996) and Tevini (1994) found that anthocyanins had been located in the root, shoot and leaves. Anthocyanins had been found in or just below the upper epidermis of leaves. Anthocyanines often appear at specific developmental stages and may be induced by a number of environmental factors including visible and UVB radiation, drought and cold temperatures. Anthocyanin content was increased under water stress condition. Leaf accumulates anthocyanins under drought conditions and the colour increased as the intensity of water deficit condition.

ii. Stomata conductance (Mmol/m2s)

Stomata conductance, transpiration and photosynthesis are affected due to water stress. Guo et al. (2006) stated that stomata conductance, transpiration and photosynthesis were affected due to water stress. A direct correlation between the xylem ABA content and stomatal conductance has been demonstrated. Changes in plant hydraulic conductance, plant nutritional status, xylem sap pH, farnesyl tranferase activity, leaf-to-air vapor pressure deficit and decrease in relative water content are other factors working in   stomatal regulation plants. Although CO2 assimilation and net photosynthesis decreases due to stomatal closure but attainment of low transpiration rate and prevention of water losses from leaves is a good tradeoff for survival in exchange of growth. Stomata can completely close in mild to severe stress depending on plant species, and tolerant species control stomata opening to allow some carbon fixation and improving water-use efficiency. The increased stomatal resistance under stress levels indicates the efficiency of a species to conserve water. Plants display a variety of physiological and biochemical responses at cellular and whole-organism levels towards prevailing drought stress, thus making it a complex phenomenon. CO_2 assimilation by leaves is reduced mainly by stomatal closure, membrane damage and disturbed activity of various enzymes, especially those of CO_2 fixation and adenosine triphosphate synthesis. Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange (Jaleel et al., 2008a-d; Farooq *et al*., 2008). Earlier efforts emphasized traits like high chlorophyll at heading (Hede *et al.,* 1999), high leaf conductance, high pubescence and peduncle volume for drought tolerance in wheat. The number of xylem vessels in the stem also plays an important role in the stress tolerance mechanism.

Hirasawa (1999) reported that stomata conductance decreased in all the varieties of rice as the intensity of water deficit increased. Rice is a notoriously drought-susceptible crop due in part to its small root system, rapid stomatal closure and little circular wax during mild water stress. Stomata conductance decreased in the varieties of rice as under drought condition. Zulkarnain *et al.* (2009) reported that the decline in stomatal conductance was faster after 6 days of stress development than under well watered condition. Stomatal conductance of MR220 and MUDA declined more rapidly than in other varieties; however, after 10 days of soil drying, all varieties (except for Jawi Lanjut) showed a considerable decrease in stomata conductance. Jawi Lanjut exhibited a higher stomatal conductance under stress than the other varieties under stress although it also had lower values after 6 days of stress treatment. Wheather drought mainly limits photosynthesis through stomatal closure or through metabolic impairment reported by Lawson *et al*. (2003); Anjum *et al.* (2003). Farooq *et al*. (2009) found that both stomatal and non-stomatal limitation was generally accepted to be the main determinant of reduced photosynthesis under drought stress.

Dingkuhn *et al*. (1989), reported that growth and production of tropical upland rice is often impeded by drought. A drought-susceptible semidwarf (IR20) and drought-resistant traditional (Azucena) rice were grown in a dryland field experiment with sprinkler irrigation during the dry season in the Philippines. Differential irrigation was imposed for 11 days during vegetative growth using a line source sprinkler. Net photosynthesis, leaf conductance, transpiration, leaf rolling and leaf water potential were determined during the stress cycle at pre-noon and afternoon, with all measurements on the same leaf. No varietal differences in maximum photosynthetic rate and in the relationship between photosynthesis and leaf conductance were observed. In both rices, partial stomatal closure and nonstomatal inhibition reduced assimilation rates in the afternoon.

iii. Leaf temperature

During photosynthesis leaves perform metabolic actions and physiologic activities. These actions increase its temperature. Leaf temperature of different rice genotypes under drought condition was different. Before drought condition leaf temperature was high and after stress was low. Siddique *et al.* (1999) reported that drought effects on the water relations of four wheat (*Triticum aestivum* L.) cultivars were evaluated. Four cultivars, Kanchan, Sonalika, Kalyansona, and C306, were grown in pots and subjected to four levels of water stress at vegetative or anthesis stages or both drought stressed plants displayed higher canopy temperature than well-watered plants at both vegetative growth and anthesis growth stages. Successive stresses at both developmental stages raised the canopy temperature much higher than in plants stressed only once. Lower leaf temperature was associated with a higher photosynthetic rate. Exposure of plants to drought led to noticeable decreases in leaf water potential and relative water content with a concurrent increase in leaf temperature.

Few laboratory studies have compared actual and predicted changes in leaf temperatures because of difficulty in characterizing the nature of heat exchange. Siddique *et al*. (1999) also reported that leaf temperatures in drought stressed plant were higher than in well-watered plants at both vegetative growth and anthesis growth stages. The plants that showed a lower leaf temperature also showed a higher photosynthetic rate. Lower leaf temperature was associated with a higher photosynthetic rate. Leaf temperatures of Sonalika and Kalyansona were significantly lower than that of C306. Stress treatments at anthesis showed C306 and Sonalika to have higher leaf temperature than Kanchan and Kalyansona. The lower photosynthetic rate in plants acclimated to a higher temperature. Leaf temperatures of Sonalika and Kalyansona were significantly lower than that of C306. Stress treatments at anthesis showed C306 and Sonalika to have higher leaf temperature than Kanchan and Kalyansona.

iv. Relative water content (RWC)

RWC was determined to give indication on the plant water status under drought condition. Sehonfeld *et al.* (1988) stated that RWC declined with increasing drought stress. Sinclair and Ludlow (1985) proposed that RWC was better measure for plant's water status. RWC decreased with water stress in all the genotypes of Common Bean (Korir *et al*., 2006). Several researchers reported that RWC of different crops was the highest in the morning and gradually decreased thereafter (Begum and Paul, 1992; Paul and Aman, 2000). Plants grown under water deficit conditions showed a lower RWC than those grown under non stress conditions. Relative water content was higher in the morning, while decreased at noon.

Lawlor & Cornic (2002) stated that the foliar photosynthetic rate of higher plants is known to decrease as the relative water content and leaf water potential decreases. Farooq *et al*. (2009) stated that photosynthetic pigments are important to plants mainly for harvesting light and production production of reducing powers. Both stomatal and non-stomatal limitation was generally accepted to be the main determinant of reduced photosynthesis under drought stress stated by Farooq *et al*. (2009). Reddy (2004) also found that the limitation of photosynthesis under drought through metabolic impairment is more complex phenomenon than stomatal limitation and mainly it is through reduced photosynthetic pigment contents in sunflower. Proline levels were more closely related to the decrease in RWC than in water potential (Naidu *et al.,* 1992; Iannucci, 2000 and Stoyanov, 2005). This implies that the metabolic differences among cultivars may reflect differences in water status achieved, rather than metabolic differences at a given water status.

v. ABA accumulation

Closure of stomata and induction of the expression of multiple genes involved in defense against the water deficit are known functions of ABA. Peleg *et al.* (2011), found that in case of rice shoot accumulate proline in water stress condition and also ABA accumulate in water stress condition. Several factors involve like ABA concentration, age of plant, physiological status of plant, method of application. Cornic and Massacci (1996) and Mwanamwenge *et al*. (1999), reported that the effect of stress is usually perceived as a decrease in photosynthesis and growth. Phytohormones are known to play crucial role in plant growth and development reported by Beaudoin *et al*. (2000). ABA is one of the stress hormones that plays a critical role in regulating plant water status and osmotic stress tolerance (Luan, 2002; Zhu, 2002; Bonetta and Mccourt, 1998; Mahajan and Tuteja, 2005) as well as various aspects of growth by regulating dormancy, maturation and adaptation to abiotic stresses (Beaudoin *et al.,* 2000., Zhang *et al.* 2006). ABA can act as a long distance communication signal between water deficit roots and leaves by inducing the closure of stomata and reducing water loss through transpiration (Morgan, 1990; Davies and Zhang, 1991) and might promote grain filling through regulating the sink's strength reported by Yang *et al.* (1999). The plant hormone ABA accumulates under-water deficit conditions and plays a major role in response and tolerance to dehydration. The amount of ABAs in xylem saps increases substantially under reduced water availability in the soil, and this results in an increased ABA concentration in different compartments of the leaf. Another well-known effect of drought in plants is the decrease in PM-ATPase activity. Low PM-ATPase increases the cell wall pH and lead to the formation of ABA- form of abscisic acid. ABA- cannot penetrate the plasma membrane and translocate toward the gourd cell by the water stream in the leaf apoplasm. High ABA concentration around guard cell results in stomata closure and help to conserve water. RWC decreased with water stress in all the tested genotypes. Similar observations have been repotted in Common Bean (Korir *et al*., 2006). The plant hormone ABA accumulates under-water deficit conditions and plays a major role in response and tolerance to dehydration. Closure of stomata and induction of the expression of multiple genes involved in defense against the water deficit are known functions of ABA.

vi. Mineral nutrition

Water stress also affects plant mineral nutrition and disrupts ion homeostasis. Calcium plays an essential role in structural and functional integrity of plant membrane and other structures. Decrease in plant Ca2+ content was reported in many plants. Water Stress approximately 50% decrease in Ca2+ in drought stressed maize leaves, while in roots Ca2+concentration was higher compared to control. Potassium is an important nutrient and plays an essential role in water relation, osmotic adjustment, stomatal movement and finally plant resistance to drought. Decrease in K+ concentration was reported in many plant species under water deficient condition, mainly due to membrane damage and disruption in ion homeostasis. K+ deficient plant has lower resistance to water stress. Nitrogen metabolism is the most important factor that influences plant growth and performance. Disruption in Nmetabolism is a crucial in-plant injury under the water deficit conditions. Some studies showed the reduction of nitrate uptake and decrease in nitrate reductase activity under water stress. Plants display a range of mechanisms to withstand drought stress. The major mechanisms include curtailed water loss by increased diffusive resistance, enhanced water uptake with prolific and deep root systems and its efficient use, and smaller and succulent leaves to reduce the transpirational loss. Among the nutrients, potassium ions help in osmotic adjustment; silicon increases root endodermal silicification and improves the cell water balance. Low-molecular-weight osmolytes, including glycinebetaine, proline and other amino acids, organic acids, and polyols, are crucial to sustain cellular functions under drought. Plant growth substances such as salicylic acid, auxins, gibberrellins, cytokinin and abscisic acid modulate the plant responses towards drought. Polyamines, citrulline and several enzymes act as antioxidants and reduce the adverse effects of water deficit.

vii. Sugar content

Usman *et al*. (2013) stated that drought affected the growth and reduced the fresh shoot and root weights, root and shoot lengths and also carotenoids. Drought affected the rate of photosynthesis, accumulation of total soluble sugars, and the photosynthetic pigments. Ahmadi and Baker (1999) reported that ABA is involved in osmolyte regulation under moisture stress conditions. Mahajan and Tuteja (2005) reported that under severe drought, growth was inhibited by high concentration of ABA and sugar, whereas low concentrations promote growth. ABA applications enhanced the percentage recovery of drought plants. Increased rates of photosynthesis and higher chlorophyll content might cause accumulation of sugars due to ABA treatments (Dong *et al.*, 1995 and Ndung *et al*., 1997). Drought tolerance in plants is enhanced by ABA treatment possibly due to the accumulation of osmolytes such as sugars. Rewatering drought stressed plants may change hormonal concentrations (balance) and enhance the remobilization of pre-stored carbon in vegetative tissues to the grains of rice plant reported by Yang (2001). Wade *et al*. (1999) found that water-deficit may occur early in the growing season or any time from flowering to grain filling and the intensity of the stress depends on the duration and frequency of water-deficit.

2.6 Effects of drought stress on yield component

i. Total dry matter

Fetching greater harvestable yield is the ultimate purpose of growing crops. The crop species show great differences for final harvestable yield under drought stress. In early plantings of sunflower, the yield increase was associated with both an increase in grain number and in individual grain weight.The partitioning of dry matter to the head is critical in the process of yield determination in water stressed parsley (Petropoulos *et al*., 2008).The effect of water deficits on harvest index of sunflower is complex due to interactions between the timing and intensity of the stress relative to the developmental processes that determine the components of yield. Exposure of sunflower plants to drought stress at bud initiation stage was more detrimental to seed and biological yield than at seed filling stage (Prabhudeva *et al*., 1998). Hossain (2001) and Lum (2014) reported that in the activities of shoot length, root length and dry matter yield and biochemical parameters were decreases under drought condition. Fukai and Cooper (1995) reported that under low-moisture stress, traits that help the plant gain access to additional reserves were more important than traits associated with reducing moisture losses. Mayaki *et al.* (1976) reported that drought affects photosynthesis directly and indirectly and consequently dry matter production and its allocation to various plant organs. So, total dry matter production was decreased under drought condition. Decreased total dry matter under lower soil moisture might be due to inhibited photosynthesis. Zubaer *et al.* (2007) reported that different moisture levels and rice genotypes interacted significantly for producing total dry matter per hill. Total dry matter per hill was maximum at 100% FC followed by 70%FC and it was lowest at 40% FC in all the rice genotype at all growing stages. So, total dry matter production was decreased with decreasing soil moisture levels. Decreased total dry matter under lower soil moisture might be due to inhibited photosynthesis. Flowering and maturity showed similar pattern in production total TDM. The results also showed that water stress affects more at flower and maturity stages than that at booting stages. Acosta-Gallegos and Adams (1991) reported that leaf expansion rate and crop growth rate at mid-pod-filling were greatly reduced by drought stress, resulting in significant reductions in total dry matter (DM).

ii. Shoot dry weight

Mohammadian *et al*., (2005) explained that mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes. Drought stress affects the growth, dry matter and harvestable yield in a number of plant species. Drought stress affects the growth, dry matter and harvestable yield in a number of plant species. Water stress gradually causes reduction in the shoot weight. Mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes. Lafitte *et al*. (2007) reported that a moderate stress tolerance in terms of shoot dry mass plants was noticed in rice. Generally, under stress condition, crop yield is related with dry matter.

iii. Root dry weight

Islam *et al.* (2004) reported that root dry weight of French bean at harvest remarkable increased with the decreased in the moisture level. Asch *et al.* (2005) advocated that drought is a major stress affecting rainfed rice systems. Root characteristics such as root length density, root thickness, changes in root dry matter and rooting depth and distribution have been established as constituting factors of drought resistance. Deep rooting cultivars are more resistant to drought than those with shallow root systems, changes in root dry matter and rooting depth. Sikuku *et al.* (2010), reported drought tolerant cultivars have deep and thick roots. The thick roots are positively correlated with xylem vessel area, which are vital to the conductance of water from soil to the upper parts of the plants to meet the evaporative demand.

iv. Panicle dry weight

Water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which results low in gain weight and increases empty grains (RRDI, 1999).Zubaer *et al.* (2007) who stated that reduced grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to soil moisture stress. The results also agree with Castilo *et al.* (1987) and Hossain (2001). Tsuda and Takami (1991) observed that water stress reduced grain weight. Islam *et al*. (1994) observed that yield losses resulting from water deficit are particularly severe when drought strikes at booting stage.

v. Weight of thousand grains

Zubaer *et al* (2007) reported that in rice genotypes, the largest grain was found at 100% FC, followed by 70% FC, and the smallest was found at 40% FC. The results showed that 1000 grain weight was reduced with reduced soil moisture levels. Lower soil moisture might decrease translocation of assimilates to the grain which lowered grain size. But the degree of reduction in 1000-grains size weight was different in different genotypes. Percent reduction was lower in Binadhan 4(4.14 to 6.37%) than in Basmoti (6.75to 12.5%) and RD 2585 (4.57 to 14.64%).

Islam *et al.* (1994), RRDI (1999), O'Toole *et al* (1979) and Tsuda and Takami (1991) also stated that water stress reduced grain weight.

vi. Grain yield

Stress during grain filling stage decreased grain weight. Begum (1992) showed that water stress after flowering decreased the individual grain weight. Tsudo and Takami (1991) advocated that water stress reduced grain weight. O'Toole *et al.* (1979) reported that stress during grain filling stage reduces the weight of individual grain weight. The reproductive stages such as panicle initiation, panicle development, flowering and enthesis, meiotic development of gametes, fertilization and grain filling were sensitive to water stress and causes spikelet sterility and loss of yield potential. Drought also reduced potential spike number and decreased translocation of assimilates to the grains at or before panicle initiation.

Zubaer *et al.* (2007) reported that different soil moisture levels and rice genotypes interacted significantly for grain yield per hill. All the genotypes produced the highest grain yield per hill at 100% FC followed by 70% FC and the lowest yield per hill was obtained at 40%FC. So, it was observed that grain yield per hill decreased in decreasing soil moisture level. Reduced grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to soil moisture stress. Water stress reduced the head diameter, 100- achene weight and yield per plant in sunflower. There was a negative correlation of head diameter with fresh root and shoot weight, while a positive one between dry shoot weight and achene yield per plant under water stress (Tahir *et al.* 2002).Water stress for longer than 12days at grain filling and flowering stage of sunflower (grown in sandy loam soil) was the most damaging in reducing the achene yield in sunflower (Reddy *et al*., 2004), seed yield in common bean and green gram (Webber *et al*., 2006), maize (Monneveux *et al*., 2006) and *Petroselinum crispum* (Petropoulos *et al*., 2008). Blum (2000) discussed genotypic variation for the ability to store and mobilizes carbohydrates for seed filling during terminal moisture stress.Differences in the combining ability of genotypes for this trait contribution were observed.

vii. Number of filled grain

Decreased filled grains per panicle under lower soil moisture levels might be due to inhibition of translocation of assimilate to the grains due to moisture stress. Hossain (2001) and O'Toole *et al.*

(1979) reported that stress during grain filling stage reduces the weight of individual grain. Bakul (2009) reported that stress at vegetative stage gave the lowest number of filled grain per panicle. Islam *et al.* (1994) stated that moisture stress affected grain formation and gradually increased sterility. Yoshida (1985) reported that water stress reduced number of filled grain per panicle. Decreased filled grains per panicle under lower soil moisture levels might be due to inhibition of translocation of assimilate to the grains reported by Hossain (2001). The RRDI (1999) stated that stress during grain filling stage decreased grain weight. Tsudo and Takami (1991) advocated that water stress reduced grain weight. Water 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 to assist plant growth under severe drought conditions in pearl millet (Shao *et al*., 2008). Tuong *et al*. (1993), stated that the reproductive stages such as panicle initiation, panicle development, flowering and enthesis, meiotic development of gametes, fertilization and grain filling were sensitive to water stress.

viii. Number of unfilled grain

Hossain (2001), Yamboo and Ingram (1988) and Begum (1990) observed that water stress after flowering, increased the number of empty spicklets per panicle. Increased unfilled grains per panicle under lower soil moisture level might be due to inactive pollen grain for dryness, incomplete development of pollen tube; insufficient assimilates production and its distribution to grains. Zubaer *et al*.(2007)stated that *r*educed grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to soil moisture stress. In some other studies on maize, drought stress greatly reduced the grain yield, which was dependent on the level of defoliation due to water stress during early reproductive growth (Kamara *et al*. 2003; Monneveux *et al*. 2006). Water stress reduces seed yield in soybean usually as a result of fewer pods and seeds per unit area. In water stressed soybean the seed yield was far below when compared to well-watered control plants (Specht *et al*., 2001). O' Toole and Moya (1981) also reported that increased unfilled grains per panicle under lower soil moisture level might be due to inactive pollen grain for dryness, incomplete development of pollen tube; insufficient assimilates production. Begum (1990), who observed that water stress after flowering, increased the number of empty spicklets per panicle. Increased unfilled grains per panicle under lower soil moisture level might be due to inactive pollen grain for dryness, incomplete development of pollen tube; insufficient assimilates production and its distribution to grains. Water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which results low in gain weight and increases empty grains (RRDI, 1999). Islam *et al.* (1994), who stated that moisture stress affected grain formation and gradually increased sterility. O'Toole *et al.* (1979) also reported that stress during grain filling stage reduces the weight of individual grain.

ix. Specific leaf area (SLA)

*Vile et al. (2005) advocated that s*pecific leaf area (SLA) is defined as the ratio of leaf area to dry mass. Specific leaf area can be used to estimate the reproductive strategy of a particular plant based upon light and moisture (humidity) levels, among other factors. Specific leaf area is one of the most widely accepted key leaf characteristics used during the study of leaf traits. Drought and water stress have varying effects on specific leaf area. In a variety of species, drought decreases specific leaf area. For example, under drought conditions, leaves were, on average, smaller than leaves on control plants.This is a logical observation, as a decrease in surface area would mean that there would be fewer ways for water to be lost. Species with typically low specific leaf area values are geared for the conservation of acquired resources, due to their large dry matter content, high concentrations of cell walls and secondary metabolites, and high leaf and root longevity. Marron *et al.* (2003) stated that in some other species, such as Poplar trees, specific leaf area will decrease overall, but there will be an increase in specific leaf area until the leaf has reached its final size. After the final size has been reached, the specific leaf area will then begin decreasing. Specific leaf area values in plants under water limitation. An example of increasing specific leaf area values as a result of drought stress is the birch tree species (Laureano et al. 2008). Birch tree specific leaf area values significantly increased after two dry seasons, though the authors did note that, in typical cases, lowered specific leaf area values are seen as an adaptation to drought stress. Leaf area index refers to the leaf area (one side) per unit area of land. The importance of this unit of measure is in relation to interception of light for maximum growth. Liu *et.al.* (2004) stated that drought stress significantly decreased SLA in severe water stress, this adaptive mechanism of cowpea to water stress helps in reducing water loss from the evaporative surfaces. Specific leaf area is one of the most widely accepted key leaf characteristics used during the study of leaf traits. In some other species, such as Poplar trees, specific leaf area will decrease overall, but there will be an increase in specific leaf area until the leaf has reached its final size. After the final size had reached, the specific leaf area will then begin decreasing. Specific leaf area can be used to estimate the reproductive strategy of a particular plant based upon light and moisture (humidity) levels.

CHAPTER 3

MATERIALS AND METHODS

The overall research work was consisted of three pot culture experiments which were conducted under the rain protected polyethyline shelter in the field and laboratory that were done within the year from 2012 to 2014. Data were collected on different morpho-physiological and biochemical characters. The materials used and methods followed during the conduction of research have been described below very briefly under the following headings:

3. 1 Site description

The experiment was conducted at the Agricultural Botany research field of Sher-e-Bangla Agricultural University, Dhaka -1207. Geographically the experimental site was situated at $23^{o}77'$ N latitude and $88^{o}40'$ E longitude at an altitude of 8.6 meter above sea level (Anon, 2004).The experimental site belongs to the Agro-ecological zone (Appendix I) of “The Modhupur Tract”, AEZ-28 (Anon, 1988a). The soil of this region 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., 1988b).

3. 2 Climate and duration

The experimental sites were characterized by sub-tropical climate, high temperature, high relative humidity and heavy rainfall with occasional gusty winds in April-July (Kharif season-1) and scanty/ insufficient rainfall. Moderately low temperature during the Rabi season (November-March). The meteorological data during the experimental period (September-October, 2012 to February- July, 2013 and 2014) were presented in Appendix II. The duration of the experiment was September - October, 2012 to February-July, 2014.

3. 3 Soil

The soil of the experimental field of SAU belongs to Tejgaon series under Modhupur Tract. The soil of the experimental site belongs to the general soil type. The soil of the experimental pots was red brown terrace soil (cultivated long time). The textural class of its soil was silty loam. Soil pH ranges from 5.4-5.9, organic matter 1.09% and N, P, K, S was 0.07%, 8.5ppm, 28 ppm, 28 ppm respectively. (Source, Depatment of soil science, Sher-e-Bangla Agricultural University, Dhaka). The experimental area was flat having available irrigation and drainage system and above flood level.

3.4 Plant materials

A total of ten BRRI materials as BR21, BR24, BRRI dhan42, BRRI dhan43, BRRI dhan48, BRRI dhan55 and lines BR6976-11-1, OM1490, BR6976-2B-15 and tolerant check (Hashikalmi, Dharial were collected from Genetic Resource and Seed Division, Bangladesh Rice Research Institute (BRRI).

SL. No	Genotypes	Source of collection	Remarks
1	BR21	Bangladesh Rice Research Institute (BRRI)	HYV
2	BR24	BRRI	HYV
3	BRRI dhan42	BRRI	HYV
4	BRRI dhan43	BRRI	HYV
5	BRRI dhan48	BRRI	HYV
6	BRRI dhan55	BRRI	HYV
7	OM1490	BRRI	Inbreed line
8	BR6976-2B-15	BRRI	Inbreed line
9	BR6976-11-1	BRRI	Inbreed line
10	Hashikalmi	BRRI	Localvariety
11	Dharial	BRRI	Localvariety

3.5 Description of genotypes

According to BRRI Annual Report 1988-1989 to 2011-12, the descriptions were given below:

1.BR21 (Niamat)

BR21 (Niamat) is a modern variety developed by BRRI in 1986. It is recommended for Aus season. Growth duration is about 110 days. Grain characteristics are medium and coarse. Average produces yield of 3.0 t/ha and this variety has some ability to avoid water stress through elongated roots.

2. BR24 (Rahamat)

BR24 (Rahamat) is a modern variety developed by Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur, Bangladesh in 1992. It is recommended for Aus season. Its growth durationis about 105 days. Grain characteristics are medium long and fine. The grains are medium bold with light golden husks and kernels are white in colour. Average produces yield of 3.5 t/ha. This variety has some ability to avoid water stress through elongated roots.

3. BRRI dhan42

BRRI dhan42 is a modern variety developed by BRRI in 2004. It is recommended for Aus season (March- July). Its growth duration is about 100 days. Grain characteristics are medium, bold and white. Direct seeded (DS) upland rice. Average produces yield of 3.5 t/ha. This variety has some ability to avoid water stress through elongated roots that is moderately drought tolerant. Thousand grains weight 15g. Plant height 93.69-105 cm. Number of panicle/ plant 7.69.

4. BRRI dhan43

BRRI dhan43 is a modern variety developed by BRRI in 2004. It is recommended for Aus seasons. Its growth duration is about 110 days. Grain characteristics are medium, and DS upland. On an average it produces yield of 3.5 t/ha. This variety has some ability to avoid water stress through elongated roots. Thousand grains weight 23.96 g. Plant height 100-104 cm. Protein content 11.7%. Number of panicle per plant 8.69.

5. BRRI dhan48

BRRI dhan48 is modern variety developed by BRRI in 2008. It is recommended for Aus season. Its growth duration is about 110 days. Grain characteristics are medium bold and white. On an average it produces yield of 5.5 t/ha. This variety has some ability to avoid water stress through elongated roots. Thousand grains weight 23.37 g. Plant height 103-105 cm. Protein content 11.6%. Number of panicle per plant 7.8.

6. BRRI Dhan55

BRRI dhan55 is a salt tolerant variety developed by BRRI in 2011. It is recommended for Aus and Boro season. Its growth duration is about 105-110 days. Grain characteristics are long and thin or medium slender. On average it produces yield of 4.0 t/ha. Majority farmers were interested to grow BRRI dhan55 for very attractive yield and grain size with reasonably shorter growth duration. Thousand grains weight 15.8 g. Plant height 115 cm. Protein content 11.6%.

7. OM1490

OM1490 lines are good yielder, grain yield 3.8-4 (t/ha). Thousand grain weight 22.75-25.3 g. Plant height 94-110 cm. OM1490 matured in the shortest period (101 days) whereas other two entries matured in 106 days. That means OM1490 is five days earlier with a slightly higher yield than the other two advanced lines. OM1490 is also four days earlier than the standard check variety BRRI dhan43.

8. BR6976-2B-15

This lines are good yielder that is yield 3.3 ton/ ha. Plant height 76 cm. and growth duration is about 114 days.

9. BR6976-11-1

This lines are good yielder that yield 3.7 ton/ ha. Plant height 85.1cm. Its growth duration is about 115 days.

10. Hasikalmi

Hashikalmi is a local variety. It is recommended for Aus season. Its growth duration is about 95-108 days. Grain characteristics are medium, bold and black colour. On an average it produces yield of 2.3 t/ha. This variety has some ability to avoid water stress through elongated roots. Plant height 124.5cm.

Dharial

Dharial is a local variety developed by BRRI. It is recommended for Aus season. Its growth duration is about 100 days. Grain characteristics are medium and black colour. On an average it produces yield of 2.5 t/ha and plant height is high. This variety has some ability to avoid water stress through elongated roots.

The experiment was conducted at the Agricultural Botany research field of Sher-e-Bangla Agricultural University. A total of eleven BRRI materials as BR21, BR24, BRRI dhan42, BRRI dhan43, BRRI dhan48, BRRI dhan55 and lines BR6976-11-1, OM1490, BR6976-2B-15 and two water stress tolerant varieties Hashikalmi, Dharial collected from Genetic Resource and Seed Division, Bangladesh Rice Research Institute (BRRI).

Seed treatment

Seeds of uniform size and shape of each genotype were treated with Bavistin 5gm for 20 minutes. The solution was prepared by dissolving 5 gm of Bavistin in 1/2 liter of water. Treated seeds were place in the Petridis with water. Pre-soaked six sprouted seeds were grown under rain protected polyethylene shelter under natural conditions in root elongation tube on September 19, 2012 (Plate 1.1).

Experiment -1

SCREENING OF RICE GENOTYPES FOR THEIR DEEP ROOTING ABILITY.

The objectives of this study were as follows

To find out the response of root to water stress

3.6.1 Experimental duration and design

Seeds were grown in root elongation tube on September 19, 2012 (Plate 1.1) to study for their deep rooting ability. Plants were grown in a rain protected polyethylene shelter under natural light conditions in root elongation tube. The experiment was laid out in Randomized Complete Block Design (RCBD) considering four replications. Eleven rice genotypes were used. The total number of root elongation tubes was 44. The layout of the experiment has been shown in Appendix III. The seedlings of 30 days were used for data collection in this experiment.

3.6.2 Preparation of root elongation tube

Root elongation tube was 75 cm long and 15 cm in diameter. Perforated polyethylene tubes were filled up with sand (60): soil (40) mixture. Whole soil was mixed with Yoshida culture solution (Yoshida *et al.* 1976) so that the soil became wet but not like wet clay (BRRI, 2012). Yoshida's culture solution was used as feed of plant.

3.6.3 Preparation of Yoshida's culture solution

Yoshida's culture solution was prepared from the stock solution based on the formula of Yoshida *et al.,* (1976). This solution contains macro and micro elements of plant. Macro elements were NaH_2PO_4 (80.60 g), NH_4NO_3 (182.8g), K_2S0_4 (142.8g), $MgS0_4$ (648g), $CaCl_2$ (177.2g) and micro elements were Mn (3.00 g), Mo (0.148 g), B (1.868 g), Zn (0.070 g), Cu (0.062 g), Fe (15.40 g) with 100ml H_2S0_4. Yoshida solution mixed with soil and sand. Optimum soil moisture conditions were maintained for the seedling establishment.

Imposing water deficit

The seedlings were normally irrigated up to fourteen days of seedlings for ensuring normal growth. After fourteen days water stress was impose. Water deficit was imposed on 15-30 days old seedlings and data were recorded using 30-days old seedlings. Water deficit treatment was imposed by applying Yoshida's culture solution at the rate of 5 ml per tube (BRRI, 2006).

Collection of seedlings for data recording

Data were recorded using 30-day old seedlings. All of the seedlings of 30 days old were collected (Plate 1.2) and data were recorded. Roots and shoots were separated (joint point of root and shoot) with the help of a sharp knife.

Detailed procedures of recording data

Cumulative root length (root expansion in each 10 cm depth)

After harvest (30 days old seedling) root elongation tube (70 cm) were cut out into seven pieces (each of 10 cm). Then the roots were washed and carefully separated with a strainer and separately collected in seven plastic pots. Cumulative root length (root expansion at 10-70 cm depth of soil) was measured by total number of root which was expanded in every 10 cm depth of root elongation tube out of 70 cm (BRRI, 2006).

Root dry weight

After oven dry for 72 hours at 72^0C in each sample (10-70) cm depth of total root, root dry weighed (g) was counted by using digital electronic balance of different rice genotypes.

Plate 1.1. Seedlings grown in root elongation tube

Plate 1.2. Seedlings in root elongation tube (70 cm) for data collection

Plate 1.3. Root elongation tube (70 cm) cut into 7 pieces (10 cm/ piece)

Root-shoot ratio

The root shoot ratio was measured from root weight and shoot weight.

$$\text{Root shoot ratio} = \frac{\text{Root dry weight}}{\text{Shoot dry weight}}$$

Experiment -2

The second experiment was conducted at the research farm and Plant Physiology Laboratory, Dept. of Agricultural Botany, and the Agricultural Botany research field of Sher-e-Bangla Agricultural University, Dhaka-1207 under polythene shed. The experiment was carried out in

Randomized Complete Block Design (RCBD) with four replications. A total of ten rice genotypes as BR21, BR24, BRRI dhan42, BRRI dhan43, BRRI dhan48, BRRI dhan55 and lines BR6976-11-1, OM1490, BR6976-2B-15 and water stress tolerant variety Hashikalmi were collected from Genetic Resource and Seed Division, Bangladesh Rice Research Institute (BRRI).

Seed treatment and sowing

Seeds of uniform size and shape of each genotype were treated with Bavistin 5gm for 20 minutes. The solution was prepared by dissolving 5g of Bavistin in 1/2 liter of water. Treated seeds were place in the Petridis with water. Pre-soaked sprouted seeds were sown on March, 2013 in earthen pots under the rain protected polyethylene shade. The sprouted seeds were normally irrigated for ensuring normal growth of seedlings.

Pot preparation and fertilizer management

Earthen pots of 38 cm X 25 cm in size were used and filled up with 10 kg sandy loam soil. The soil of the pot was fertilized uniformly with 0.9, 0.8, 0.8 g urea, triple super phosphate and muriate of potash corresponding to 160-150-150 kg urea, triple super phosphate and muriate of potash per hectare, respectively. (BRRI, 2008)

Design and drought treatments were

The experiment was laid out in Randomized Complete Block Design (RCBD) considering three replications, three treatments and ten rice genotypes (90 pots) were used. Treatments were

T_1 = Normal irrigation throughout the experimental period (control).

T_2 = Normal irrigation up to 30 days and after that no irrigation for 7 days, then irrigated continuously.

T_3 = Normal irrigation up to 30 days and after that no irrigation for 15 days and then irrigated continuously.

Thinning, intercultural operations, and weeding

Seedlings were thinned out after two weeks of establishment and five healthy seedlings of uniform size were kept for growth per pot. Normal agricultural practices were applied for all treatments. Intercultural operations, weeding, top dressing was done whenever it was necessary. Adequate plant protection measures were taken to keep the plants free from diseases and pests.

General observation and detailed procedures of the experiment

Water deficit was imposed on 31 days old seedlings. All the pots were irrigated up to thirty days of seedlings age for ensuring normal growth. In case of treatment-1, no stress was imposed, plants were irrigated continuously. In case of treatment-2, water stress was imposed for 7 days on 31 days old seedlings in 10 genotypes and after that irrigation was done continuously until harvest. In case of treatment-3, water stress was imposed for 15 days in 10 genotypes on 31 days old seedlings and after that the plants were irrigated continuously until harvest.

Detailed procedures of recording data

Different morphological, physiological parameters were recorded at different stages of plant.

i. Soil water content: Soil water content (centi bar, cb) was measured with a tensiometer after providing water stress condition and before stress.

ii. Shoot height at maturity

Shoot height (cm) of 5 plants was determined by measuring from the joint of root and stem to the tip of flag leaf.

iii. SPAD value (Soil Plant Analysis Development): **SPAD** value was recorded with SPAD meter.

iv. Leaf area

Ten leaves were selected from plant samples and their length and breadth were measured and was multiplied by a factor of 0.75 (Yoshida, 1981). Leaf area was measured with the following formula: Leaf area (L) = k x l x w where, k = adjustment factor (0.75), l = length of a leaf blade, w = breadth of a leaf blade. The Leaves were packed with brown paper and oven dried for 72 hours at 72^0C. Dry weight of leaves was recorded.

v. Days to maturity

The maturity of grain was determined when the grain weight was found maximum and the colour of the grain turned to yellowish.

v**i. Length of panicle**

Length of panicle (cm) was taken from basal node of the rachis to apex of each panicle.

vii. Total dry matter

Total dry matter (root, shoot and panicle) was measured after oven drying for 72 hours at 72^0C.

viii. Number of total and effective ineffective tillers per plant

Number of total and effective tillers/ plant was counted. The panicles which had at least one grain was considered as effective tillers. The tiller having no panicle was regarded as ineffective tillers.

ix. Weight of 1000-grain

After sun drying and oven drying for 72 hours at 72^0C thousand cleaned grains weight (g) was counted. One thousand cleaned oven dried grains were counted randomly from each sample and weighed by using digital electronic balance and the mean weight was expressed in gram.

x. Biological yield

Biological yield was calculated with the formula (Biological yield = Grain yield +Straw yield).

xi. Harvest index (%)

It denotes the ratio of economic yield to biological yield and was calculated with following formula (Donald, 1963). Harvest index (HI) was calculated with the following formula

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

xii. Leaf rolling

Leaf rolling was assessed visually in each pot, in all the treatment. The pots were given mean leaf rolling score, ranging from 1 to 5 with 1 being flat and 5 a tightly rolled (O'Toole *et al.*, 1979).

Experiment -3

The third experiment was conducted at the Agricultural Botany research field of Sher-e-Bangla Agricultural University, Dhaka. Three BRRI materials as BRRI dhan55 (V_1), BR6976-2B-15 (V_2) and tolerant check Hashikalmi (V_3) were collected from Genetic Resource and Seed Division, Bangladesh Rice Research Institute (BRRI).

Seed treatment and sowing

Seeds of uniform size and shape of each genotype were treated with Bavistin 5gm for 20 minutes. The solution was prepared by dissolving 5g of Bavistin in 1/2 liter of water. Treated seeds were place in the Petridis with water. Pre-soaked sprouted seeds were sown on March, 2014 in earthen pots under the rain protected polyethylene shade.

Pot preparation and fertilizer management

Earthen pots of 38 cm X 25 cm in size were used and filled up with 10 kg sandy loam soil. The soil of the experimental area was sandy and sandy loam. The soil of the pot was fertilized uniformly with 0.9, 0.8, 0.8 g urea, triple super phosphate and muriate of potash corresponding to 160-150-150 kg urea, triple super phosphate and muriate of potash per hectare, respectively. (BRRI, 2008). Experimental duration was March to July, 2014.

Design and layout of the experiment

The experiment was designed as RCBD, three replications, three genotypes and seven water deficit treatments (63 pots) were used. Intercultural operations, thinning, weeding and plant protection measures were done. Seven drought conditions were used as treatments that started from 20 days of seedling age.

$T_{0=}$ Irrigated continuously throughout the experimental period (control).
T_1= Drought condition during 7 days, when the age of the seedling was 20 days
T_2=Drought condition was applied for second 7 days, when the age of the seedling was 35 days
T_3= Drought condition was applied for third 7 days, when the age of the plant was 55 days
T_4= Drought condition was applied for fourth 7 days, when the age of the plant was 75 days
T_5= Drought condition was applied for fifth 7 days, when the age of the plant was 95 days
T_6= Drought condition was applied for sixth 7 days, when the age of the plant was 115 days

General observation of the experiment

After seedling establishment, three uniform and healthy seedlings were allowed to grow per pot. The sprouted seeds were normally irrigated for ensuring normal growth. Water stress was imposed for seven days, when the age of the plant was 20, 35, 55, 75, 95 and 115 days.

Detailed procedures of recording data

Different physiological and biochemical parameters were recorded at seedling, vegetative and reproductive stages. Brief outlines of the data recording procedure have been given below:

i. Soil water content was measured by tentiometer. Leaf area, SPAD value, shoot height, days to maturity, number of effective tillers, total number of tillers per plant were counted.

ii. Stomatal conductance, leaf temperature and leaf humidity

Stomatal conductance, leaf temperature, leaf humidity and specific leaf weight (SLW) were measure by porometer at 8.00am and at 12.00am in all genotypes.

iii. Relative water content (RWC)

RWC was determined to give indication on the plant water status under drought condition. The fully developed the leave of each genotype were carefully collected at anthesis. Immediately after cutting at the base of lamina, leaves were sealed within plastic bags and quickly transferred to the laboratory. Fresh weights were determined immediately or within 2 h after excision. Turgid weights were obtained after soaking leaves in distilled water in test tubes for 16 to 18 h at room temperature (about 20°C) and under the low light conditions of the laboratory. After soaking, leaves were quickly and carefully blotted dry with tissue paper in preparation for determining turgid weight. Dry weights were obtained after oven drying the leaf samples for 72 h at 70°C. RWC was calculated from the equation of Schonfeld *et al.* (1988). The fresh, turgid and dry weights of the leaves were used to calculate the relative water content of leaves as follows-

$$\text{RWC} = \frac{\text{Fresh weight - Dry weight}}{\text{Turgid weight – Dry weight}} \text{ X } 100$$

iv. Specific leaf area (SLA) and Specific leaf weight (SLW)

The fully developed the leave stem and panicle sample of each genotype were carefully collected at anthesis. At first the samples were air dried for 6 to 8 hours, then the samples were packed separate with brown paper packet and were oven dried the samples for 72 h at 70°C. For the calculation of specific leaf area (SLA), specific leaf weight (SLW), leaf weight ratio (LWR), the dry weight of leaf, stem were recorded separately and dry weight of leaf, stem, panicle were altogether regarded as total above ground dry matter. Then the SLA, SLW, LWR were calculated with the following formula -

$$\text{Specific leaf area (SLA)} = \frac{\text{Leaf area}}{\text{Dry weight of leaf}} \ (\text{cm}^2/\text{g})$$

$$\text{Specific leaf weight (SLW)} = \frac{\text{Dry weight of leaf}}{\text{Leaf area}} (\text{cm}^2/\text{g})$$

$$\text{Leaf weight ratio (LWR)} = \frac{\text{Dry weight of leaf}}{\text{Above ground dry weight}}$$

v. Total dry weight and panicle dry weight

Total dry matter (root, shoot and panicle) was measured after oven drying for 72 hours at 72^0C.

vi.. Weight of 1000-grain

After sun and oven drying thousand cleaned grains weight (g) was counted randomly from each sample and weighed by using digital electronic balance.

vii. Number of filled and unfilled grain

Number of filled and unfilled grain was counted. Grain was considered to be filled if any kernel was present there in and unfilled grains mean the absence of any kernel inside in. The number of filled grains and the unfilled grains panicle^{-1} gave the total number of grains panicle^{-1}.

viii. Spikelet sterility percentage

Spikelet sterility percentage was recorded from the main stem panicle. Number of filled and unfilled grain were separated and counted manually. The spikelet sterility percentage was calculated using the following formula-

$$\text{Spikelet sterility (\%)} = \frac{\text{Unfilled spikelet per panicle}}{\text{Total spikelet per panicle}} \times 100$$

The biochemical parameters conducted at central laboratory of Agricultural Botany lab.

Plant growth under drought were influenced by altered photosynthesis, respiration, translocation, ion uptake, leaf proline accumulation, soluble sugar (carbohydrates), insoluble sugar (starch), nutrient metabolism, and hormones. In this study, leaf proline accumulation, soluble sugar (carbohydrates), insoluble sugar (starch), proline was determined.

i. Leaf proline accumulation

At the end of the stress the middle portion of flag leaf were collected for proline estimation following nin-hydrin method (Bates *et al.*1973). The protocol is based on the formation of red colored form zone by proline with ninhydrin in acidic medium, which is soluble in organic solvents like toluene.

Instruments, glassware and reagents

Test-tube, Test-tube stand, micro-pipettes (20-200ml, 100-1000ml and 5ml), hatman No.1 filter paper, visible range spectrophotometer, centrifuge tube, centrifuge mechine. Reagents were Glacial acetic acid (Analytical grade), Salfosalycylic acid (3%): Three gram of sulphosalycylic acid was dissolved in 100ml of distilled water. Orthophoohoric acid (6 N): Required volume of orthophoric acid (38.1) were taken the volume were made to 100ml, using distilled water to get 6N Orthophoohoric acid. Ninhydrin: Ninhydrin (1.25g) were dissolved in a blend of 30 ml of glacial acetic acid 20 ml of 6N orthophoric acid.

Procedure

1. Plant tissue 0.5 g were homogenized in 5 ml of 3% sulphosalycylic acid using pre washed morter and pestle
2. The homogenate were filtered through whatman No. 1 filter paper and collect filtrate for the estimation of proline content.
3. 2ml of extract were taken in the test tube and add 2ml of glacial acetic acid and 2ml of ninhydrin reagent.
4. Heat reaction mixture in a boiling water bath at $100^{o}c$ for 1 hour. Brick red color were developed.

5. After cooling the reaction mixtures, 4ml of toluene were added and then transferred to a separating funnel.

6. After mixing, the chromospheres containing toluene were separated and absorbance were read at 520 nm in spectrometer against toluene blank.

7. Standard curve of proline were taking 5 to 100 µg ml^{-1}concentration.

8. Free proline content was estimated by referring to a standard curve made from known concentrations of proline by taking following formula.

µ moles proline/ g of fresh plant materials =

{(µg proline/ ml X ml toluene)/ 115.5 µg/ µ moles}/ g sample

Where, FW = Fresh weight of leaf tissue

A = Absorbance at 520 nm, D = Initial dilution, 115.5 = Molecular weight of proline

Preparation of proline standard curve

80 mg of pure proline was dissolved into 100 mL of distilled water to get 800 ppm proline stock solution for preparing proline standard curve. By diluting this solution, 50 ppm, 100 ppm, 200 ppm, 400 ppm and 800 ppm solution were prepared in 20 mL each. The absorbances were measured with the help of Spectrophotometer at 520 nm. By plotting the concentration of proline (ppm) in 'X' axis and obtained absorbance reading in 'Y' axis a standard curve was prepared (Appendix V). From the absorbance reading obtained from samples, their respective proline content was estimated in ppm by using proline standard curve and converted into micro gram per gram (µg/g) unit using the following formula:

$$\text{Amount of proline}(\mu\text{g/g}) = \frac{x}{2} \times \frac{10}{500} \times 1000$$

ii. Extraction of anthocyanins

According to Mehrtens *et al.* (2005) anthocyanins were extracted from rice leaves.In the study, total anthocyanins were extracted from rice leaves using methanol and 1% HCL. Just after collection fresh sample were grounded finely with mortar and pastel. After grinding, samples were incubated overnight at room temperature in extraction buffer. 0.5g finely ground sample place in 15ml centrifuge tube and 60 ml of methanol were added with 1.6 ml HCL. Homogenates/ extracts were centrifuged at 16000g for 15 min and absorption of the extracts was determined at 530 and 657 nm by spectrometer. Then, anthocyanins were quantified according to the formula proposed by Mehrtens *et al.* (2005) as follows: $Q_{Anthocyanins} = (A_{530}–0.25×A_{657}) ×M^{-1}$; $Q_{Anthocyanins}$: amount of anthocyanins, A_{530}: absorption at 530 nm wavelength, A_{657}: absorption at 530 nm wavelength, M: fresh weight (g) of the tissues. (60ml MEOH and 1.6 ML 37% HCL). Estimation of soluble sugar (carbohydrate): Carbohydrate content (sum of sugar and starch) of flag leaf was determined with the method described by Yoshida *et al.* (1975). Plant samples were collected from all treatment and replications.

iii. Estimation of soluble sugar

Dried composite sample were grounded finely with mortar and pastel. 100 mg finely ground sample place in 15ml centrifuge tube and 10ml of 80% ethanol were added. The tubes were covered with aluminum and kept in a boiling water bath 80-85^{0}c for 30 minutes. Then the sample were centrifuged at 5000 rpm (by G-13 Centrifuge Machine, Model: NF 200, Turkey) for 10 minutes at room temperature) and decanted in to a 50 ml beaker. These extractions were repeated three or more 3 times. The alcohol extract was evaporated on a boiling water bath 80-85 ^{0}c until most of the alcohol were removed (the volume was reduced to about 3ml.). The volume was made up to 25 ml with distilled water. 5ml of this diluted sugar extract were taken in to100ml volumetric flask and should be made up the volume with distilled water. 5ml diluted sugar take into Pyrex test tube which containing standard glucose (0, .01, .025, .05, 0.1, 0.2 and 0.3 mg/5ml) were put into ice bath. 10ml anthron reagents were added slowly in each test tube. Anthron reagents were prepared- 2 g anthrone were dissolved in one-liter concentrated sulfuric acid and stored in a refrigerator and a fresh solution. A Fresh solution was prepared every day. Reagent run down the side of the test tube and stirred slowly with a glass rod. Then the tubes were put in boiling water bath for exactly 7.5 minutes and cool down immediately in ice. Then the absorbance measured at 630 nm and sugar content was estimated using standard curve.

Calculation: The regression equation obtained from the standard curve is given below-

$Y= 0.3x – 0.14$, Where, y= absorbance at 630 nm, X = amount of glucose in mg

The amount of sugar in the extracts was obtained from the regression equation by putting the respective absorbance values of the extracts and taking into consideration the appropriate dilution factor.

iv. Estimation of starch

The residue left in the centrifuge tube after collecting starch extract were dried in an oven at 80^0C and 2ml distilled water were added to each centrifuge tube. The tubes were put in boiling water bath for 15 minutes and stirred occasionally. Then the tubes were allowed to cool and 2ml 9.2N $HClO_4$ (perchloric acid) were added to each tube while were stirred occasionally or 15 minutes and made up 10 ml of distilled water. The supernatant was collected and add 2m 4.6N HClO4 were added to the residue and stirred for 15 minute and the solution made up 10ml distilled water. Then suspension centrifuge and made up 50 with distilled water. 5ml starch extract were transferred to 50 ml volumetric flask and made up the volume with distilled water. 5ml diluted extract starch taken into separate 50 ml Pyrex test tubes which contains standard glucose (0.1, 0.25, 0.50, 0.75,1 and 1.5 mg/5ml including 0.6ml 0.46 N HCl04 solution for each tube) were put into ice bath and add 10ml Anthron reagent were added slowly, the reagent being allowed to run down the side of the test tubes. The solution was stirred slowly with a glass rod. Then the tubes were put in boiling water bath for exactly 7.5 minutes and cool down immediately in ice. Then the absorbance measured at 630 nm and sugar content was estimated using standard curve.

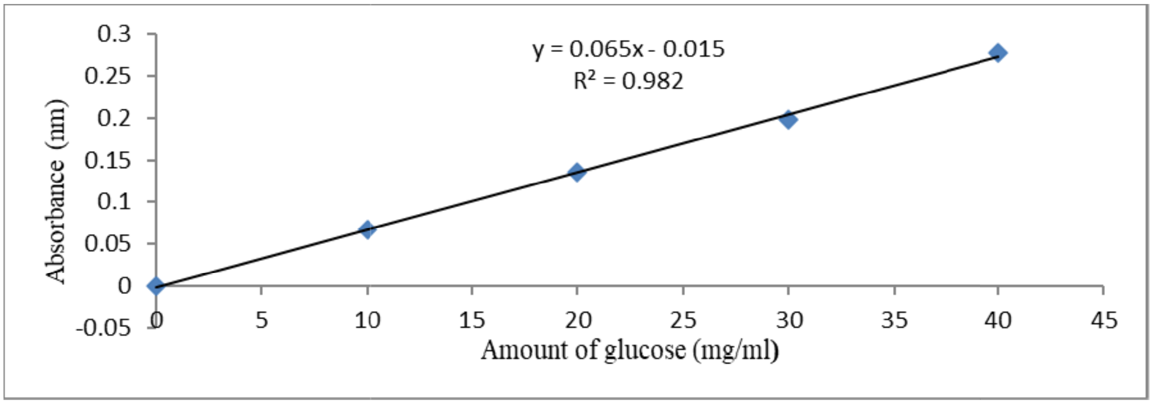
Calculation

The regression equation obtained from the standard curve is given below-

$Y= 0.165x + 0.015$ Where, y= absorbance at 630 nm

X = amount of glucose in mg

The amount of starch in the extracts was obtained from the regression equation by putting the respective absorbance values of the extracts and taking into consideration the appropriate dilution factor.



Calibration curve for the estimation of starch concentration

v. Data analysis

The data were statistically analyzed following MSTAT-C software package and the mean differences were adjusted by Duncan's Multiple Range Test (DMRT) at 5% level of significance Gomez and Gomez, (1984).

CHAPTER 4

RESULTS AND DISCUSSION

Three pot experiments were conducted to study the behavior of ten rice genotypes following water stress effect. In an attempt to infer the strategies of water stress tolerance of those genotypes the first experiment was conducted, where the screening of rice genotypes for their deep rooting ability was studied. In the second experiment was the effect on growth and development was studied. In the third experiment morpho-physiological responses and biochemical parameters were studied under water stress durations with selected rice genotypes. The results of the three experiments have been presented and discussed in this chapter.

Experiment -1

SCREENING OF RICE GENOTYPES FOR THEIR DEEP ROOTING ABILITY

The objectives of the study were screening of rice genotypes for their deep rooting ability of different rice genotypes and the results of this experiment have been presented in the form of tables and figures along with necessary discussion in this chapter.

1. Cumulative root length (CRL)

Root length of different rice genotypes under water stress conditions up to 70 cm depth have been shown in the Fig. 1.1. At first 1-10 cm depth the highest CRL found was 993.3 cm in BRRI dhan55 and the lowest CRL was 679.7 cm in BR21. At 11-20 cm depth the highest CR L was 629.3 cm in BRRI dhan55 and the lowest CRL found was 138.1 cm in BR21. At 21-30 cm depth the highest CRL was 276 cm in BRRI dhan55 and the lowest CRL found were 139.8 cm in BRRI dhan43. At 31-40 cm depth the highest CRL found was 183 cm in BRRI dhan55 and the lowest CRL found was 115.9 cm in BR6976-11-1. At 41-50 cm depth the highest found was 119 cm in Hashikalmi and the lowest CRL was 62.67 cm in BR 6976-2B-15. At 51-60 cm depth the highest (CRL) was 68.37cm in BRRI dhan55 and the lowest CRL found were 15.30 cm in BR 6976-11-1. At 61-70 cm depth the highest CRL found was 22 cm in BRRI dhan55, Hashikalmi and the lowest CRL found was 6 cm in BR 6976-11-1. In this study it was observed that in 10- 30 cm depth root length was less affected of eleven rice genotypes under water deficit conditions.

In this study, root length was found the highest in BRRI dhan55 and Hashikalmi. The root length decreased in BR21, BR24, BRRI dhan43, BR 6976-11-1 compared to the water stress tolerant genotypes Hashikalmi, BRRI dhan55 and Dharial. These results have got the conformity with the results of Usman *et al*. (2013) who stated that the root length of upland rice varieties exhibited significant reduction at highest water stress level as compared to control. Henry *et al* (2011) stated that genetic variation for deep root growth in drought-stressed rice was observed. Drought tolerant genotypes possess deep root, short height of shoot and high root-shoot ratio under water deficit conditions. Sikuku *et al.* (2010), reported drought tolerant cultivars have deep and thick roots. Asch *et al.* (2005) advocated that drought is a major stress affecting rainfed rice systems. Root characteristics such as root length density, root thickness and rooting depth and distribution have been established as constituting factors of drought resistance. When water deficit occurs, the most effective resistance mechanism available to the rice plant is a deep root system consisting of mostly thick roots that enables the plant to avoid the adverse effects of internal water deficit (Chang, 1972). Root uptake from the lower layers where water is expected to be available, this would help to maintain a good plant water potential which has a demonstrated positive effect on yield under stress reported by Mumbani and Lal (1983).

2. Root dry weight

Root dry weight (g) of different rice genotypes under drought conditions has been shown (Fig. 1.2). At 1-10 cm depth the highest root dry weight was 1.75 g in BRRI Dhan55 and the lowest root dry weight was 1.26 g in BR21. At 11-20 cm depth the highest root dry weight was 0.77g in BRRI Dhan55 and the lowest root dry weight was 0.45 g in BRRI Dhan42. At 21-30 cm depth the highest root dry weight was 0.30 g in BRRI Dhan55 and Hashikalmi and the lowest root dry weight was 0.23 g in BR21. At 31-40 cm depth the highest root dry weight was 0.09 g in BRRI Dhan55 and the lowest root dry weight was 0.12 g in BR24 and BR6976-2B-15. At 41-50 cm depth the highest root dry weight was 0.09 g in BRRI Dhan55, Hashikalmi and the lowest root dry weight was .05 g in BR6976-2B-15 and BR6976-11-1. At 51-60 cm depth 0.07g in BRRI dhan55 and Hashikalmi and the lowest root dry weight was 0.04g in BR6976-2B-15 and BR6976-11-1. At 61-70 cm depth the highest root dry weight was 0.05 g in BRRI Dhan55and Hashikalmi and the lowest root dry weight was 0.02 g in BR6976-2B-15 and BR6976-11-1.

In this study, tolerant genotypes BRRI Dhan55 and Hashikalmi have been shown the highest root dry matter at 1 to 70 cm depth of soil and the lowest root dry weight was 0.02g in BR6976-2B-15 and BR6976-11-1. The results have the infirmity with the results of Lum (2014) who reported that eight local upland rice (*Oryza sativa* L.) varieties that were drought affected, Kusam (drought-sensitive variety) was markedly affected than the drought tolerant varieties in the activities of root dry matter. The root dry weight was decreased under mild and severe water stress in *Populus* species (Wullschleger *et al.*, 2005). Asch *et al.* (2005) advocated that rice reacted to drought stress with reductions biomass production, changes in root dry matter and rooting depth. Deep rooting cultivars are more resistant to drought, changes in root dry matter and rooting depth. Asch *et al.* (2005) stated that drought effect assimilate accumulation between root and shoot.

3. Root shoot ratio

Root shoot ratio of different rice genotypes under drought conditions has been shown (Fig. 1.3). Significant differences were found among the genotypes for Root shoot ratio. The highest Root shoot ratio found was 0.07 in BRRI dhan55 and Hashikalmi and the lowest Root shoot ratio was found 0.04 in BR21 and BR 6976-2B-15.In this study, water stress tolerant genotypes showed higher root shoot ratio compared to susceptible genotypes. Here, the highest root shoot ratio was found in BRRI dhan55 followed by in Hashikalmi and the lowest root shoot ratio was found in BR 6976-2B-15.

The results of the experiment was in agreement with Mohammadian *et al*. (2005), who reported that mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes. Sharp *et al.,(*2004) in maize who reported that the root shoot ratio was increased when the soil was subjected to water deficit condition. Under drought condition, the root shoot ratio was lower and the root shoot ratio was higher in drought tolerant genotype. Jawi Lanjut varieties showed high root shoot ratio than the other varieties under the water stress treatment. Kulkarni *et al.* (2008) reported that the root shoot ratio was reduced when the soil was subjected to water deficit condition.

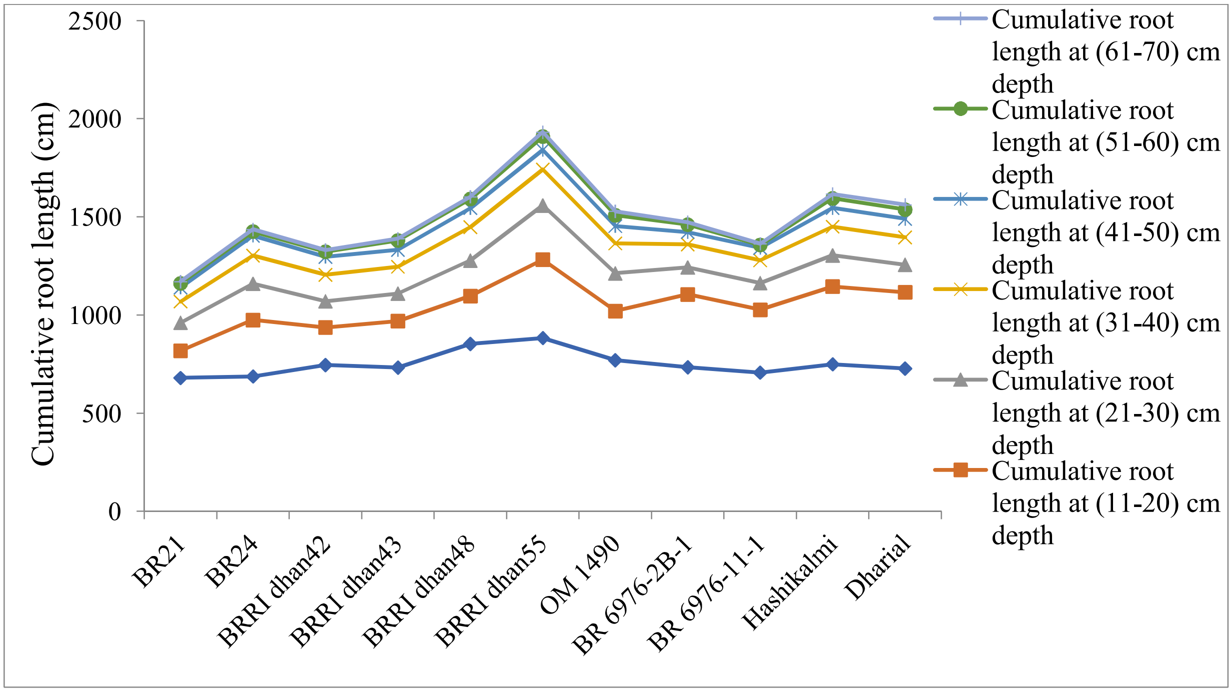


Fig.1. Cumulative root length at 10-70 cm depth in soil of rice genotypes under water deficit conditions

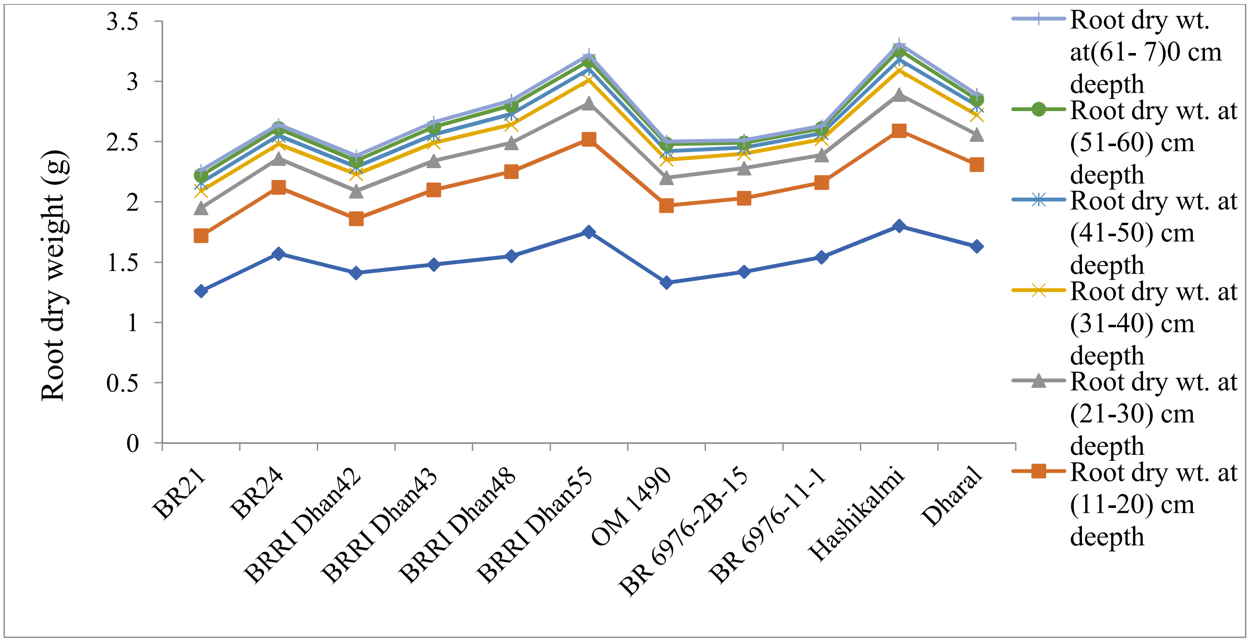


Fig. 2. Root dry weight (g) at (10 – 70) cm depth in soil of different rice genotypes under water deficit conditions

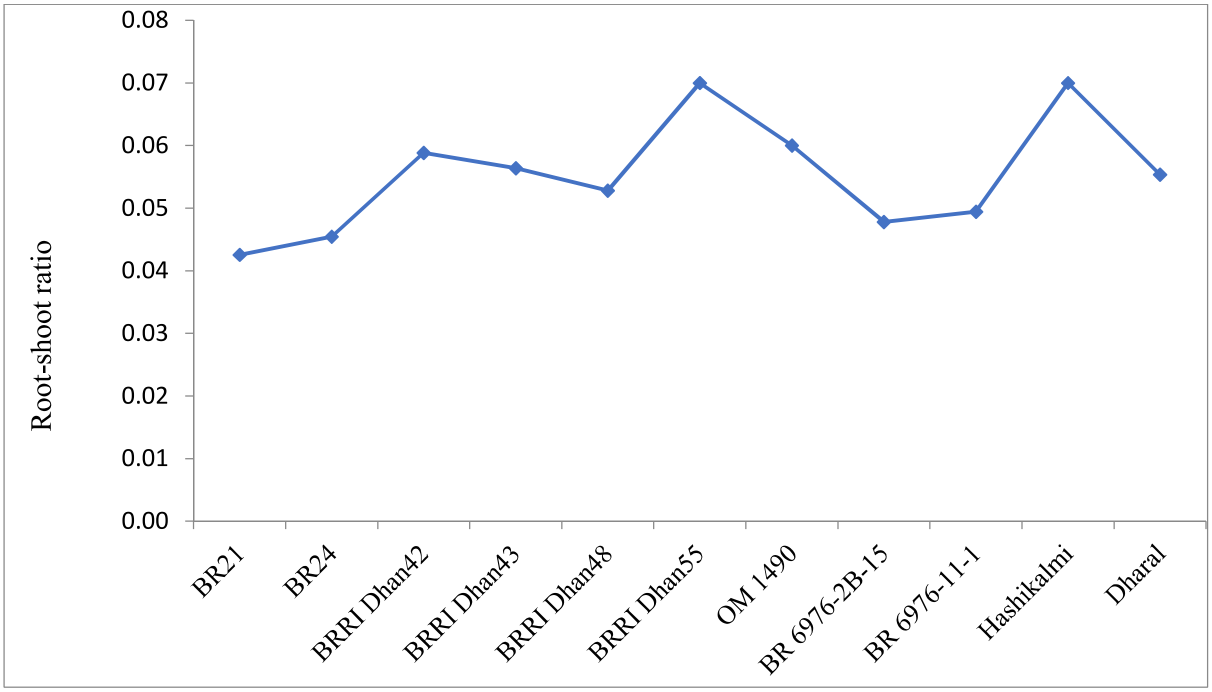


Fig. 3. Root shoot ratio of different rice genotypes under water deficit conditions

Experiment -2

WATER STRESS EFFECT ON GROWTH AND DEVELOPMENT OF DIFFERENT RICE GENOTYPES

The objectives of the study were to assess the effect on growth and development of different rice genotypes due to water stress of different duration and the results of this experiment have been presented in the form of tables and figures along with necessary discussion in this chapter.

1.1 Soil moisture content

Soil moisture content (tentiometer readings in centibar) of soil pots containing different rice genotypes under water stress condition have been shown in the Table. 1. Before water stress the highest soil moisture content found was 1.67 cb in the soil of pot containing genotype BR6976-11-1 and the lowest reading was 0.90 cb which was not significantly different. After 7 days water stress the highest soil moisture content found was 29 cb in the soils of BR24, BRRI dhan43, BRRI dhan55 and BR6976-11-1 and the lowest was found 28.69 cb in the soils of BR21, BRRI dhan42, BRRI dhan48, BR6976-2B-15 and Hashikalmi. After 15 days water stress the highest soil moisture content found was 31.67 in BR24, 31.33 in BRRI dhan55 and the lowest was found 30.67cb in BRRI dhan48 which was not significantly different. It was observed that when water stress condition prevails due to soil moisture decrease root cannot uptake water to which plant growth was retarded, morpho-physiological, metabolic and biological processes were disturbed. In severe stress condition all processes were attacked and finally death of plants was observed.

Table 1. Tentiometer reading (before and after 7- and 15-days water stress) of soil of rice genotypes

Tentiometer reading (cb)			
Genotypes	Before stress	After 7 days water stress	After 15 days stress
BR21	0.90	28.00	31.00
BR24	1.03	29.00	31.67
BRRI dhan42	0.90	28.00	31.33
BRRI dhan43	1.0	29.00	31.00
BRRI dhan48	0.97	28.67	30.67
BRRI dhan55	0.90	29.00	31.33
OM 1490	1.0	28.67	31.00
BR 6976-2B-15	0.93	28.00	31.00
BR 6976-11-1	1.67	29.00	31.00
Hashikalmi	1.0	28.00	31.00
CV (%)	0.01	1.2	0.98

Table 2. Effect of different duration (days) of water stress on plant height of rice genotypes

Genotypes	Plant height (cm)			Reduction (%) of plant eight	
	Control	7 days stress	15 days stress	7 days tress	15 days stress
BR21	102.0 c	95.00 bc	75.33 c	7	26
BR24	105.0 c	98.33 b	95.67 a	6	9
BRRI dhan42	101.0 c	96.00 bc	77.50 c	5	23
BRRI dhan43	102.7 c	94.67 bc	85.50 b	7	16
BRRI dhan48	103.0 c	99.00 b	95.33 a	4	7
BRRI dhan55	114.0 b	112.0 a	94.07 a	2	18
OM 1490	103.0 c	90.33 c	81.00 bc	12	21
BR 6976-2B-15	74.67 e	70.00 e	67.33 d	6	10
BR 6976-11-1	86.00 d	77.33 d	75.00 c	10	13
Hashikalmi	115.0 a	108.7 a	96.00 a	5	17
CV (%)	7.53	10.08	9.51		

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

Plant height

Plant height of different rice genotypes under water stress condition have been shown in the table 2. Significant differences were found among the varieties and the treatments for the character of plant height. At 7 days water stress stress the highest plant height found was 112 cm in BRRI dhan55, the second highest was found 108.7 cm in Hashikalmi and the lowest plant height found was 70 cm in BR6976-2B-15. At 15 days water stress the highest plant height was found 96 cm in Hashikalmi and the lowest was found 67.33 cm in BR6976-2B-15. At no stress the highest plant height found was 115 cm in Hashikalmi and the second highest plant height was found 114 cm in BRRI dhan55 and the lowest plant height was 74.67 cm in BR6976-2B-15.

When water stress was applied at early stage of plant growth, the plant height was retared. Plant height of different rice genotypes under water stress condition found significant reduced compared with the control. Variation in plant height among the genotypes also indicates that different genotypes had different water requirement. The results have the similarity with the results of Bokul *et al.* (2009) who stated that plant height is affected by drought stress. This reduction in growth might be due to low osmotic potential as well as a decrease in wall extensibility and cellular expansion (Mohammadkhani and Heidari, 2008). Zubaer *et al*. (2007) found that under water stress plant height affected at booting, flowering and maturity stages.

Leaf area

Leaf area of different rice genotypes under water stress conditions have been shown in the table 3. Significant differences were found among the varieties and the treatments for leaf area. At 7 days water stress the highest leaf area was found 47.27 cm^2 in BRRI dhan55 and the lowest was 36.96 cm^2 in BRRI dhan42. At 15 days drought stress the highest leaf area found was 39.34 cm^2 in BRRI dhan55 and the lowest was 28.93 cm^2 in BR21. At control the highest leaf area found was 59.78 cm^2 in Hashikalmi and 58.44 in BRRI dhan55 and the lowest was 40.69 cm^2 in BR24.

At 7 and 15 days water stress the reduction percent of leaf area were found 18.94 and 48.55 in BRRI dhan55 respectively compared to control. In this study, leaf area varied significantly in different genotypes under different duration of water stress condition. The results have been agreement with the results of Wullschleger *et al*. (2005) who reported that water deficit stress mostly reduced leaf growth and in turn the leaf areas in many species of plant like *Populus*. Drought stress suppresses leaf expansion and midday photosynthesis and reduces photosynthesis rate and leaf area due to early senescence (Kramer and Boyer, 1995).

SPAD reading after anthesis

The SPAD value of different rice genotypes under water stress condition have been shown in the Table 4. SPAD reading was recorded from the flag leaf of all tillers and average value was taken after anthesis**.** At 7 days drought stress the highest SPAD value found was 46.17 in BRRI dhan55 and the lowest was 38.47 in OM1490. At 15 days drought stress the highest SPAD value found was 45.50 in BRRI dhan55, the lowest was 38.03 in OM1490. At control the highest SPAD value found was 46.67 in BRRI dhan55 and the lowest was found 41.33 in OM1490. SPAD value represents the greenness of the leaf. SPAD value was recorded after anthesis. After anthesis SPAD value slightly increased and then gradually decreased with advanced towards maturity. In this study, at 7 days stress the highest SPAD value was found in BRRI dhan55 followed by Hashikalmi. This result has the similarity with the results of Zhang and Kirkham (1996) who advocated that decreased of chlorophyll content during drought stress depending on the duration and severity of drought level. Abaaszadeh *et al.* (2007) reported that chlorophyll concentration decreases under water stress condition. One of the most important changes under drought stress is the decrease in the total chlorophyll content reported by Begum and Paul (2007). Decreasing of chlorophyll content in plants such as *Paulownia imperialis* (Astorga, 2010) bean (Beinsan *et al*. 2003) was reported under drought stress condition. The degradation of chlorophyll increases with the age towards maturity, as a result SPAD value gradually decreased from anthesis to maturity in all the genotypes.

Days to maturity

In this study, days to maturity of different rice genotypes under water stress have been shown in the Table 5. Significant differences were found among the varieties and the treatments for this character. At 7 days stress the highest days to maturity was 106 in BR21 and the lowest was 94 in Hashikalmi. At 15 days stress the highest days to maturity required 111 in BR 6976-2B-15, and the lowest was 92 in BRRI dhan43. At no stress the highest days to maturity was 113.7 in BRRI dhan55 and the lowest was 96.67 in Hashikalmi. Under water deficit conditions plant showed early senescence. Early senescence causes low yield. In the study, under water stress condition the highest days to maturity was found in BR21 and the lowest was found in Hashikalmi (V3). In this study, water stress had significant effect on day to maturity. These results have the conformity with the results of Zubaer *et al*. (2007) who showed that water stress affected to early flowering and maturity stages.

Length of panicle at mature stage

In this study, lengths of panicle (cm) of different rice genotypes under water stress condition have been shown in the tables 6. Significant differences were found among the varieties and the treatments for panicle length. At 7 days stress the highest panicle length found was 20.00 cm in BRRI dhan55 and the lowest found was 17.33 cm in BR21. At 15 days stress the highest panicle length found was 18.70 cm in Hashikalmi and the lowest found was 14.57 cm and 14.92 cm BR 6976-2B-15. At control the highest panicle length found was 23.76 cm in Hashikalmi and the lowest found was 20.80 cm in BRRI dhan42. Under water stress condition there were remarkable differences on panicle length among the genotypes. At 7 and 15 days stress BRRI dhan55, Hashikalmi produced the largest panicle (reduction percent was 15 and 26.22 in BRRI dhan55 and 16.54, 21.30 in Hashikalmi, respectively). Largest length of panicle contains more grain which was of high weight of panicle than small length of panicle. At 15 days stress the smallest panicle length showed in BR21 and BR 6976-2B-15 (the reduction percent was 33.47, 28.37, respectively). As a result, yield losses. Similar result was obtained by Islam *et al*. (1994) who reported that moisture stress reduced the length of panicle. The results have also the agreement with the results of Bokul *et al. (*2009) who found that panicle length was decreased due to drought conditions at reproductive stage.

1000- Grain weight

In this study, thousand weights of grain (g) of different rice genotypes under water stress condition have been shown in the Table 7. Significant differences were found among the varieties and the treatments for this character. At 7 days stress the highest thousand grain weight was in 20.33g BRRI dhan48 and the lowest thousand grain weight found was 14.10 g in BRRI dhan42.

Table. 3. Effect of different duration (days) of water stress on leaf area of rice genotypes

Genotypes	Leaf area (cm^2)			Reduction (%) of leaf area	
	Control	7 days stress	15 days stress	7 days stress	15 days stress
BR21	41.16 d	39.64 bcd	28.93 c	3.69	42.27
BR24	40.69 d	39.13 bcd	30.79 bc	3.83	32.15
BRRI dhan42	46.33 cd	36.96 d	29.88 bc	20.22	55.05
BRRI dhan43	46.74 cd	38.48 bcd	29.39 bc	17.67	59.03
BRRI dhan48	54.31 abc	44.60 abc	34.86 abc	17.88	55.79
BRRI dhan55	58.44 ab	47.27 a	39.34 a	18.94	48.55
OM 1490	53.00 abc	37.52 cd	31.92 bc	29.21	66.04
BR 6976-2B-15	41.74 d	39.59 bcd	31.15 bc	14.75	49.09
BR 6976-11-1	48.01 bcd	39.97 bcd	29.54 bc	16.75	62.53
Hashikalmi	59.78 a	44.85 ab	35.63 ab	24.97	67.78
CV (%)	11.67	8.90	10.27		

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

Table 4. Effect of different days water stress on SPAD value after anthesis of rice genotypes

Genotypes	SPAD value		
	Control	7 days stress	15 days stress
BR21	45.07	41.63 b	40.20
BR24	44.67	42.70 b	40.89
BRRI dhan42	43.40	42.30 b	41.67
BRRI dhan43	43.33	42.50 b	40.37
BRRI dhan48	43.83	40.77 b	38.30
BRRI dhan55	46.67	46.17 a	45.50
OM 1490	41.33	38.47 d	38.03
BR 6976-2B-15	43.83	41.67 b	41.10
BR 6976-11-1	42.33	41.37 b	40.67
Hashikalmi	46.67	42.97 b	41.20
CV (%)	7.64	5.99	9.72

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

Table 5. Effect of different duration of water stress on maturity of different rice genotypes

Genotypes	**Days to maturity**		
	Control	7 days stress	15 days stress
BR21	109.7 a	106.0 a	96.33 ab
BR24	105.0 b	98.67 cde	94.33 ab
BRRI dhan42	100.0 cd	98.00 de	92.33 b
BRRI dhan43	110.3 a	98.00 de	92.00 b
BRRI dhan48	110.0 a	103.0 abc	96.00 ab
BRRI dhan55	113.7 a	104.7 ab	98.33 a
OM 1490	103.7 bc	101.0 bcd	96.33 ab
BR 6976-2B-15	102.0 bc	98.33 de	111.0 a
BR 6976-11-1	103.3 bc	99.00 cd	94.67 ab
Hashikalmi	96.67 d	94.33 e	94.00 ab
CV (%)	2.80	4.591	4.54

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

Table 6. Effect of different days water stress on the length of panicle of rice genotypes

Genotypes	**Length of panicle (cm)**			**Reduction fpaniclelength(cm)%**	
	Control	7 daysstress	15 day stress	7 days stress	15 day stress
BR21	21.9 abc	17.33 b	14.57 c	20.87	33.47
BR24	21.57 abc	19.10 ab	17.17 abc	11.45	20.40
BRRI dhan42	20.80 c	19.36 a	17.60 ab	6.92	15.38
BRRI dhan43	20.83 c	19.20 ab	16.03 abc	7.83	23.04
BRRI dhan48	21.86 abc	19.78 a	17.20 abc	9.52	21.32
BRRI dhan55	23.53 ab	20.00 a	17.36 abc	15.0	26.22
OM 1490	21.03 bc	18.99 ab	17.00 abc	9.70	19.16
BR 6976-2B-15	20.83 c	19.50 a	14.92 bc	6.39	28.37
BR 6976-11-1	21.26 abc	19.77 a	16.07 abc	7.01	24.41
Hashikalmi	23.76 a	19.83 a	18.70 a	16.54	21.30
CV (%)	7.98	5.82	8.65		

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

Table 7. 1000- grains weight of different rice genotypes under water stress conditions

Genotypes	1000 grains weight (g)			Reduc.(%) of 1000 grains wt	
	No stress	7 days stress	15 days stress	7 days stress	15day stress
BR21	19.16 cd	15.03 b	14.10 abc	21.56	24.58
BR24	19.11 cd	15.56 b	11.04 d	18.58	42.23
BRRI dhan42	15.36 e	14.10 b	12.00 cd	8.20	21.88
BRRI dhan43	23.93 a	16.20 b	12.59 bcd	32.30	47.39
BRRI dhan48	23.37 ab	20.33 a	14.45 ab	13.01	33.03
BRRI dhan55	16.75 e	15.65 b	15.55 a	6.57	7.16
OM 1490	21.25 bc	16.15 b	11.67 d	24.00	45.08
BR 6976-2B-15	21.69 ab	14.50 b	11.31 d	33.15	47.86
BR 6976-11-1	22.74 ab	15.04 b	11.59 d	33.86	49.03
Hashikalmi	18.53 d	17.07 ab	13.96 abc	7.88	24.66
CV (%)	6.61	12.86	9.49		

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

Table 8. Total numbers of tillers/ plant of different rice genotypes under water stress conditions

Genotypes	Total number of tillers/ plant			Reduc. of total No.of illers/plant(%)	
	Control	7days stress	15days stress	7days stress	15day stress
BR21	27.33 bc	21.33 de	17.21 c	21.95	37.03
BR24	25.88 c	20.33 e	17.33 cd	21.45	33.04
BRRI dhan42	24.04 cd	20.43 e	17.00 cd	15.02	29.28
BRRI dhan43	23.33 d	21.00 de	16.69 c	9.99	34.11
BRRI dhan48	33.78 abc	24.33 cde	19.54 bc	7.25	42.16
BRRI dhan55	36.33 a	34.60 b	24.33 a	4.76	33.93
OM 1490	23.69 d	22.33 de	16.87 c	5.74	28.79
BR 6976-2B-15	26.65 bc	24.00 cde	17.08 cd	9.94	35.91
BR 6976-11-1	25.67 c	24.33 cde	18.00 bc	5.22	29.88
Hashikalmi	36.05 a	35.00 a	24.00 ab	2.91	33.43
CV (%)	13.08	17.38	10.00		

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

Table 9. Effect of different duration of water stress on effective tillers/plant of rice genotypes

Genotypes	**Effective tillers/ plant**		
	Control	7 days stress	15 days stress
BR21	9.62 c	8.68 c	7.00 cd
BR24	10.10 c	9.07 bc	8.12 bc
BRRI dhan42	7.893 c	7.36 c	5.13 d
BRRI dhan43	8.900 c	7.85 c	6.07 d
BRRI dhan48	14.28 ab	7.02 c	5.67 d
BRRI dhan55	15.87 a	12.22 a	10.35 a
OM 1490	8.227 c	10.13 ab	10.33 a
BR 6976-2B-15	12.63 b	10.90 ab	10.00 a
BR 6976-11-1	9.180 c	8.350 c	7.04 cd
Hashikalmi	14.40 ab	12.83 a	8.93 ab
CV (%)	10.96	11.87	12.99

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

1000- grain weight

In this study, thousand weights of grain (g) of different rice genotypes under water stress condition have been shown in the Table 7. Significant differences were found among the varieties and the treatments for this character. At 7 days stress the highest thousand grain weight was in 20.33g BRRI dhan48 and the lowest thousand grain weight found was 14.10 g in BRRI dhan42. At 15 days stress the highest thousand grain weight was 15.55 g in BRRI dhan55 and the lowest was 11.04 g in BR24. At control thousand grain weights was 23.93 g in BRRI dhan43. In this study, the highest thousand grain weight was found 20.33g in BRRI dhan48 at 7 days stress, 15.55 g was found in BRRI dhan55 at 15 days stress and the lowest was 11.04 g in BR24. This result has the similarity with the results of Zubaer *et al*. (2007) who showed that 1000 grains weight was reduced with reduced soil moisture levels. The RRDI (1999) stated that stress during grain filling stage decreased grain weight. Begum F.A. (1992) conducted that water stress after flowering decreased the individual grain weight. Islam *et al.* (1994) also stated that water stress reduced grain weight.

Total number of tillers per plant

In this study, total number of tillers per plant of different rice genotypes under water stress condition has been shown in the Table 8. Significant differences were found among the varieties and the treatments for this character. At 7 days stress the highest number of tillers per plant found was 35.00 in Hashikalmi, the second highest was found 34.60 in BRRI dhan55 and the lowest number of tillers per plant found was 20.33 in BR24. At 15 days stress BRRI dhan55 produced the highest numbers of tillers (24.33) followed by Hashikalmi (24.00) and the lowest number of tillers per plant found was 16.69 in BRRI dhan43, 16.87 in OM1490, 17.00 in BRRI dhan42, 17.21 in BR21. Under control condition plant produced the highest numbers of tillers was found in BRRI dhan55 (36.33), Hashikalmi (36.05) and the lowest numbers of tillers were produced in 23.33 in BRRI dhan43, OM1490 (23.69). Total number of tillers varied significant among the genotypes at different stress condition. In this study, among the genotypes it was found that the total number of tillers was reduced under water stress condition at vegetative stage. In all water stress duration tiller production were the highest in BRRI dhan55 and Hashikalmi compared to other genotypes. In this result, at 7 days stress the highest number of tillers per plant was found in BRRI dhan55 (the reduction percent was 4.76), followed by Hashikalmi (2.91). At 15 days stress BRRI dhan55 produced the highest numbers of tillers followed by Hashikalmi which was statistically similar. It might be due to less amount of water uptake to prepare sufficient food and inhibition of stomatal conductance, dry matter production, leaf area and photosynthesis (Ekanayake, 1987). Similar results also agree with the results of Boonjung and Fukai (1996) who observed that early drought may reduce tiller number and reductions were often minimal yield. Islam *et al*. (1994) reported reduced tillering during vegetative stages under water stress.

Effective tillers/ plant

In this study, total number of effective tillers/ plants of different rice genotypes under water stress condition have been shown in the Table 9. Significant differences were found among the varieties and the treatments for this character. At 7 days stress the highest number of effective tillers found was 12.83 in Hashikalmi followed by 12.22 in BRRI dhan55 and the lowest number of tillers was 7.02 in BRRI dhan48. At 15 days stress the highest number of effective tillers was

10.35 in BRRI dhan55 and the lowest numbers of tillers was 5.13 in BRRI Dhan42. At no stress condition tolerant genotype Hashikalmi (14.40) and BRRI dhan55 (15.87) produced the highest number of effective tillers which was statistically similar and the lowest number was found 7.89 in BRRI dhan42. Tolerant check Hashikalmi and BRRI dhan55 produced the highest number of effective tillers at 7days. Number of effective tillers per plant of different rice genotypes decreased with the increase in water stress condition. It might also be happened for less amount of water uptake to increased plant growth, leaf area and to prepare sufficient food and inhibition cell division. This result has showed Ekanayake (1987) who observed the percentage of fertile tiller is severely affected by moisture stress. Kramer and Boyer (1995) stated that drought stress suppresses and number of effective tillers means number of panicles per plant cannot increase due to early senescence.

Leaf rolling

Leaf rolling score is an eye estimation process of leaf rolling under water stress treatment. Leaf rolling score of different genotypes have been shown (Fig. I). At 7 days stress leaf rolling score was minimum and at 15 days stress leaf rolling score was highest compared to control. It depends on intensity and duration of drought. At 15 days stress the highest leaf rolling score 4.1 was found in BR24, OM1490 and BR 6976-11-1and lowest leaf rolling scores 2 were found in BRRI dhan42, BRRI dhan48 and BRRI dhan55. Leaf rolling may help in maintaining internal plant water status. Low leaf rolling score is considered as comparatively resistant to water stress. The results have the conformity with the results of Zulkarnain *et al.* (2009) who found that the sensitive rice varieties showed higher leaf rolling score and the tolerant cultivars showed lower leaf rolling. Leaf rolling under water stress condition helps plant to minimize water loss by transpiration, decreased leaf temperature and protect the plant from drying. After a long time, drought condition the leaves of all rice varieties (tolerant and sensitive) were rolled at midday. Higher proline content increased the RWC of the leaf and the leaf rolling was lower in this genotype. Ha (2014) reported that the use of delayed leaf rolling under water stress as an important selection criterion for dehydration avoidance. Delayed leaf rolling was considered as a desirable character in rice (Maji, 1994).

Number of panicle/ plants at harvest

Number of panicle per plant of different rice genotypes under drought condition have been shown in the Fig.II. Significant differences were found among the varieties and the treatments for this character. At 7 days drought stress the highest number of panicle/plants found were 21 and 17 in BRRI dhan55 and Hashikalmi respectively and the lowest number of panicle/plants found were BR21, OM1490. At 15 days drought stress the highest number of panicle/plants found were 18 and 14 in BRRI dhan55 and Hashikalmi respectively and the lowest number of panicle/plants found were 7 in BR21, 6976-11-1. At no stress the highest number of panicle/ plants found was 31 in Hashikalmi and the lowest number of panicle/plants was found in OM1490. Decreased number of panicle/ plant under water stress treatment was due to reduction in tiller number. Water deficit just before flower initiation may also decreased the number of spikelet primordial (Oosteruis and Cartwright, 1983).

Panicle dry weight per plant

In this study panicle dry weight per plant of different rice genotypes under drought condition have been shown in the Fig III. Significant differences were found among the varieties and the treatments for dry weight of panicle per plant. At 7 days drought stress the highest dry weight of panicle per plant was 21.56 g in BRRI dhan55 and the lowest weight dry weight of panicle per plant was found 10.88 g in OM1490. At 15 days drought stress the highest panicle dry weight was found 7.29 g in Hashikalmi and the lowest dry weight of panicle per plant was found 1.75 g in BR24. At no stress the highest panicle dry weight was found 33.08 g in BRRI dhan55 and the lowest panicle dry weight per plant was found 18.12 g in OM1490, 23.46 g in BRRI dhan42.

There were remarkable differences on dry weight of panicle among the genotypes under drought condition. BRRI dhan55 (34.82%,35.29%), produced the highest dry weight of panicle at 7 days stress condition and at 15 days stress reduction percent was 78.87 in BRRI dhan55 and 77.53 Hashikalmi, respectively and the highest reduction was in BR24 (92.63%), BR21 (91.57%) and OM1490 (88.92%) at 15 days stress. As a result, yield losses occurred. The results have the similarity with the results of. Islam *et al*. (1994) who observed that yield losses resulting from water deficit are severe at booting stage. Water stress at or before panicle initiation reduces potential spike number, decreases translocation of assimilates to the grains, which results low in grain weight and increases empty grains (RRDI, 1999).

Total dry matter / plant at harvest

The total dry matter (g) per plant of different rice genotypes under drought condition have been shown in the Fig IV. Significant differences were found among the varieties and the treatments for the characters of total dry matter (g) per plant. At 7 days stress the highest total dry matter per plant found was 57.50 g in BRRI dhan55 followed by 55.85 g in Hashikalmi and the lowest total dry matter per plant was found 24.58 g in OM1490. At 15 days stress the highest total dry matter per plant was found 16.57 g in Hashikalmi and the lowest total dry matter per plant was 5.74 g in BR24. At control the highest total dry matter per plant was 65.42 g in BRRI dhan55, the second highest total dry matter per plant was 64.79 g in Hashikalmi and the lowest dry matter per plant found was 34.79 g in OM1490.

Due to water deficit conditions root, shoot, leaf and panicle dry weight decreased, as a result the total dry matter became lower. In this study, it was found that at 7 and 15 days stress the highest total dry matter per plant was in BRRI dhan55, the reduction percent was 7.31, 8.99, respectively and the second highest total dry matter per plant was in Hashikalmi which reduction percent was 5.94, 12.25, respectively compared to control . It was observed that the total dry matter is decreased with the decreased of morphological characters including shoot root dry weight, tiller and leaf dry weight under drought stress condition. The results have the conformity with the results of Lum *et.al* (2014) who reported that in the activities of shoot length, root length and dry matter yield and biochemical parameters were decreases under drought condition. Acosta-Gallegos, *et al.* (1991), reported that leaf expansion rate and crop growth rate at mid-pod-filling were greatly reduced by drought stress, resulting in significant reductions in total dry matter.

Yield /plant

In this study, yield/ plant of different rice genotypes under drought condition have been shown in the Table 10. Significant differences were found among the varieties and the treatments for yield/ plant. At 7 days drought stress the highest yield/ plant found was 19.77 g in BRRI dhan55, followed by 19.21 g in Hashikalmi and the lowest yield/ plant found was 9.63 g in BR24. At 15 days stress the highest yield/ plant was found 10.7g in BRRI dhan55 followed by 10.23 Hashikalmi and the lowest yield/ plant was1.68g in BR24. At control the highest yield/ plant was found 34.17g in BRRI dhan55 and the lowest yield/ plant was found 20.17 g in BRRI dhan43.

In this study, it was found that the highest yield/ plant was found in BRRI dhan55 followed by Hashikalmi at 7, 15 days water stress (the reduction percent was 42.14, 40.58, respectively. These results are consistent with the observed parameters of total dry matter, total number of tillers, effective tillers and plant height and leaf area of these varieties. Therefore, it was observed that yield/ plant was decreased when decreased number of tillers per plant, total dry weight, plant height

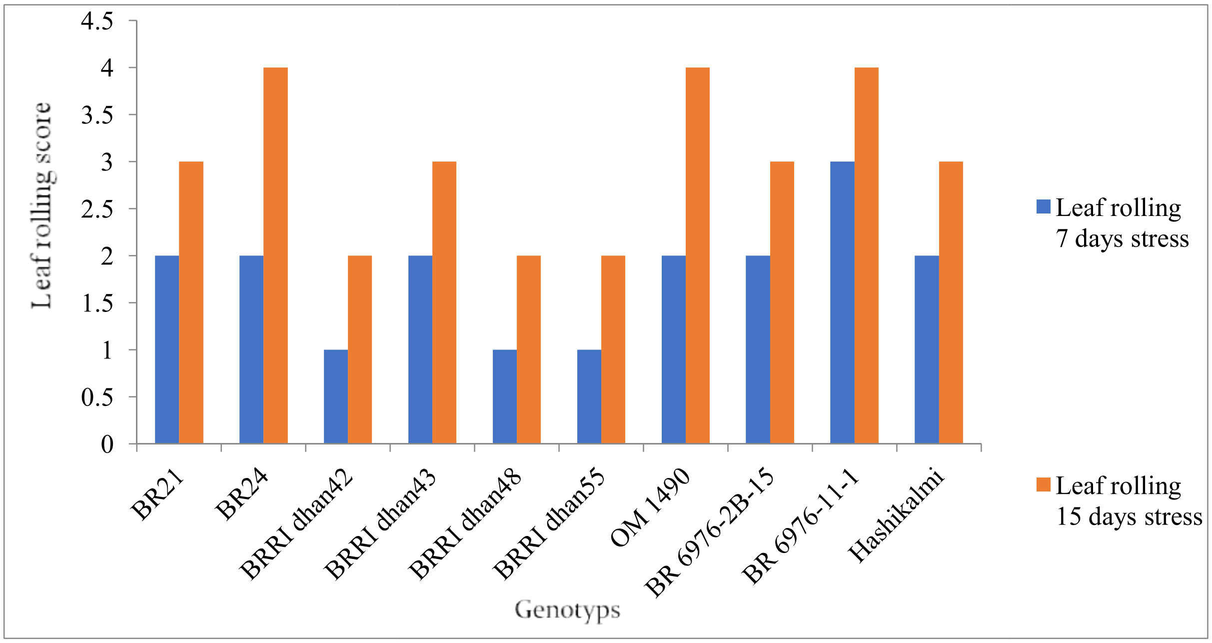


Fig I. Leaf rolling scoring at 7 days stress (blue colour) and 15 days stress (red colour) of different genotypes under drought.

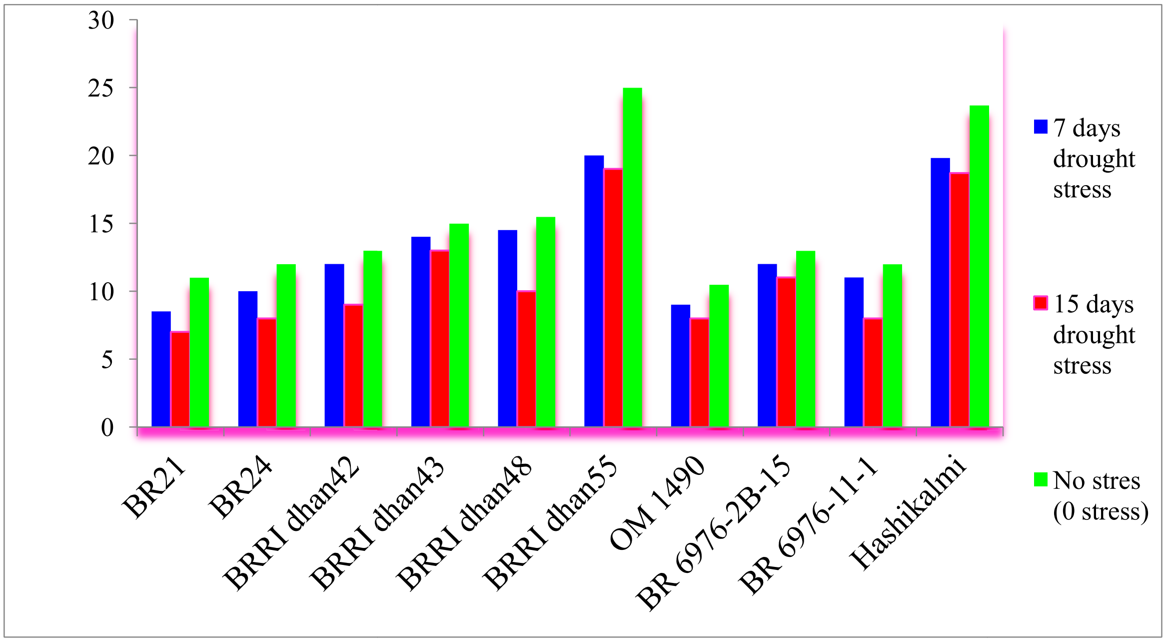


Fig II. Number of panicles at 7 days stress (blue colour), 15 days stress (red colour) and no stress (green colour) of different genotypes under drought.

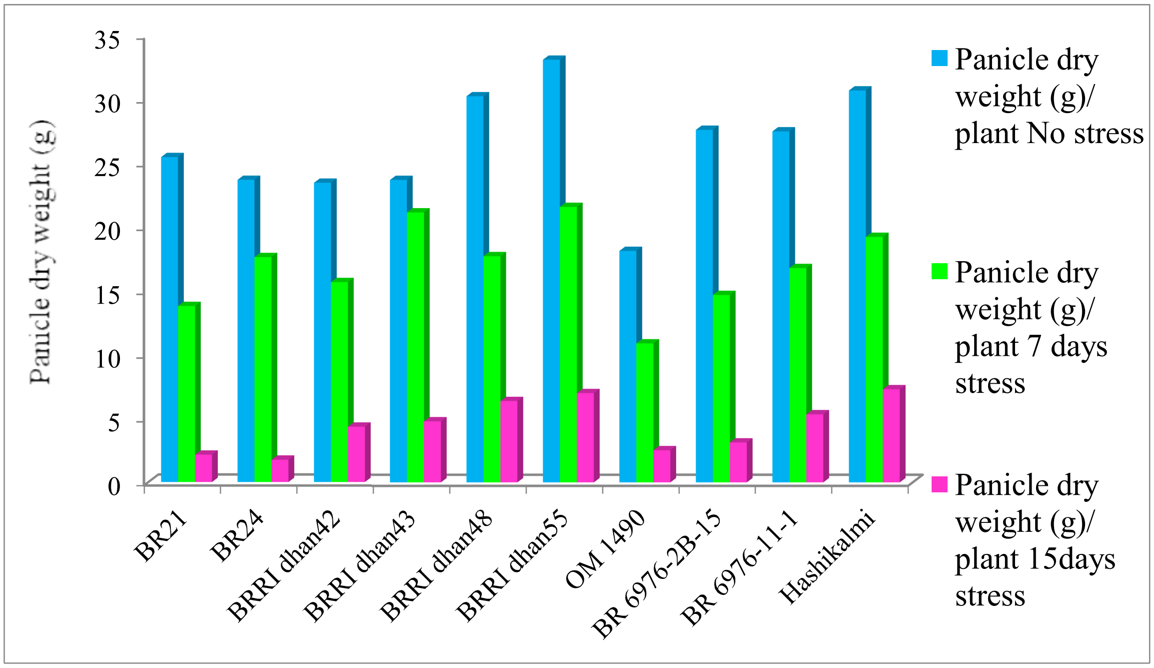


Fig. III. Effect of different durations (days) of water stress on panicle dry weight of different rice genotypes

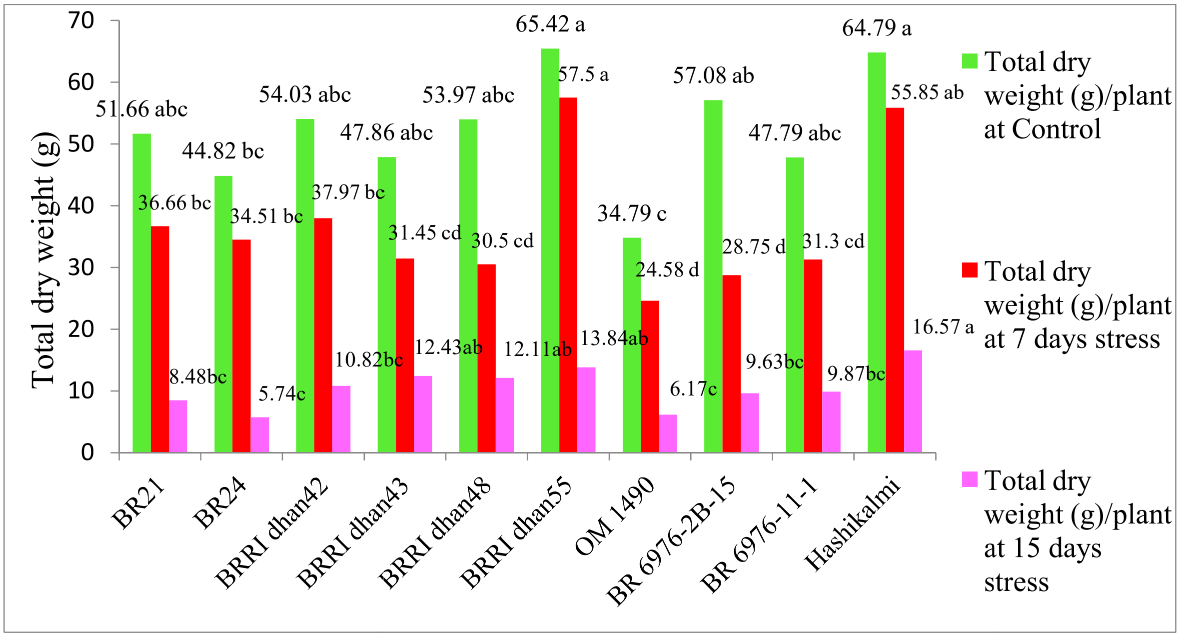


Fig. IV. Effect of different days water stress on total dry weights/ plant of rice genotypes

and leaf area were decreased under drought stress condition. On the other hand, yield is depended on the genotypes and the severity and the length of drought under drought condition. It might be due to inhibition of photosynthesis and less translocation of assimilates towards grain. The sensitive genotypes could lose their leaves, dry matter, and number of tillers and take much longer time to recover and develop new organ under drought condition. This result has the agreement with the results of Zubaer *et al*., (2007) who stated that reduced yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain. Edward and Wright (2008) also observed that the yield per plant was decreased under drought stress treatment in wheat.

Harvest index (HI)

The results of harvest index of different rice genotypes under drought condition have been shown in the Table 11. Significant differences were found among the varieties and the treatments for harvest index. At 7 days drought stress stress the highest harvest index was found 38.33 in BRRI dhan55 and the lowest was 27.56 in BR24. At 15 days stress, the highest harvest index was 35.67 in BRRI dhan55 and the lowest was found 25.33 in BR24. At control the highest harvest index was found 44.67 in BRRI dhan55 and the lowest was 34 in BR6976-11-1, 34.9 in BR24.

At 7 days drought stress the highest harvest index was found in BRRI dhan55 (reduction percent was 14.19 and the highest reduction percent was 21.03% in BR24). At 15 days stress, the highest harvest index was found in BRRI dhan55 (the reduction percent was 20.15 and the highest reduction percent was 29.04% in BR24). The results of the study agreed with the finding of Zubaer *et al*. (2007) who stated that harvest index was significantly influenced by moisture level in all rice genotypes. It might be due to the fact that water stress affects the translocation towards the grain. But the degree of reduction in HI value under lower moisture level was different in different genotypes. It was higher in Basmoti (13.15 to 36.84%) and RD2585 (12.5 to 28.12%) than that in Binadhan 4 (11.11 to 20.0 %).

Biological yield

The result of biological yield of different rice genotypes under drought condition have been shown in the Table 12. Significant differences were found among the varieties and the treatments for biological yield. At 7 days drought stress the highest biological yield found was 63.33 in BRRI dhan55 and 62.00 in Hashikalmi and the lowest biological yield was found 28.00 in BR24. At 15 days stress the highest biological yield was found 60 in Hashikalmi and BRRI dhan55 and the lowest biological yield was found 24.33 in BRRI dhan43. At control the highest biological yield was found 66.00 in BRRI dhan55followed by 63.33 in Hashikalmi and the lowest biological yield was found 39.67 in BR24. In this study, at 7 days drought stress the highest biological yield was found in BRRI dhan55, Hashikalmi (the reduction percent was the lowest 4.55% in BRRI dhan55, 1.59% in Hashikalmi) and the highest reduction percent was 36.84% in BR 6976-11-1. At 15 days water stress the lowest reduction percent was 9.09% in BRRI dhan55, 4.76% in Hashikalmi and the highest reduction percent was 51.22, 53.42 in BR21 and BRRI dhan48, respectively. The results have the conformity with the results of Prabhudeva (1998) who reported that exposure of sunflower plants to drought stress at bud initiation stage was more detrimental to seed and biological yield.

Dry matter accumulation of root

The results of dry matter accumulation of different rice genotypes under drought condition have been shown in the Fig.VI. Significant differences were found among the varieties and the treatments for this character. At 7 days drought stress the highest dry matter accumulation (root) found was 7.59g in Hashikalmi, the second highest dry matter accumulation found was 4.90g in BRRI dhan55 and the lowest dry matter accumulation was 0.89g in BRRI dhan48 which was not significantly different. At 15 days stress condition the highest dry matter accumulation was found 5.37 in Hashikalmi, the second highest dry matter accumulation was found 4.53g in BRRI dhan55 and the lowest was found 0.64g in BR24. At no drought stress the highest dry matter accumulation was found 8.19 in BRRI dhan55 followed by 8.07g in Hashikalmi and the lowest was found 2.61g in BRRI dhan43 which was not significantly different. The results have the informity with the results of Kage *et al. (*2004), who reported that plant productivity under drought stress is strongly related to the processes of dry matter accumulation and temporal root distribution. Asch *et al.* (2005) stated that drought effect assimilate accumulation between root and shoot. Asch *et al.* (2005) also advocated that rice reacted to drought stress with reductions biomass production, changes in root dry matter and rooting depth and a delay in reproductive development.

Table 10. Effect of different days water stress on yield/ plant of different rice genotypes.

Genotypes	Yield / plant (g)			Reduction (%) of yield/ plant	
	No stress	7 days stress	15days stress	7 days stress	15days stress
BR21	25.67 bc	13.0 de	2.32 ef	49.36	90.96
BR24	24.58 bcd	9.63 f	1.68 f	60.82	93.15
BRRI dhan42	21.77 cde	12.93 de	4.23 cde	40.61	80.56
BRRI dhan43	20.17 e	14.19 d	6.03 bcd	29.65	70.12
BRRI dhan48	21.00 de	16.85 bc	7.32 b	19.76	65.13
BRRI dhan55	34.17 a	19.77 a	10.7 a	42.14	68.77
OM 1490	21.49 de	10.36 ef	4.16 cde	51.79	80.64
BR 6976-2B-15	24.96 bcd	14.12 cd	4.00 def	43.43	83.97
BR 6976-11-1	28.00 b	14.03 de	6.47 bc	49.89	76.90
Hashikalmi	32.33 a	19.21 ab	10.23 a	40.58	68.36
CV (%)	8.66	10.74	22.7		

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

Table 11. Effect of different days water stress on harvest index of different rice genotypes.

Genotypes	Harvest index (%)			Reduction (%) of HI	
	Control	7 days stress	15 days stress	7 days stress	15days stress
BR21	38.05 ab	30.45 cd	27.00 d	19.97	29.04
BR24	34.90 b	27.56 d	25.33 d	21.03	27.42
BRRI dhan42	35.00 b	33.00 abcd	29.67 cd	5.71	15.23
BRRI dhan43	37.67 ab	32.67 abcd	29.67 cd	13.27	21.24
BRRI dhan48	44.67 a	37.33 ab	33.33 abc	16.43	25.39
BRRI dhan55	44.67 a	38.33 a	35.67 a	14.19	20.15
OM 1490	40.30 ab	36.67 ab	34.67 ab	9.01	13.97

BR 6976-2B-15	34.67 b	31.67 bcd	29.00 cd	8.65	16.35
BR 6976-11-1	34.00 b	34.33 abc	28.67 cd	2.97	15.68
Hashikalmi	39.38 ab	35.33 abc	30.00 bcd	10.28	23.82
CV (%)	18.90	9.18	8.61		

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

Table 12. Effect of different days water stress on biological yield of different rice genotypes

Genotypes	**Biological yield (g)/ plant**			**Reduction (%) of biological yield/ plant**	
	Control	7 days stress	15 days stress	7 days stress	15days stress
BR21	53.33 ab	43.00 ab	26.00 d	19.32	51.22
BR24	39.67 b	28.00 c	27..00 d	29.42	31.94
BRRI dhan42	49.33 ab	34.67 bc	28.00 d	31.08	43.24
BRRI dhan43	48.00 ab	36.67 bc	24.33 d	25.00	50.00
BRRI dhan48	53.67 ab	43.00 ab	25.00 d	19.88	53.42
BRRI dhan55	66.00 a	63.00 a	60.00 a	4.55	9.09
OM 1490	51.67 ab	47.33 ab	40.33 bcd	8.40	21.95
BR 6976-2B-15	50.33 ab	44.33 ab	34.00 cd	12.58	32.45
BR 6976-11-1	57.00 ab	36.00 bc	35.67 bcd	36.84	38.60
Hashikalmi	63.33 a	62.00 a	60.00 a	1.59	4.76
CV (%)	13.86	18.15	5.35		

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

Fig. V. Effect of different durations (days) of water stress on reduction percent of total dry weights/ plant (g) of different rice genotypes

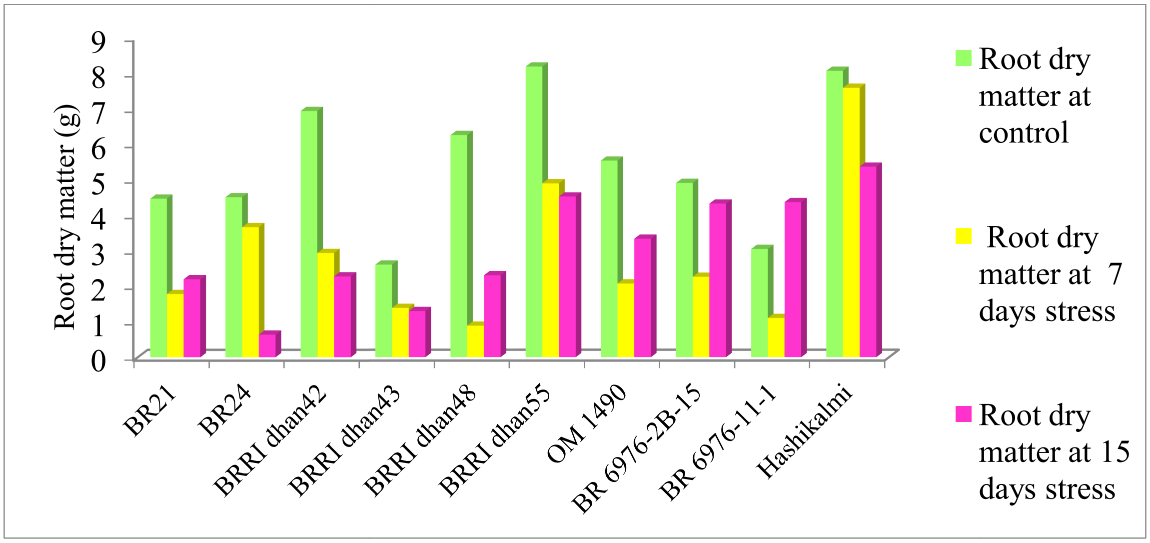


Fig. VI. Effect of different durations (days) of water stress on root dry matter accumulation of different rice genotypes

Relationship between total dry weight and yield/ plant

The relationship between **t**otal dry weight and yield/ plant was calculated and it was found that the correlation was highly significant. There was a strong positive correlation (r=0.642) between dry weight and yield/ plant (Fig.1.3). Drought stress affects total dry matter and harvestable yield in plant. The yield/ plant were the lowest when the dry weight was the lowest also. The yield/ plant were increased with the increase of total dry weight. Higher dry matter supplied more assimilates towards grain. Consequently the grain yield as well as dry weight was also higher. There was a positive correlation between shoot dry weight and achene yield per plant under water stress (Tahir *et al.* 2002). Plant productivity under drought stress is strongly related to the processes of dry matter partitioning and temporal biomass distribution (Kage *et al*., 2004).

1.23 Relationship between 1000 grains weight and yield/ plant

The result of the relationship between 1000 grains weight and yield/ plant was calculated and it was found that the correlation was highly significant. There was a positive correlation (r=0.579) between 1000 grains weight and yield/ plant (Fig.1.4).Total yield was found the lowest when 1000 grains weight was the lowest. The total yield gradually increased with the increase of individual grain weight. O'Toole *et al.* (1979) reported that water stress during grain filling stage reduces the weight of individual grain. Zubaer *et al*. (2007) showed that 1000 grain weight was reduced with reduced soil moisture levels. Higer 1000 grains weight indicates the higher dry matter content of grain which is related to yield.

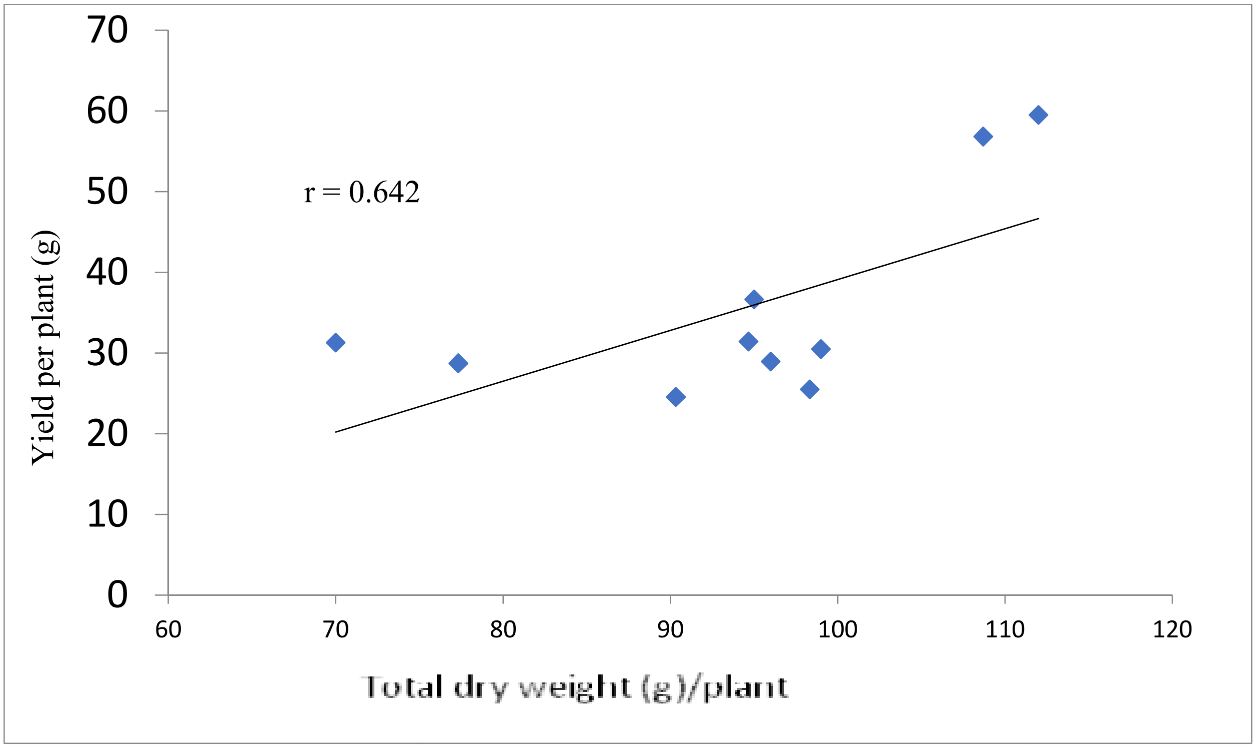


Fig. 1.3 Relationship between yield /plant and total dry weight

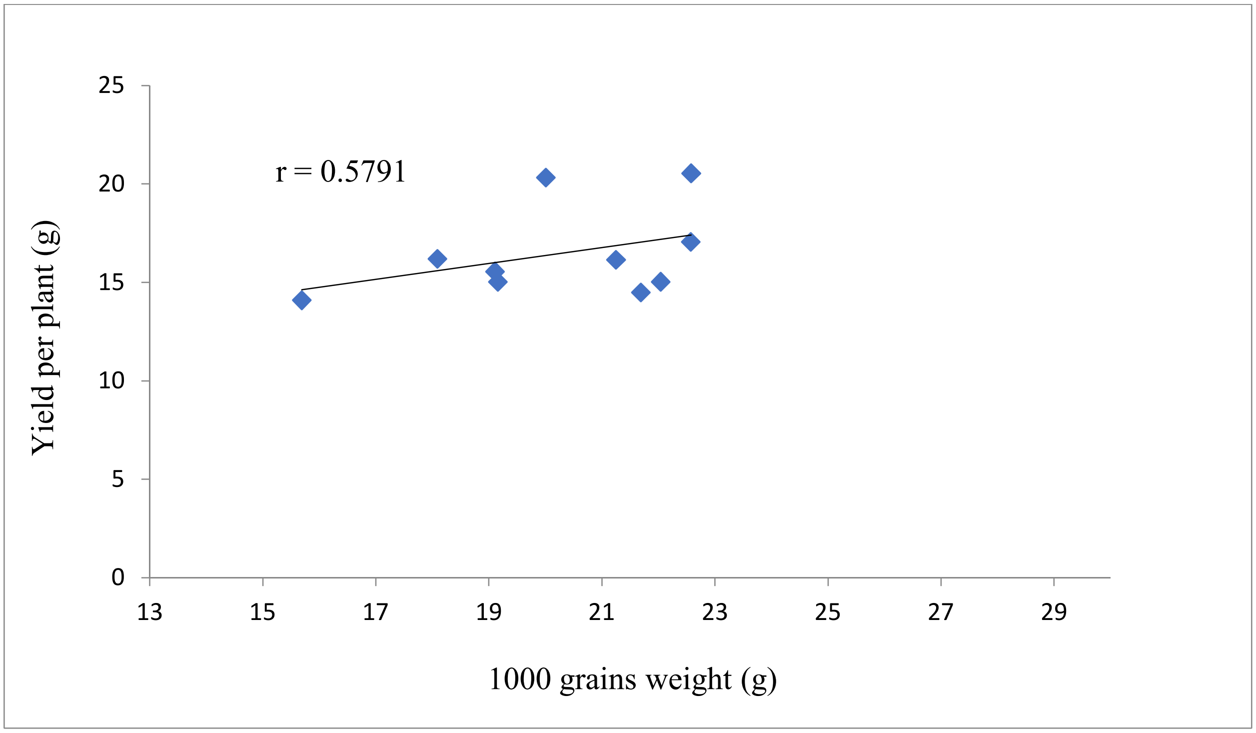


Fig. 1.4 Relationship between 1000 grains weight and yield /plant

Plate 1.1 Different rice genotypes before water stress treatment at seedling stage

Plate 1.2 Different rice genotypes after water stress treatment at seedling stage

Plate 1.3 Leaf rolling of different rice genotypes under drought condition

Experiment- 3

WATER STRESS EFFECTS ON MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL CHARACTERS OF SELECTED RICE GENOTYPES

In this experiment, the objectives were to assess morpho-physiological and biochemical of rice genotypes due to application of water stress at different age or stages of life cycle with a particular treatments and identification of the physiological parameters those play an important role in water stress tolerance and to find out their responses. Three better genotypes were selected from the first experiment according to their morpho-phsiological, yield and yield attributing characters under water stress conditions. The results of the present experiment in the form of different tables and figures along with necessary discussion have been presented below.

2.1 Soil moisture content

Soil water content of pot soil of rice genotypes under drought condition have been shown in the Tables 1a. to 1c. In case of varietal affect, the highest soil water content before stress was 2.33 cb and after stress the highest soil water was 30.28 cb (Table 1a). and in case of interaction affect, the highest soil water content before stress was 2.65 cb and the lowest was 1.33 cb and after stress, the highest soil water content was 30.93 cb and the lowest was 29.00 cb (Table.1c) which was significantly different from each other. It was observed that when water stress condition prevails due to soil moisture decrease root cannot uptake water to which plant growth was retarded, morpho-physiological, metabolic and biological processes were disturbed. Soil water is one of the most important factors limiting crop production all over the world, where irrigation is practiced or rain fed crops are grown (Carter, 1989).

2. Leaf area

Leaf area of different rice genotypes under drought condition have been shown in the Tables 2a To 2c. Significant differences were found among the varieties, the treatments and interaction effect for the characters of leaf area. In case of varietal effect the highest leaf area found was 44 cm^2 in Hashikalmi followed by 39.03 cm^2 in BRRI dhan55 and the lowest was 38.33 cm^2 in BR 6976-2B-15 (V2). In case of treatment effect the highest leaf area found was 44.11 cm^2 in control (T_0) and the lowest found was 38 cm^2 in T_1. In case of interaction effect the highest leaf area found was 46.86 cm^2 in V_3T_6 and the lowest was 20.99 in V_1T_3, V_3T_3.Due to drought stress the highest leaf area was found in Hashikalmi followed by BRRI dhan55 the lowest leaf area was found in BR 6976-2B-15.

Table 1a Varietal effect of soil water content (before and after stress) of different rice genotypes under water deficit condition

Variety	Soil water before stress (cb)	Soil water after stress (cb)
V_1 (BRRI dhan55)	2.333 c	30.28 a
V_2 (BR 6976-2B-15)	2.278 b	29.89 b
V_3 (Hashikalmi)	1.944 a	29.50 b
CV (%)	1.63	2.03
$LSD_{(0.05)}$	0.789	1.019

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

Table 1b. Drought treatment of soil water content (before and after stress) applied to different rice genotypes.

Drought treatments applied	Soil water before stress(cb)	Soil water after stress (cb)
T_1 (15 to 21 days age of plant)	2.236	29.89
T_2(35 to 41 days age of plant)	1.111	29.67
T_3(55 to 61 days age of plant)	2.01	29.88
T_4(75 to 81 days age of plant)	1.556	29.67
T_5(95 to 101 days age of plant)	1.890	30.22
T_6(115 to 121 days age of plant)	2.000	30.00
CV (%)	1.63	1.07

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

Table 1c. Interaction effect of soil water content, applied to different rice genotypes no of leaf and leaf area of three rice genotypes under water deficit condition

Interaction		**Soil water before stress(cb)**	**Soil water after stress (cb)**
V_1	T_1	2.65 ab	30.64
V_1	T_2	2.37 ab	29.63
V_1	T_3	1.27 bc	30.57
V_1	T_4	2.63 ab	30.33
V_1	T_5	2.71 ab	30.48
V_1	T_6	2.01 abc	30.27
V_2	T_1	2.34 ab	30.93
V_2	T_2	1.17 c	29.67
V_2	T_3	2.0 abc	30.33
V_2	T_4	2.61 a	29.67
V_2	T_5	2.02 abc	30.00
V_2	T_6	2.00 abc	30.08
V_3	T_1	2.38 ab	29.31
V_3	T_2	1.27 bc	29.02
V_3	T_3	2.45 ab	30.01
V_3	T_4	1.09 c	29.00
V_3	T_5	2.31 ab	29.67
V_3	T_6	2.00 abc	29.00
CV (%)		1.63	1.07

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

In this study, leaf area varied significantly under water stress condition. The results of the experiment have the similarity with the results of Eastham *et. al*., (1984) who reported that leaf expansion is most sensitive to water stress and leaf growth can be drastically reduced. Kusaka *et al*. (2005) found that development of optimal leaf area is important to photosynthesis. Kramer and Boyer (1995) also mentioned drought stress suppresses leaf expansion, tillering and midday photosynthesis and reduces photosynthetic rate and leaf area due to early senescence. The leaf growth was more sensitive to water stress in wheat than in maize and sunflower *Vigna* *unguiculata* (Manivannan 2007 and 2008). Water stress greatly suppresses cell expansion and cell growth due to the low turgor pressure. 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).

3. Number of leaves per plant

Numbers of leaves per plant of different rice genotypes under drought condition have been shown in the Tables 2a to 2c. Significant difference among the genotypes, the treatments and interaction effect for the character number of leaf was found. In this study, (varietal affect) the highest number of leaf found was 48.72 in Hashikalmi and the lowest found was 37.61 in BR 6976-2B-15 (V2) under drought condition. In case of treatment effect the highest no of leaf found was 49.44 in T_0 and the lowest was 37.61 in T_1. In case of interaction effect the highest no of leaf found was 49.38 in V_1T_0 and the lowest was 35.33 in V_2T_3 and V_3T_3.

In this study the highest number of leaf was found in Hashikalmi and the lowest was found in BR 6976-2B-15 V_2 under drought condition which was significantly different among the genotypes. The results of the experiment have agreement with the results of Zubaer *et al*. (2007) who stated that the number of leaves per hill varied significantly under different moisture levels, the highest number of leaves was found in 100% FC. At booting stage, Binadhan 4 produced the highest number of leaves per hill followed by Basmoti.

4. Specific leaf area (SLA)

Specific leaf area of different rice genotypes under drought condition have been shown in the (Tables 2a to 2c.). Significant difference among the genotypes, the treatments and interaction effect for specific leaf area was found. In case of varietal effect, the highest specific leaf area found was 196.0 (cm^2/ g) in V3 (Hashikalmi) and the lowest specific leaf area found was 186.6 ($cm^{2/}$ g) in BR6976-2B-15 (V2). In case of treatment effect the highest specific leaf area found was 198.3

Table 2a. Varietal effect of leaf area, no of leaf and specific leaf area ($cm^{2/\,g}$) of three rice genotypes under drought condition

Variety	leaf area (cm^2)	No of leaves/ plant	Specific leaf area (cm^2/ g)
V_1 (BRRI dhan55)	39.03 b	38.72 b	189.3 b
V_2 (BR 6976-2B-15)	38.33 b	37.61 bc	186.6 b
V_3 (Hashikalmi)	44.00 a	48.72 a	196.0 a
CV (%)	13.30	11.01	4.09

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

Table 2b. Drought treatment of leaf area, no of leaf and specific leaf area (cm^2/g)of three rice genotypes under drought condition

Drought treatment	leaf area(cm^2)	No of leaves/ plant	Specific leaf area/gm(cm^2/ g)
T_0 (control)	44.11 a	49.44 a	198.3 a
T_1 (15 to 21 days)	38.00 b	37.61 e	188.2 ab
T_2(35 to 41 days)	41.05 ab	38.72 de	184.9 b
T_3(55 to 61 days)	40.41 ab	42.78 bc	191.6 ab
T_4(75 to 81 days)	42.76 ab	45.32 b	191.6 ab
T_5(95 to 101 days)	43.07 ab	42.22 c	192.4 ab
T_6(115 to 121 days)	44.00 ab	48.72 a	195.2 a
CV (%)	13.30	11.01	4.09

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

Table 2c. Interaction effect of no of leaf, leaf area and specific leaf area (cm$^{2/ g}$) of three rice genotypes under drought condition

Interaction		leaf area (cm^2)	No of leaves per plant	Specific leaf area (cm^2/g)
V_1	T_0	46.86 a	49.38 a	195.2 a
V_1	T_1	35.53 bc	37.61 bcd	187.3 bc
V_1	T_2	41.52 abc	38.72 bc	185.7 bc
V_1	T_3	20.99 d	48.72 a	192.7 abc
V_1	T_4	41.05 abc	36.00 bcd	194.3 abc
V_1	T_5	40.41 abc	42.22 ab	188.7 bc
V_2	T_6	45.76 ab	42.78 ab	187.3 bc
V_2	T_0	43.22 abc	48.28 a	195.9 a
V_2	T_1	42.55 abc	43.22 ab	183.0 bcd
V_2	T_2	41.21 abc	35.33 bcd	179.0 c
V_2	T_3	34.07 c	39.56 b	188.0 bc
V_2	T_4	36.48 abc	35.69 bcd	190.3 abc
V_2	T_5	34.57 bc	39.00 b	191.0 abc
V_2	T_6	35.66 bc	38.00 bc	188.3 bc
V_3	T_0	46.95 a	48.33 a	196.2 a
V_3	T_1	41.40 abc	40.78 b	194.3 abc
V_3	T_2	43.07 abc	40.00 b	190.0 abc
V_3	T_3	20.99 d	35.33 bcd	194.0 abc
V_3	T_4	44.00 abc	38.67 bc	194.0 abc
V_3	T_5	38.33 abc	43.00 ab	190.7 abc
V_3	T_6	45.29 ab	48.67 a	196.0 a
CV (%)		13.30	11.01	4.09

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

cm^2/ g in T_0 and the lowest specific leaf area was 184 (cm^2/ g) in T_2. In case of combination effect the highest specific leaf area found was 195.2(cm^2/ g) in V_1T_0 and the lowest specific leaf area found was 179(cm^2/ g) in V_2T_2. The results have similarity with the results of Liu *et.al.* (2004)

who stated that drought stress significantly decreased SLA in severe water stress, this adaptive mechanism of cowpea to water stress helps in reducing water loss from the evaporative surfaces.

5. SPAD reading from vegetative to maturity

SPAD reading of different rice genotypes under water stress duration have been shown in the Tables 3a to 3c. SPAD reading was recorded from the flag leaf of all tillers and average value was taken during the growth period after 7 days interval from vegetative to maturity**.** Significant different among the genotypes, the treatments and interaction effect for SPAD value. In case of varietal effect the highest SPAD value found was 35.73 in Hashikalmi (V_3) followed by 35.27 in BRRI dhan55 (V_1)) and the lowest SPAD value found was 34.25 in BR 6976-2B-15 (V_2). In case of treatment effect, the highest SPAD value found was 35.45 in T_0 and the lowest SPAD value was 33.20 in T_6 which were not significantly different among the treatment. In case of combination effect (variety and treatment) the highest SPAD value found was 38.88 in V_1T_0 and the lowest SPAD value was 32.13 in V_2T_6.

SPAD value represents the greenness of the leaf. In this study, SPAD value was recorded from the flag leaf of all tillers and the average value was taken during vegetative to maturity**.** At vegetative stage SPAD reading was recorded around 35 to 39. SPAD value was recorded ranging from 37 to 39 BRRI dhan55 during anthesis. After anthesis SPAD value slightly increased and then gradually decreased with advanced towards maturity. In this study, due to drought conditions the highest SPAD value was found in V3 (Hashikalmi) followed by BRRI dhan55 (V1)) and the lowest SPAD value was found in BR 6976-2B-15 (V2) which was not significantly different among the genotypes. This result have similarity with the result of Zhang and Kirkham (1996) who advocated that decreased of chlorophyll content during drought stress depending on the duration and severity of drought level. Decreasing of chlorophyll content in plants such as *Paulownia imperialis* (Astorga, 2010) bean (Beinsan *et al.* 2003) was reported under drought stress.

6. Relative water content (RWC) of flag leaf

The relative water content of leaf of different rice genotypes under water stress duration have been shown in the Tables 3a to 3c. There was a significant difference among the genotypes, the and interaction effect for relative water content. In case of varietal effect the highest relative water content was found 95.2% in BRRI dhan55 followed by 90% in Hashikalmi and the genotypes BR 6976-2B-15 (V_2) had the lower RWC found was 80.18% under drought condition which was significantly different among the variety. In case of treatments effect T_0 had shown the higher RWC content (99.1) while lower RWC found was 90.2. In case of interaction affects V_1T_0 had higher RWC 121.4 in V_3T_0 and lower RWC 71.52 in V_2T_6 under water stress condition.

In this study, under water stress condition RWC declined. RWC were reduced in various genotypes at different growth stage. RWC was determined to give indication on the plant water status under drought condition. Among the genotypes BRRI dhan55 (V1) had higher RWC content while genotypes BR 6976-2B-15 (V2) had lower RWC. Drought stress significantly reduced RWC due to higher evaporation and water stress. The relative water content of leaf depends on the moisture content of the soil and the water absorbing capacity of the root. RWC of different crops was the highest in the morning and gradually decreased. The results have the similarity with the results of

Chowdhury (2009) stated that relative water content (RWC) values of seven genotypes at three different growth stages water stress significantly reduced RWC in the morning (8:00am) and also at noon (1:00pm). Several researchers reported that RWC of different crops was the highest in the morning and gradually decreased thereafter (Paul and Aman, 2000).

7. Leaf dry weight

Leaf dry weight of different rice genotypes under drought condition have been shown in the Tables 4a to 4c. There was a significant difference among the genotypes, the treatments and interaction effect for leaf dry weight. In case of varietal effect the highest leaf dry weight found was 0.26g in BRRI dhan55 followed by 0.25 in V_3 (Hashikalmi) and the lowest leaf dry weight found was 0.23 in BR 6976-2B-15 (V_2). In case of treatment effect the highest leaf dry weight found was 0.21 in T_0 and the lowest leaf dry weight content found was 0.17 in $T_{5,}$ T_5 which was significantly different among the treatments. Combination effect of variety and treatment the highest leaf dry weight found was 0.26 in V_1T_0 and the lowest was 0.12 in V_2T_1.

Table: 3a. Varietal effects of SPAD value and RWC of rice genotypes under water stress

Variety	SPAD value	RWC

V_1 (BRRI dhan55)	35.27 ab	95.20 a
V_2 (BR 6976-2B-15)	34.25 b	80.18 b
V_3 (Hashikalmi)	35.73 a	90.0 ab
CV (%)	7.94	26.57

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

Table: 3b. Varietal effects of SPAD value and RWC of rice genotypes under water stress

Treatment	SPAD value	RWC
T_0 (Control)	35.45 a	99.1
T_1 (15 to 21 days)	35.81 ab	90.2
T_2(35 to 41 days)	35.79 ab	93.74
T_4(75 to 81 days)	36.14 ab	90.36
T_5(95 to 101 days)	33.43 b	95.32
T_6(115 to 121 days)	33.20 b	98.71
CV (%)	7.94	26.57

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

Table 3c. Interaction effect of spade value and RWC of three rice genotypes underwater stress

Interaction effect		Spade value	RWC
V_1	T_0	38.88 a	121.4 a
V_1	T_1	37.45 ab	104 abc
V_1	T_1	36.60 ab	103.8 abc
V_1	T_2	37.03 ab	98.60 abc
V_1	T_3	37.70 ab	95.21 abc
V_1	T_4	34.70 b	97.58 abc
V_1	T_5	33.27 bc	105.9 abc
V_1	T_6	32.30 bc	114.1 ab
V_2	T_0	38.34 a	82.89 bc
V_2	T_1	35.17 ab	75.94 bc
V_2	T_2	32.86 bc	79.81 bc
V_2	T_3	35.50 ab	77.86 bc
V_2	T_4	34.35 ab	76.59 bc
V_2	T_5	33.47 b	71.52 bc
V_2	T_6	32.13 bc	82.36 bc
V_3	T_0	39.88 a	121.9 a
V_3	T_1	35.67 ab	98.8 abc
V_3	T_2	37.47 a	99.8 abc
V_3	T_3	37.50 a	97.08 abc
V_3	T_4	36.37 ab	105.5 abc
V_3	T_5	32.53 bc	81.15 bc
V_3	T_6	33.83 bc	118.8 ab
CV (%)		7.94	25.57

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

Liu *et. al*. (2004) stated that drought stress significantly decreased plant total dry mass, but the proportion of changes differed among root, stem, and leaf, whereas leaf dry mass ratio was decreased.

8. 1000- grains weight

Weight of thousand grains (g) of different rice genotypes under drought condition have been shown in the Tables 4a to 4c. Significant difference among the genotypes, the treatments and interaction effect for weight of thousand grains. In case of varietal effect the highest weight of thousand grains found was 16 g in BRRI dhan55 followed by Hashikalmi (V_3) and the lowest weight of thousand grains found was 11.67g in BR 6976-2B-15 (V_2). In case of treatment effect on the highest weight of thousand grains was 22.00 (g) and the lowest weight found was 14.76g in T_6 which was not significantly different among the treatment. In case of combination effect (variety and treatment) the highest weight of thousand grains found was 22.66 g (V_3T_5) and the lowest weight of thousand grains found was 11.67 g in V_1T_3.

Weight of thousand grains of different rice genotypes was different under drought condition which depends on the individual grain weight. In this study, BRRI dhan55 and Hashikalmi possess the highest weight of thousand grains. Considering the treatment effect the highest weight of thousand grains was in T_0. Considering the combination effect the highest weight of thousand grains found was in V_1T_0. Under drought conditions BR 6976-2B-15 was mostly source limited during grain filling stage as a result, grain weight decreased. The result have infirmity with the results of Zubaer *et al*. (2007) who showed that 1000 grain weight was reduced with reduced soil moisture levels. Begum (1992) showed that water stress after flowering decreased the individual grain weight. Tsudo and Takami (1991) advocated that water stress reduced grain weight. RRDI (1999) stated that stress during grain filling stage decreased grain weight.

9. Anthocyanin content of leaf

Anthocyanin content ($\mathbf{Q_{Anthocyanins} = (A_{530}–0.25×A_{657}) ×M^{-1}}$) of different rice genotypes under drought condition have been shown in the Fig.1. Here the highest anthocyanin content was found in 0.464 in BRRI dhan55 (V1) followed by 0.402 in Hashikalmi (V3) and the lowest found was

Table 4a. Varietal effect of leaf dry weight (g) and weight of 1000- grains (g) of three rice genotypes under water stress condition

Variety	Leaf dry weight(g)	Weight of 1000- grains (g)
V_1 (BRRI dhan55)	0.26 a	16.00 a
V_2 (BR 6976-2B-15)	0.23 b	11.67 c
V_3 (Hashikalmi)	0.25 ab	15.86 b
CV (%)	0.19	9.31

Values followed by different letter(s) indicate significantly different from each other by DMRT at 5%

Table 4b. Treatment effect of leaf dry weight (g) and weight of 1000- grains (g) of three rice genotypes under water stress condition

Drought treatment	Leaf dry weight	Weight of 1000- grains (g)
T_0 (control)	0.21 a	22.00 a
T_1 (15 to 21 days)	0.17 d	16.79 ab
T_2(35 to 41 days)	0.20 ab	16.32 ab
T_3(55 to 61 days)	0.19 b	19.17 a
T_4(75 to 81 days)	0.19 b	17.79 ab
T_5(95 to 101 days)	0.17 d	16.44 ab
T_6(115 to 121 days)	0.18 c	14.76 d
CV (%)	0.19	9.31

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

Table 4c. Interaction effect of leaf dry weight (g) and weight of 1000 -grains (g) of three rice genotypes under water stress condition

Interaction		leaf dry weight (g)	1000-grains wt (g)
V_1	T_0	0.26 a	22.66 a
V_1	T_1	0.2033 ab	18.50 abcde
V_1	T_2	0.1967 ab	14.26 def
V_1	T_3	0.2100 ab	11.67 f
V_1	T_4	0.1700 ab	22.00 ab
V_1	T_5	0.1433 ab	14.78 cdef
V_1	T_6	0.1600 ab	16.79 abcdef
V_2	T_0	0.2567 a	21.45 abc
V_2	T_1	0.1267 b	16.32 abcdef
V_2	T_2	0.1967 ab	19.17 abcd
V_2	T_3	0.1700 ab	17.79 abcdef
V_2	T_4	0.2733 a	16.44 abcdef
V_2	T_5	0.1533 ab	16.76 abcde
V_2	T_6	0.2000 ab	17.41 abcdef
V_3	T_0	0.2033 ab	22.66 a
V_3	T_1	0.1700 ab	22.00 ab
V_3	T_2	0.2067 ab	18.62 abcde
V_3	T_3	0.2167 ab	21.00 abc
V_3	T_4	0.1533 ab	21.33 ab
V_3	T_5	0.2100 ab	16.67 abcdef
V_3	T_6	0.1867 ab	15.45 bcdef
CV (%)		0.19	9.31

Values followed by different letter(s) indicate significantly different from each other 5% level.

0.305 in V2 (BR 6976-2B-15). Anthocyanin content was increased under water stress condition. The lowest anthocyanin content was 0.0062 which was well water green color leaf.

In the study, anthocyanin content was increased under water stress condition. Leaf accumulates anthocyanins under drought conditions and the red colour increased as the intensity of water deficit increased. Under drought condition BRRI dhan55 (V1) produced more anthocyanins followed by Hashikalmi (V3) to survive plant against stress conditions. This results have the similarity with the results of Scott (1999) who stated that anthocyanin were water soluble pigments found in all plant tissues due to stress condition. Andersen and Jordheim (2006) reported that anthocyanins usually appear red colour in leaf cells due to stress condition, but depending on their chemical nature and concentration, the vacuolar pH and interactions with other pigments, they can result in red, pink, purple, blue, orange, brown, and even black leaf colours. Krol *et al*. (1995) and Burger and Edwards (1996) also mentioned anthocyanins had been located in the root, shoot and leaves. Anthocyanins had been found in or just below the upper epidermis of leaves. Davies (2004) published the articles that coloration have assumed red foliage to be the outcome of the production of anthocyanins on plant.

10. Stomatal conductance

Stomatal conductance of different rice genotypes under drought condition have been shown in the (Fig. 2 to 3). In the study, stomata conductance decreased in the varieties of rice after drought condition. Before stress the highest stomatal conductance was 1502.7 (µmol/$m^{-2}s^{-1}$) in BRRI dhan55 followed by 1490.5 (µmol/$m^{-2}s^{-1}$) in Hashikalmi and the lowest was 861.4 (µmol/$m^{-2}s^{-1}$) in BR6976-2B-15. After stress the highest stomatal conductance was 187.5 (µmol/$m^{-2}s^{-1}$) in BRRI dhan55 followed by 173.7 (µmol/$m^{-2}s^{-1}$) in Hashikalmi and the lowest was 135.1 (µmol/$m^{-2}s^{-1}$) in BR6976-2B-15.

In the study, stomatal conductance declined in case of all varieties of rice under drought condition. After stress condition stomatal conductance was highest in BRRI dhan55 followed by Hashikalmi and lowest in BR6976-2B-15. In case of treatment effect before water stress stomatal conductance was high and gradually decreases under drought condition. At the beginning of this experiment stomata conductance of 1st to 3rd stress was high in all the genotypes and gradually declined as the intensity of water deficit increased and then in recovery stage conductance was increased. Stomata conductance of different rice genotypes was decreased under drought condition. The results conform to the results of Hirasawa (1999) who showed that stomata conductance decreased in all the varieties of rice as the intensity of water deficit increased. Rice is a notoriously drought-susceptible crop due in part to its rapid stomatal closure and little circular wax during mild water stress. Zulkarnain *et al.* (2009) reported that the decline in stomatal conductance was faster after 6 days of stress development than under well-watered condition. Stomatal conductance of MR220 and MUDA declined more rapidly than in other varieties.

11. Leaf temperature

Leaf temperature of different rice genotypes under drought condition have been different in the (Fig 4.). The lower leaf temperature was at 8.00am and at 12.00am leaf temperature was high in all the genotype under drought condition. In the morning leaf temperature was $(33.2- 33.6)^{0}$C in BR6976-2B-15 followed by Hashikalmi and BRRI dhan55 comparatively low and gradually increased in the noon 12 am (34.4 - 34.7) ^{p0}C under water stress condition. Leaf temperature was higher in drought stressed plant than in well-watered plants. Leaf temperatures of Hashikalmi were lower than that of BR6976-2B-15. The plants that showed a lower leaf temperature also showed a higher photosynthetic rate. Higher leaf temperature also showed a lower photosynthetic rate. So, under drought condition leaf temperature was higher and before drought condition leaf temperature was lowest. The results would compare with Siddique *et al*. (1999), who reported that leaf temperature in drought stressed plant were higher than in well-watered plants at both vegetative growth and anthesis growth stages. Lower leaf temperature was associated with a higher photosynthetic rate. Leaf temperatures of Sonalika and Kalyansona were significantly lower than that of C306.

12. Leaf humidity (%)

Leaf humidity of different rice genotypes under water stress condition have been shown in the Fig.5. Before water stress condition leaf humidity was high in all varieties. At the starting stage of water stress treatment the leaf humidity was higher which gradually decreases after water stress treatment. Leaf humidity was depended on severity of water stress and duration of water stress condition.

The results conform to the results of Liu *et.al*. (2004) who stated that drought stress significantly decreased specific leaf area can be used to estimate the reproductive strategy of a particular plant based upon light and moisture (humidity) levels, among other factors.

13. Specific leaf weight (SLW)

Specific leaf weight (SLW) is defined as the mass of leaf dry matter per unit of leaf area. SLW also expressed the thickness of leaf. Specific leaf weight (SLW) of different rice genotypes under water stress condition have been shown in the Fig.6.The plant with higher SLW (thick leaf) possess more mesophyll cells for photosynthesis. SLW gradually increased with decreasing soil moisture content (Fig). But there were no significant difference among the treatments in those genotypes. The highest specific leaf weight (SLW) found was 6.88 mg/ cm^2 in BRRI dhan55 and the lowest SLW found was 6.15 mg/ cm^2 in BR 6976-2B-15 (V_2).

14. Days to flowering

Days to flowering of different rice genotypes under drought condition have been shown (Tables 5a to 5c). Significant difference among the genotypes, the treatments and interaction effect for days to flowering The highest days to flowering found was 61.22 in BRRI dhan55 followed by 58.44 in BR 6976-2B-15 (V_2) and the lowest days to flowering found was 56.39 in Hashikalmi (V_3) (Table 3.5). In case of treatment effect, the highest day to flowering found was 61.88 in T_0 and the lowest found was 56.22 in T_5 (Table 3.6). In case of combination effect the highest days to flowering was 62.78 in V_1T_0 and the lowest was 52.67 in V_3T_5 (Table 3.7).

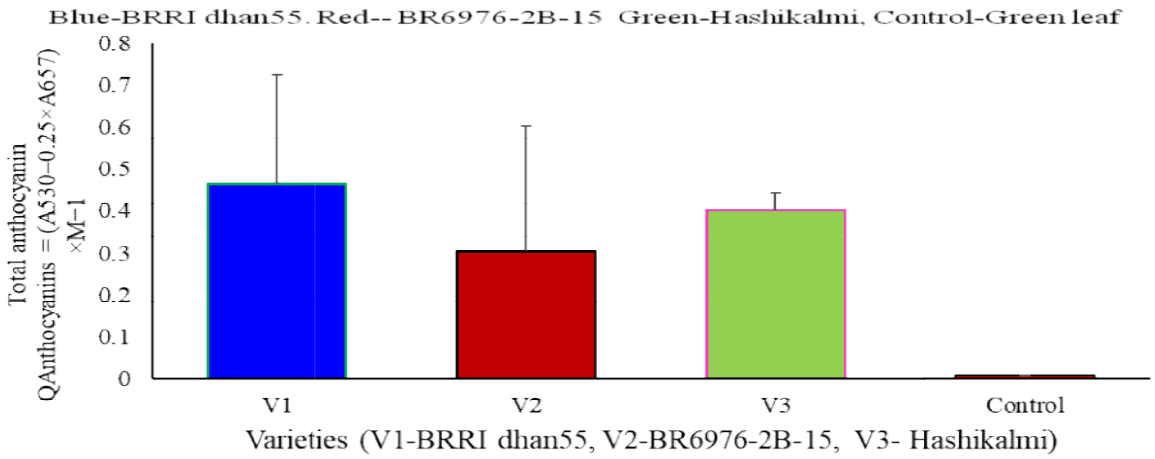


Fig. 1. Anthocyanin content of three rice genotypes under water deficit conditions.

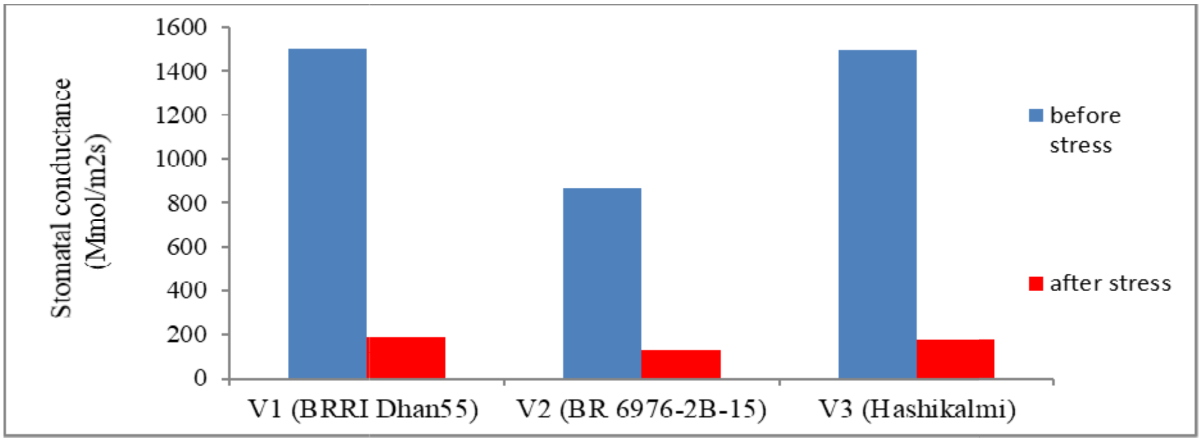


Fig. 2. Stomata conductance before and after stress of three rice genotypes under drought condition

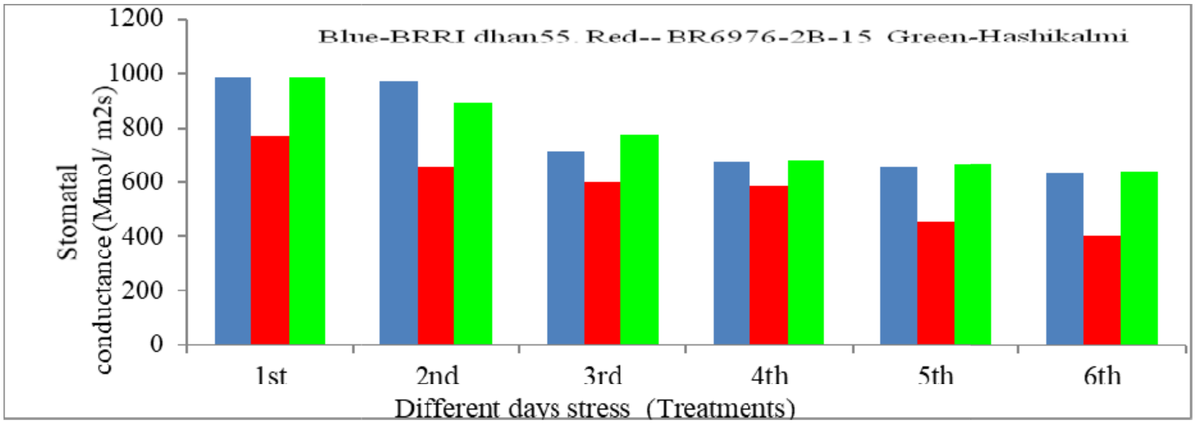


Fig. 3. Stomata conductance at 15 DAS (1st), 35 DAS (2nd), 61 DAS (3rd), 81 DAS (4th), 101 DAS (5th), 121 DAS (6th) days drought condition stress) of three rice genotypes

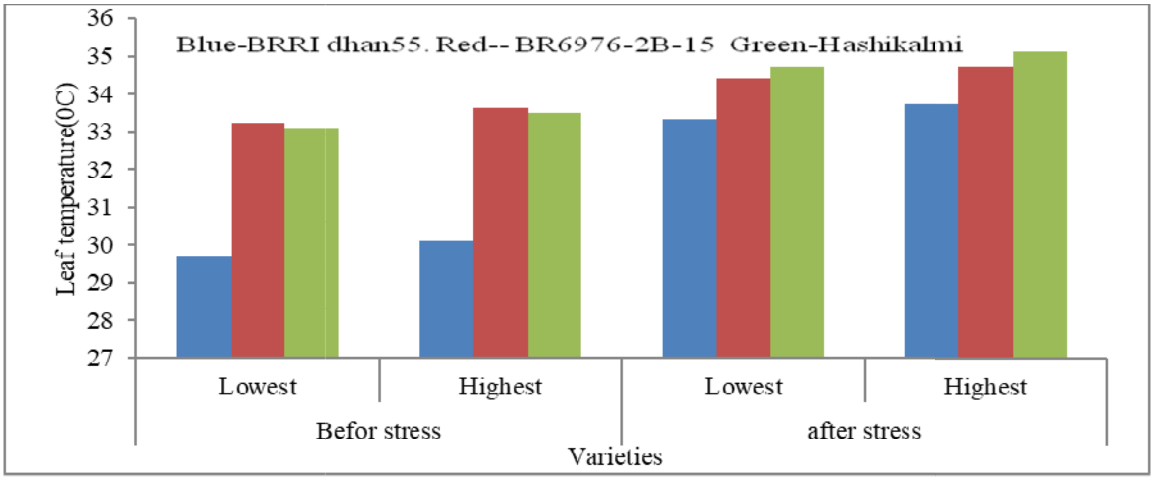


Fig. 4. Effect of leaf temperature before and after drought stress of three rice genotypes

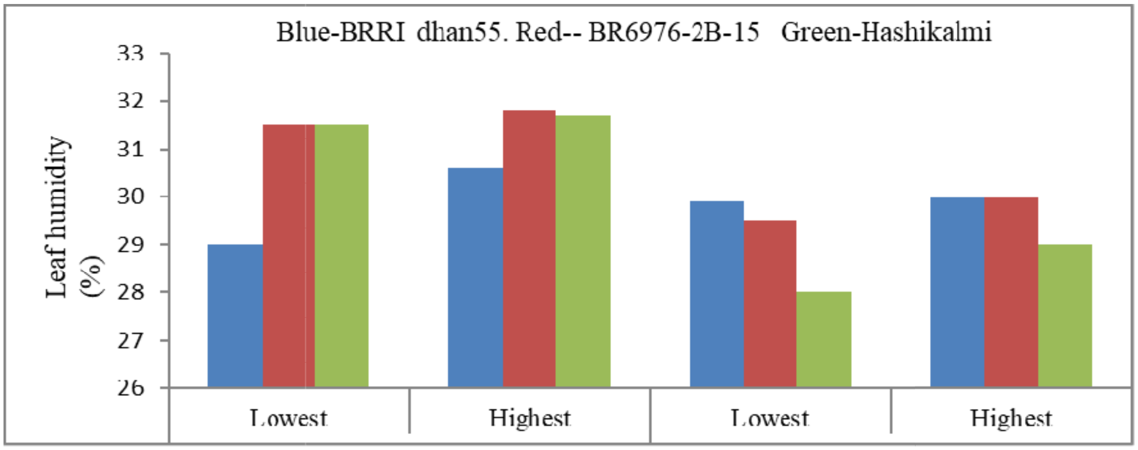


Fig. 5. Effect of water stress on leaf humidity of leaf at before and after stress of three rice genotypes

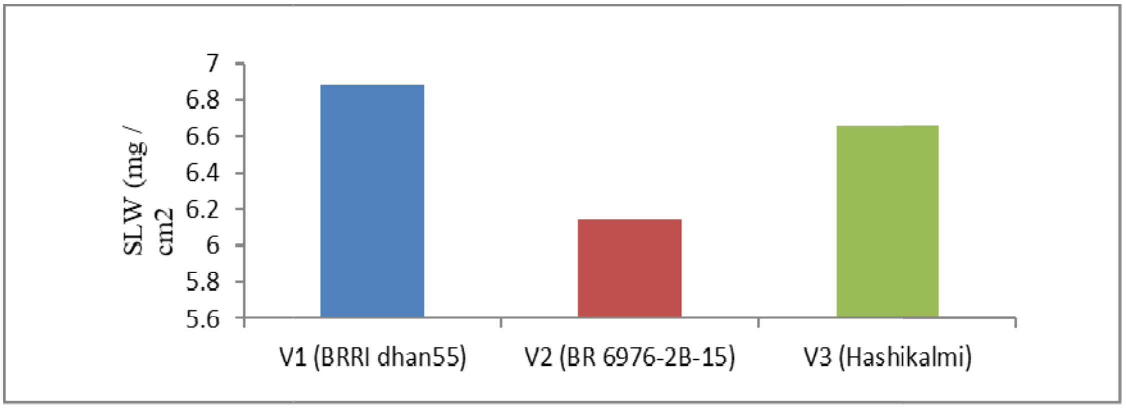


Fig. 6. Effect of water deficit on specific leaf weight (SLW) of three rice genotypes

In this study, under water stress early flowering showed. The highest days to flowering found in BRRI dhan55 (V_1) which was significantly different among the genotypes. When early flowering showed due to water stress, plant growth hampered, tillering, spicklet of panicle reduced, as a result yield decreased. The results have the similarity with results of Zubaer *et al*. (2007) who showed that water stress affects more at flower stage than that other stages. Begum (1992) conducted that water stress effect on flowering decreased the individual grain weight. Water deficit just before flower in initiation may also decrease the number of spicklet primordial at this stage (Oosteruis and Cartwright, 1983).

15. Days to maturity

Days to maturity of different rice genotypes under drought condition have been sown in the Tables 5a. to 5c. Significant different among the genotypes, the treatments and interaction effect for the characters of days to maturity was found. In this present study the highest days to maturity was 114.9 in BR 6976-2B-15 (V_2) and the lowest days to maturity found was 96.6 in Hashikalmi (V_3) (Table 3.5). In case of treatment effect on the highest days to maturity found was 113 in T_0 and the lowest days to maturity found was 96.4 in T_5 (Table 3.6). In case of combination effect the highest days to maturity found was 115.3 in V_1T_0 and the lowest days to maturity was 95.52 in V_3T_1 (Table 3.7).

In this study early maturity showed due to drought stress which had significant effect on days to maturity. The highest days to maturity were in BRRI dhan55 and the lowest days to maturity in Hashikalmi (V_3) which was significantly different among the genotypes. The results have conformity with the results of Zubaer *et al*. (2007) who showed that water stress affects more at maturity stages. Early maturity showed due to drought stress which was similar to this present study. The results also showed that water stress affects more maturity stages than that at booting stages. Due to water stress condition plant showed early maturity by reducing tillering, number of panicle, spikelet, suppresses leaf expansion which causes leaf senescence. Early senescence causes low yield. Faster recovery of tolerant genotype was also associated with a shorter day to maturity (Singh *et al*. 2009). Levitt (1980) stated that crop maturity period was shortened by environmental stresses, which was mainly due to limited source caused by leaf senescence for the sink. Drought

Table 5a. Varietal effect of stress on days to flowering and days of maturity and panicle dry weight of three rice genotypes under drought

Variety	Days to flowering (DAS)	Days to maturity (DAS)
V_1 (BRRI dhan55)	61.22 a	113.3 a
V_2 (BR 6976-2B-15)	58.44 bc	114.9 b
V_3 (Hashikalmi)	56.39 b	97.9 bc
CV (%)	3.26	4.92

Values followed by some letter(s) indicate significantly different from each other by DMRT at 5% level. Table 5b.

Table 5b.Treatment effect on days of flowering and days to maturity of three genotypes under drought rice

Treatment effect	Days to flowering (DAS)	Days to maturity (DAS)
T_0 (control)	61.88 a	113.0 a
T_1 (15 to 21 days)	61.78 a	98.3 b
T_2(35 to 41 days)	61.00 ab	105.4 ab
T_3(55 to 61 days)	59.67 b	99.0 b
T_4(75 to 81 days)	61.00 ab	98.1 b
T_5(95 to 101 days)	56.22 a	96.4 c
T_6(115 to 121 days)	58.44 ab	112.9 a
CV (%)	3.26	4.92

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

Table 5c. Interaction effect of days to flowering and days to maturity of three rice genotypes under water deficit conditions.

Interaction effect		Days to flowering (DAS)	Days to maturity (DAS)
V_1	T_0	62.78 abc	115.3 a
V_1	T_1	61.67 bc	113.3 abc
V_1	T_2	61.33 bc	112.3 abc
V_1	T_3	60.33 cdef	112.3 abc
V_1	T_4	61.33 bc	111.3 abcd
V_1	T_5	60.00 cdefg	111.7 abcd
V_1	T_6	62.67 abc	110.7 abcde
V_2	T_0	59.78 cdef	115.3 a
V_2	T_1	58.00 efg	113.3 abc
V_2	T_2	58.67 efg	112.3 abc
V_2	T_3	57.33 fg	112.3 abc
V_2	T_4	59.33 cdef	111.3 abcd
V_2	T_5	59.33 cdef	115.0 a
V_2	T_6	58 .65 efg	114.3 bcde
V_3	T_0	56.78 fg	98.3 cde
V_3	T_1	55.67 fg	95.52 de
V_3	T_2	53.00 g	99.0 cde
V_3	T_3	58.3 efg	98.1 cde
V_3	T_4	54.38 fg	96.4 de
V_3	T_5	52.67 g	98.3 cde
V_3	T_6	58.33 efg	105.4 ab
CV (%)		3.26	4.92

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

stress suppresses leaf expansion and midday photosynthesis and reduces photosynthesis rate and leaf area due to early senescence (Kramer and Boyer, 1995).

16. Proline accumulation

Proline standard curve of different rice genotypes under drought condition have been shown in the Fig. (Appendix-VI). Proline content (µg/g) of different rice genotypes under drought condition have been shown (Tables 6a to 6c). Significant difference among the genotypes, the treatments and interaction effect for the character of proline content were found. In this study, in case of varietal affect the highest proline content found was 2.15 (µg/g) in BRRI dhan55 (V1) followed by 2.14(µg/g) in Hashikalmi (V3) and the lowest proline content found was 2.13 in BR6976 2B-15. In case of treatment effect the highest proline content found was 2.13 (µg/g) in T_0 and the lowest proline content found was 1.73 (µg/g) in $T_{3\ \mathrm{under}}$ drought condition. In case of interaction effect the highest proline content found was 2.26 (µg/g) in V_1T_0 and the lowest proline content found was 1.4 (µg/g) in V_3T_3 and in $V_2T_{6\ \mathrm{under}}$ drought condition.

Due to drought condition higher proline accumulation in BRRI dhan55 (V1) and comparatively lowest proline content was in BR6976 2B-15 which was significantly different among the genotypes. This results agree with the result of Anjum *et al.,* (2011) who reported that proline accumulation was the first response of plants exposed to water-deficit stress in order to reduce injury to cells. Progressive drought stress induced a considerable accumulation of proline in water stressed maize plants. A similar finding was observed with the results of Stoyanov (2005), who reported that tolerant cultivar showed the highest accumulation of proline in bean plants. The highest accumulation of proline due to water stress was observed in genotype BB24 (382%) followed by BB43 (368%) and the lowest accumulation was in BB04 (163%). Genotype BARI bushbean-2 exhibited an intermediate behavior in proline accumulation. Accumulation of proline content under water stress indicates accumulated proline might act as a compatible solute regulating and reducing water loss from the plant cell during water deficit (Yokota *et al*., 2006) a Decreasing of turgor pressure is the first reason for proline accumulation under drought stress condition. One of the physiological responses that plants use against drought is proline accumulation (Girousse *et al*., 1996). The proline accumulated in plants under water stress can protects the cell by balancing the osmotic potential of cytosol with that of vacuole and external environment (Pireivatloum *et al*.,2010). The level of increase in the proline concentration in response to water stress varied between the rice varieties. Thus, the proline content is a good indicator for screening drought tolerant varieties in water stress condition (Bayoumi *et al*., 2008; Rahdari *et al*., 2012).

17. Soluble sugar content

Soluble sugar content of leaf of different rice genotypes under drought condition have been shown in the Tables 6a to 6c. Significant difference among the genotypes, the treatments and interaction effect for soluble sugar content were found. In case of varietal effect the highest sugar content found was 0.20 mg/g in BRRI dhan55 (V1) followed by 0.19 mg/g Hashikalmi and the lowest sugar content found was0.18 mg/g in BR 6976-2B-15 (V2). In case of treatment effect the highest sugar content found was 0.199 mg/g in T_0 and the lowest sugar content found was 0.13 mg/g in T_5. In case of combination effect the highest sugar content found was 0.200 mg/g in V_2T_0 and the lowest sugar content found was 0.112 mg/g in V_2T_2. Due to water stress conditions, soluble sugar content of leaf of different rice genotypes was found significantly much lower. BRRI dhan55 and tolerant check Hashikalmi which was less affected and the lowest soluble sugar content was found in BR 6976-2B-15 (V2). The soluble sugar content was much lower under water stress condition and this might be due to lower RWC, chlorophyll content, stomatal conductance and higher leaf rolling. Similar observations have been reported in Mahajan and Tuteja (2005) who showed that under severe drought, growth was inhibited by high concentration of ABA and sugar, whereas low concentrations promote growth. ABA applications enhanced the percentage recovery of drought plants.

18. Starch content

Starch content of different rice genotypes under drought condition have been shown in the Tables 6a to 6c. In case of varietal effect the highest starch content found was 0.067 mg/g in Hasikalmi (V3) followed by 0.057 mg/g in BRRI dhan55 and the lowest starch content found was 0.054 mg/g in BR 6976-2B-15 (V2) which was significant difference among the genotypes. In case of treatment effect, the highest starch content was 0.063 mg/g in T_6 and the lowest starch content was 0.054 mg/g in T_0 which were significantly different among the treatment. In case of combination effect the highest starch content found was 0.067 mg/g and the lowest starch content found was 0.053mg/g which were not significantly different from each other.

Due to water stress treatments starch content of different rice genotypes was significantly different among the genotypes. But the reduction was comparatively lower in BR 6976-2B-15

(V2) compared to other genotypes. Among the genotypes, in drought plant, the starch content was also found comparatively higher in BRRI dhan55 among the genotypes under water stress conditions, due to limitation of gas diffusion and reduced stomatal conductance, the production of carbohydrate is hampered. So, the rice genotypes that maintained higher carbohydrate before drought, they develop new leaves more quickly and accumulated greater biomass during recovery (Singh *et al*. 2014).

19. Total number of spikelets/ panicle

Total number of spikelets of different rice genotypes under drought condition have been shown in the Tables 7a to 7c. Significant difference among the genotypes, the treatments and interaction effect for total number of spikelets/ panicle were observed. In case of varietal effect the highest total number of spikelets/ panicle found was 176.7 in BRRI dhan55 (V_1) followed by Hashikalmi (169.0) and the lowest number of spikelets/ panicle found was 158 in BR 6976-2B-15 (V_2). In case of treatment effect the highest number of spikelets/ panicle found was 158 in T_0 and the lowest number of spikelets/ panicle found was found 139.6 in T_1. In case of combination effect the highest number of spikelets/ panicle was found 200 in V_0T_1 and the lowest number of spikelets was 120 in V_3T_3. When photosynthesis became lower, all the spikelets did not get sufficient assimilates, as a result decreased the number of filled grain. Total number of spikelet per panicle recorded was the highest in BRRI dhan55 (V1) (where as the reduction percent of filled grain was 5.42) followed by Hashikalmi (the reduction percent of filled grain was 6.51). In case of treatment effect T_2, T_3 produced the lowest number of total grains (the reduction percent of filled grain was 7.77, 7.45 respectively) and treatment $T_{0,}$ T_6 produced the highest number of total grain (the reduction percent of filled grain was 7.84, 8.00 respectively). The total number of spikelets per panicle found was recorded much lower in BR 6976-2B-15 (reduction percent of filled grain was 6.33). In case of combination effect the highest reduction percent of filled grain was 10.97% in V_3T_4 and the lowest reduction percent of filled grain was 6.02% in V_1T_1. Due to drought stress, the number of spikelets per panicle or seed setting rate was decreased. After drought condition the tolerant genotype would quickly recover their biomass, leaves and then develop new growth. The less tolerant genotype would lose their biomass, leaves and take much longer time to recover and then develop new growth. Decreased spikelets per panicle under lower soil moisture levels might be due to inhibition of stomatal conductance, translocation of assimilate to the grains. Due to water stress condition

Table 6a. Varietal effect of proline, soluble sugar and starch content of three rice genotypes under water stress conditions

Variety	Proline(µg/g)	Soluble sugar (mg/g)	Starch (mg/g)
V_1 (BRRI dhan55)	**2.15 a**	**0.20 a**	**0.057 b**
V_2 (BR 6976-2B-15)	**2.16 b**	**0.18 b**	**0.054 b**
V_3 (Hashikalmi)	**2.14 ab**	**0.19 ab**	**0.067 a**
CV (%)	**0.013**	**0.766**	**0.012**
LSD$_{(0.05)}$	0.7327	2.081	1.972

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

Table 6b. Treatment effects of proline, soluble sugar and starch content genotypes under water stress condition

Drought treatment	Proline(µg/g)	Soluble sugar (mg/g)	Starch mg/g
T_0(control)	**2.13 a**	**0.199 a**	**0.062 ab**
T_1 (15 to 21 days)	**1.81 bc**	**0.171 bc**	**0.057 bc**
T_2(35 to 41 days)	**1.91 bc**	**0.198 ab**	**0.058 bc**
T_3(55 to 61 days)	**1.73 c**	**0.168 c**	**0.062 ab**
T_4(75 to 81 days)	**1.81 bc**	**0.190 bc**	**0.054 bc**
T_5(95 to 101 days)	**1.90 bc**	**0.13 c**	**0.060 b**
T_6(115 to 121 days)	**2.00 b**	**0.193 b**	**0.063 ab**
CV (%)	**0.671**	**0.766**	**0.012**

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

Table 6c. Interaction effect of proline, sugar and starch of three rice genotypes under water stress condition

Interaction		Proline(µg/g)	Soluble sugar mg/g	Starch mg/g
V_1	T_0	2.26 a	0.20 a	0.067 a
V_1	T_1	1.57 ghi	0.187 a	0.056 bc
V_1	T_1	1.77 def	0.184 a	0.061 ab
V_1	T_2	1.89 cde	0.124 b	0.060 ab
V_1	T_3	1.80 def	0.171 a	0.060 abc
V_1	T_4	1.91 cd	0.198 a	0.063 ab
V_1	T_5	2.00 ab	0.168 a	0.062 ab
V_2	T_6	2.13 ab	0.199 a	0.067 a
V_2	T_0	1.59 ghi	0.193 a	0.057 bc
V_2	T_1	1.73 defg	0.200 a	0.058 bc
V_2	T_2	1.92 cd	0.112 b	0.061 abc
V_2	T_3	1.81 cdef	0.190 a	0.060 abc
V_2	T_4	1.70 efg	0.196 a	0.060 abc
V_2	T_5	1.40 i	0.180 a	0.060 abc
V_3	T_0	2.25 a	0.200 a	0.067 a
V_3	T_6	1.92 cd	0.197 a	0.053 bc
V_3	T_1	1.70 efg	0.193 a	0.060 abc
V_3	T_2	1.70 efg	0.200 a	0.050 bc
V_3	T_3	1.50 hi	0.137 a	0.600 abc
V_3	T_4	1.63 fgh	0.193 a	0.060 abc

V_3	T_5	2.20 ab	0.200 a	0.057 bc
CV (%)		0.671	7..66	10.16

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

the total dry matter became lower. The results have the similarity with the results of Zubaer *et al*.(2007) who stated that reduced grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to water stress.

20. Number of unfilled grains

Number of unfilled grains/ panicle of different rice genotypes under drought condition have been shown in the tables 7a to 7c. Significant difference among the genotypes, the treatments and interaction effect in number of unfilled grains/ panicle was observed. In case of varietal effect the highest unfilled grains/ panicle found was 11 in Hashikalmi followed by 10.00 in BR 6976-2B-15 (V_2) and the lowest unfilled grain found was 9.58 in BRRI dhan55 (V_1) In case of treatment effect the highest unfilled grain found was 12.38 (T_0) and the lowest unfilled grain found was 10.38 in T_1. In case of combination effect of the highest unfilled grain found was 18.88 in V_3T_0 and the lowest unfilled grain found was 10.27 in V_2T_3.In this study, it was found that drought stress greatly reduced filled grain and increased the number of unfilled grain. Due to water stress, the current stomatal conductance decreased, as a result the current photosynthesis became lower, insufficient assimilates production was seen and its distribution to grains was insufficient, all the spikelets did not get sufficient assimilates which resulted increased the number of empty grains and decreased the number of filled grains ultimately causes yield losses (Zubaer *et al*.2007)The results have the similarity with the results of Begum (1992), who observed that water stress after flowering, increased the number of empty spicklets per panicle. Increased unfilled grains per panicle under lower soil moisture level might be due to inactive pollen grain for dryness, incomplete development of pollen tube; insufficient assimilates production and its distribution to grains. Water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which results low in grain weight and increases empty grains (RRDI, 1999). Zubaer *et al*. (2007) stated that reduced grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to soil moisture stress

21. Reduction percentage of filled grains

Reduction percent of filled grains of different rice genotypes under drought condition have been shown in the tables 7a to 7c. In case of varietal effect the highest reduction percent of filled grains was found 6.51% in Hashikalm followed by 6.33% in BR 6976-2B-15 (V_2) and the lowest was found 5.42 in BRRI dhan55. In case of treatment effect, the highest reduction percent of filled grain was 8.00 and the lowest sterility percent found was 6.74 in T_4. In case of combination effect the highest reduction percent of filled grain was 10.97% in V_3T_4 and the lowest reduction percent of filled grain was 6.02% in $V_1T_{1.}$ In this study, it was found that the lowest reduction percent of filled grains was 5.42 in BRRI dhan55 (V1) and the highest reduction of filled grain was found in Hashikalmi (V_3) and in case of treatment effect the highest reduction percent of filled grains was 7.84, 8.00 in $T_{0,}T_6$ respectively. Therefore it is suggested that sterility percentage increased with increasing drought duration and number of unfilled grains, decrease in filled grains per plant, tiller number, panicle number, leaf number, plant height. A significant decrease in panicle number and filled grain per plant, increased in number of unfilled grain were the main causes of sterility percentage increase due to drought treatment. These results have the conformity with the results of O'Toole and Moya (1981), who observed increased sterility in rice under water stress condition. This result also agrees with (Begum (1992), who observed that water stress after flowering, increased the number of empty spicklets per panicle. Increased unfilled grains per panicle under lower soil moisture level occurs which decreases translocation of assimilates to the grains, ultimately which results low in gain weight and increases empty grains (RRDI, 1999). Zubaer *et al.*(2007) stated that reduced grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to soil moisture stress.

22. Total dry weight (root, shoot and panicle)/ plant at harvest

Total dry weight per plant (g) of different rice genotypes under drought condition have been shown in the Tables 8a to 8c. Significant difference among the genotypes, the treatments and interaction effect in total dry weight per plant was observed. In case of varietal effect the highest total dry weight per plant found was 64.79g in Hashikalmi followed by 57.08g in BRRI dhan55 and the lowest weight found was 44.82g in BR 6976-15-2B (V2). In case of treatment effect the highest total dry weight per plant was 58.05 in T_0 and the lowest was 34.79 in T_3. In combination effect the highest total dry weight per plant was 65.05 in V_1T_0 and the lowest was 28.66 in V_2 T_4.

Due to drought stress conditions root, shoot, leaf and panicle dry weight decreased, as a result the total dry matter became lower. In this study, the highest total dry weight per plant was in BRRI dhan55 and the Hashikalmi and the lowest weight was in BR 6976-15-2B V2 which was significantly different among the genotypes. This might be due to reduction in tiller number, panicle number and filled grain per plant, plant height, leaf area etc. All of this ultimately affected the grain yield under water stress treatment. The results also agree with the results of Liu *et.al*. (2004) who stated that drought stress significantly decreased plant total dry mass, but the proportion of changes differed among root, stem, and leaf, whereas leaf dry mass ratio was decreased. Tsuda and takami (1991) who observed that water stress reduced grain weight. Water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which results low in grain weight and increases empty grains (RRDI, 1999). Zubaer *et al*.(2007) stated that *r*educed grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to soil moisture stress. Asch *et al.* (2005) advocated that drought is a major stress affecting rainfed rice systems. Root characteristics such as root length density, root thickness, changes in root dry matter and rooting depth and distribution have been established as constituting factors of drought resistance.

23. Harvest index (HI)

The result of harvest index (%) of different rice genotypes under drought condition have been shown in the Tables 8a to 8c. Significant differences were found among the varieties and the treatments for harvest index. In case of varietal effect the highest harvest index found was 0.40 in BRRI dhan55 followed by 0.329 in Hashikalmi and the lowest harvest index found was 0.325 in BR 6976-15-2B (V2). In case of treatment effect the highest harvest index found was 0.40 in T_0 and the lowest harvest index found was 0.32 in T_1. In combination effect the highest harvest index was 0.46 in V_1T_0 and the lowest harvest index was 28.66 in V_3 T_3.

In this study, the highest harvest index found was 0.40 in BRRI dhan55 and the lowest harvest index was found in BR 6976-15-2B (V2). The results have the similarity with the results of Zubaer *et al*. (2007) who stated that harvest index was significantly influenced by moisture level in all rice genotypes. It might be due to the fact that water stress affects the translocation towards the grain. But the degree of reduction in HI value under lower moisture level was different in different genotypes. Muchow (1989) stated that where water shortage occurred, harvest index was more conservative than biomass accumulation; harvest index was reduced only when water deficits severely decreased grain-yield.

Table 7a. Varietal effects on the total no. of spikelets/ panicle, no. of unfilled grains /panicle and reduction % of filled grains of rice genotypes under water stress

Variety	Total number of spikelets/ panicle	No of unfilled grains/ panicle	Reduction(%) of filled grains
V_1 (BRRI dhan55)	176.7 a	9.58 c	5.42
V_2 (BR 6976-2B-15)	158.0 c	10.00 b	6.33
V_3 (Hashikalmi)	169.0 b	11.00 a	6.51
CV (%)	4.18	11	

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

Table 7b. Treatment effects on the total no. of spikelets/ panicle, no. of unfilled grains / panicle and reduction % of filled grains of rice genotypes under water stress

Drought treatment	Total number of spikelets/ panicle	No of unfill grains / panicle	Reduction(%) of filled grains/panicle
T_0 (Control)	158.0 a	12.38 a	7.84
T_1 (15to 21 days)	139.6 d	10.84 c	7.77
T_2(35 to 41 days)	144.4 cd	10.76 c	7.45
T_3(55 to 61 days)	149.7 bc	10.81 c	7.22
T_4(75 to 81 days)	154.1 ab	10.38 c	6.74
T_5(95 to101days)	147.4 bc	11.23 b	7.62
T_6(115to121days)	154.8 ab	12.36 a	8.00
CV (%)	4.18	11	

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

Table 7c. Interaction effects on the total no. of spikelet/ panicle, no. of unfilled grains and the reduction % of filled grains/ panicle of rice genotypes under water stress

Interaction		Total number of spikelets/ panicle	No. of unfilled grains/ panicle	Reduction(%) of filled grains
V_1	T_0	200.0 a	15.45 ab	7.73
V_1	T_1	184.0 b	11.08 d	6.02
V_1	T_2	147.4 fgh	11.00 d	7.46
V_1	T_3	169.0 cd	11.68 cd	6.91
V_1	T_4	139.6 h	10.84 d	7.77
V_1	T_5	144.4 gh	11.23 cd	7.78
V_1	T_6	149.7 fgh	10.81 d	7.22
V_2	T_0	154.1 efg	15.19 ab	9.86
V_2	T_1	161.2 de	12.38 bc	7.68
V_2	T_2	154.8 efg	10.76 d	6.95
V_2	T_3	129.4 i	10.27 d	7.94
V_2	T_4	158.0 ef	11.00 cd	6.96
V_2	T_5	137.1 h	11.17 cd	8.15
V_2	T_6	124.8 i	12.36 bc	9.90

V_3	T_0	182.0 b	18.88 a	10.37
V_3	T_1	178.3 bc	13.07 c	7.33
V_3	T_2	178.3 bc	11.47 cd	6.43
V_3	T_3	120.7 i	12.30 bc	10.19
V_3	T_4	121.0 i	13.27 abc	10.97
V_3	T_5	122.7 i	10.66 d	8.69
V_3	T_6	121.0 i	11.95 cd	9.88
CV (%)		4.18	14.50	

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

24. Grain yield per plant

Yield/ plant (g) of different rice genotypes under drought condition have been shown in the Tables 8a to 8c. Significant difference among the genotypes, the treatments and interaction effect for yield/ plant were found. In case of varietal effect the highest yield/ plant found was 23.80 g in BRRI dhan55 (V_1) followed by 21.77.g in Hashikalmi (V_3) and the lowest found was 21.33g in BR 6976-2B-15 (V_2). In case of treatment affect the highest yield/ plant found was 22.08 in T_0 control and the lowest yield/ plant found was 14.44g in T_6. In case of combination effect (variety and drought treatment) the highest yield/ plant found was 23.80 in V_1T_0 and the lowest yield/ plant (g) found was 12.20 g .

In this study, the highest yield/ plant in BRRI dhan55 followed by tolerant check Hashikalmi and the lowest yield/ plant was found in BR 6976-2B-15 under water deficit condition. Reduction in grain yield due to water deficit condition is depended on genotypes, the length of drought treatment and severity of water stress. The lowest grain yield per plant was recorded in V2 genotypes. The results also have the similarity with the results of Zubaer *et al*.(2007) who stated that reduced grain yield under lower soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards grain due to soil moisture stress. This might be due to reduction in tiller number, panicle number and filled grain per plant, dry weight, RWC, leaf area etc. As a result of drought, the stomatal conductance and gas exchange were decreased. All of this ultimately affected the grain yield under water stress treatment. The yield components like grain number and grain size were decreased under drought stress treatment in wheat (Edward and Wright, 2008). Water deficit during vegetative, flowering and grain filling stage reduced grain yield.

3.25 Relationship between relative water content (RWC) and the proline content of leaf

The results of the relationship between relative water content (RWC) and the proline content plant was also recorded and the results indicated that there was a negative correlation (r= -0. 858) between relative water content (RWC) and the proline content (Figure 3.6). The relationship was highly significant. When the relative warter content of leaf was higher r, the little proline content

Table 8a. Varietal effect on total dry weight/ plant, harvest index (%) and yield/ plant of three rice genotypes under water stress condition

Variety	Total dry weight/plant(g)	Harvest index(%)	Yield/ plant (g)
V_1 (BRRI dhan55)	57.08 b	0.401 a	23.80 a
V_2 (BR 6976-2B-15)	44.82 c	0.325 b	21.33 b
V_3 (Hashikalmi)	64.79 a	0.329 b	21.77 b
CV (%)	10.52	19.88	14.50

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

Table 8b. Treatment effect on total dry weight per plant, harvest index (%) and yield/ plant of three rice genotypes under water stress condition

Drought treatment	Total dry weight /plant (g)	Harvest index (%)	Yield/ plant (g)
T_0 (Control)	58.05 a	0.40 a	22.08 a
T_1 (15 to 21 days)	53.97 abc	0.32 c	14.44 d
T_2(35 to 41 days)	44.82 bc	0.33 c	15.13 cd
T_3(55 to 61 days)	34.79 c	0.32 bc	16.33 cd
T_4(75 to 81 days)	57.08 ab	0.34 bc	17.04 bcd
T_5(95 to 101 days)	47.79 abc	0.34 b	17.91 bc
T_6(115 to 121 days)	58.79 a	0.36 ab	21.00 ab
CV (%)	10.52	19.88	14.50

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

Table 8c. Interaction effects on total dry weight per plant, harvest index (%) and yield/ plant of three rice genotypes under water stress condition

Interaction		Total dry weight/plant (g)	Harvest index	Yield/ plant (g)
V_1	T_0	65.05 a	0.46 a	23.80 a
V_1	T_1	44.82 abc	0.36 cdefg	15.50 def
V_1	T_2	34.79 bc	0.35 defg	19.11 abcde
V_1	T_3	41.66 abc	0.39 bcd	19.40 abcde
V_1	T_4	47.79 abc	0.42 ab	18.11 bcdef
V_1	T_5	57.08 ab	0.41 abc	21.00 abc
V_1	T_6	64.79 a	0.42 ab	22.04 a
V_2	T_0	65.42 a	0.29 gh	22.70 a
V_2	T_1	35.43 bc	0.31 fgh	15.13 ef
V_2	T_2	44.36 abc	0.34 defgh	14.44 ef
V_2	T_3	37.04 bc	0.32 efgh	12.20 g
V_2	T_4	28.66 d	0.31 fgh	16.33 cdef
V_2	T_5	35.74 bc	0.34 defgh	21.77 abc
V_2	T_6	52.33 ab	0.30 gh	21.66 abc
V_3	T_0	65.05 a	0.32 efgh	22.78 a
V_3	T_1	36.95 bc	0.36 bcdef	17.33 bcdef
V_3	T_2	51.66 ab	0.23 i	18.67 abcde
V_3	T_3	53.97 ab	0.32 efgh	19.03 abcde

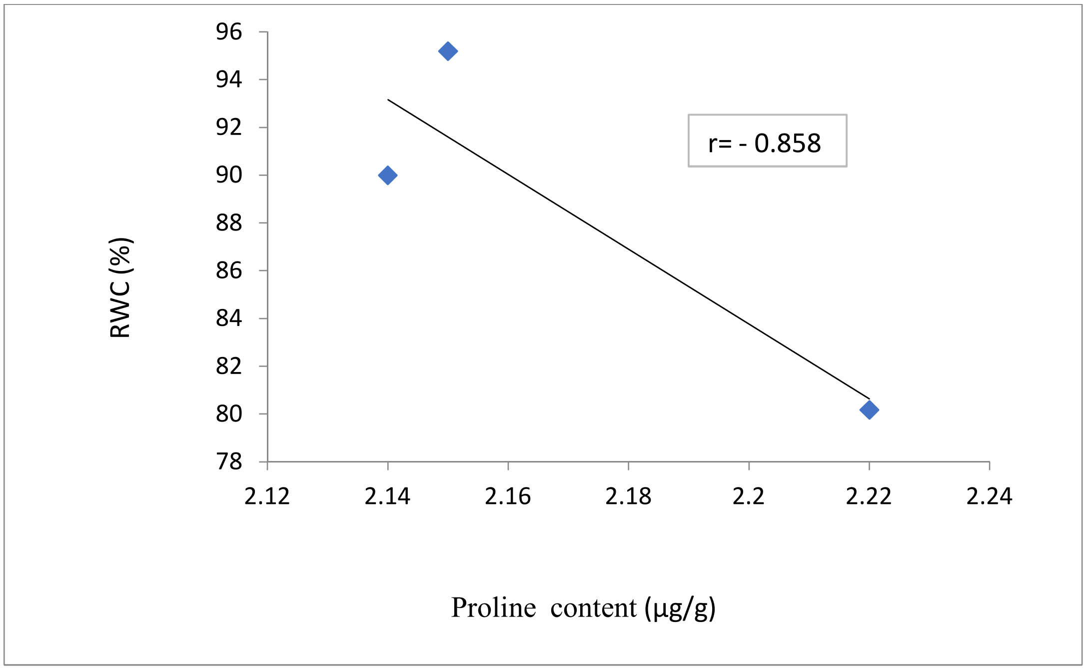
V_3	T_4	54.03 ab	0.35 defg	17.55 cd
V_3	T_5	47.86 abc	0.28 h	18.65 abcde
V_3	T_6	65.42 a	0.37 bcde	20.33 ab
CV (%)		12.25	19.88	14.50

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

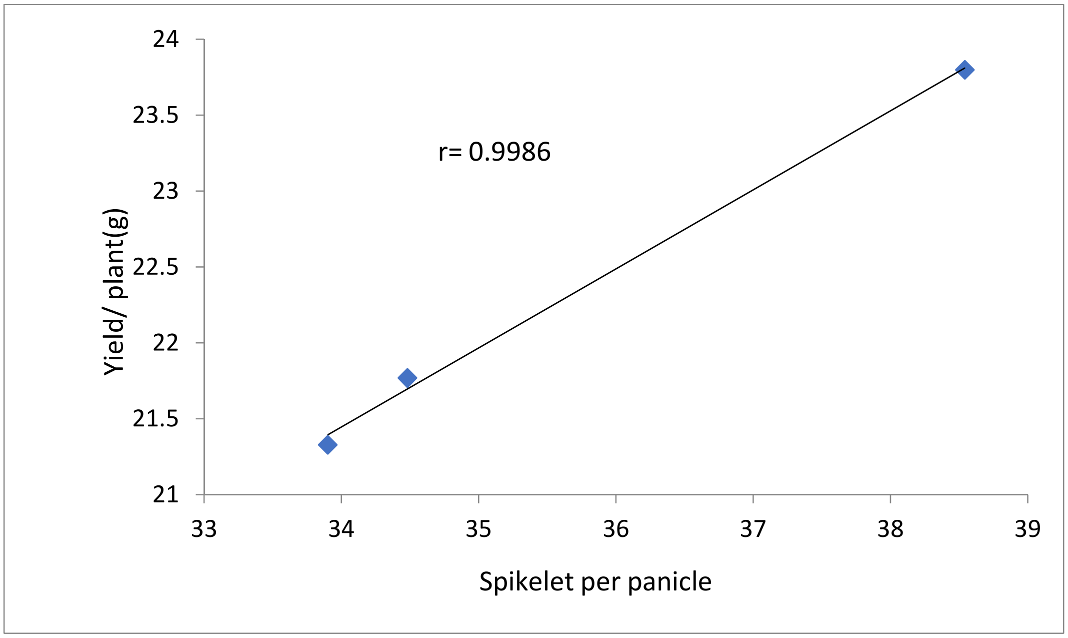
was found in leaf under that situation. It was reported that the osmotic adjustment is an adaptive process, which can reduce some of the harmful effects of water deficits (Sellammal *et al*., 2014). Under water stress condition, proline act as an osmolytes and proline helps to accumulates more water. Kumar *et al.,* (2014) found that drought stress at reproductive stage caused reduction in relative water content (31.57) and increased in proline content.

3.26 Relationship between grain yield/ plant and spikelet/ panicle (r = 0.9986)

In this experiment, the relationship between yield/ plant and the number of spikelet/ panicle were calculated and was found that the corelation was highly significant. There was a strong positive correlation (r= 0.9986) between yield/ plant and the number of spikelet/ panicle (Fig 3.7). The total yield was found lowest when the number of spikelet/ panicle was the lowest under water deficit condition. The total yield gradually increased with the increasing the number of spikelet/ panicle. The total yield was recorded the highest when the number of spikelet/ panicle was the highest. The number of spikelet per panicle or seed setting rate decrease was the main causes of yield decline due to drought treatment. The results have the conformity with the result of Begum (1992) observed that water stress decreased the number of spicklets per panicle as a result yield decreases. There was a corelation between the number of spikelet/ panicle and yield/ plant.



Fi g. 3.7 Relationship between RWC and proline content (r = -0. 858)



Fi g. 3.8 Relationship between grain yield/ plant and spikelet/ panicle (r = 0.9986)

3.27 Relationship between yield/ plant and the number of unfilled grain/ plant (r = - 0.76)

The results of the relationship between yield/ plant and the number of unfilled grain/ plant were calculated and it was found that the relation was highly significant. There was a strong negetive correlation (r= - 0.759) between yield / plant and the number of unfilled grain/ plant (Figure 3.8). The total yield was the lowest when the number of unfilled grain/ plant was the highest also. The total yield gradually increased with the decrease the number of unfilled grain/ plant. The total yield was recorded the highest when the number of unfilled grain/ plant was also lowest. O'Toole *et al.* (1979) reported that water stress during grain filling stage reduces the individual grain weight and increase the number of unfilled grain. There was a strong negetive correlation between yield / plant and the number of unfilled grain. The yield components like grain number and grain size were decreased under drought stress treatment in wheat (Edward and Wright, 2008). A common adverse effect of water stress on plants is the reduction in yield and the number of unfilled grain.

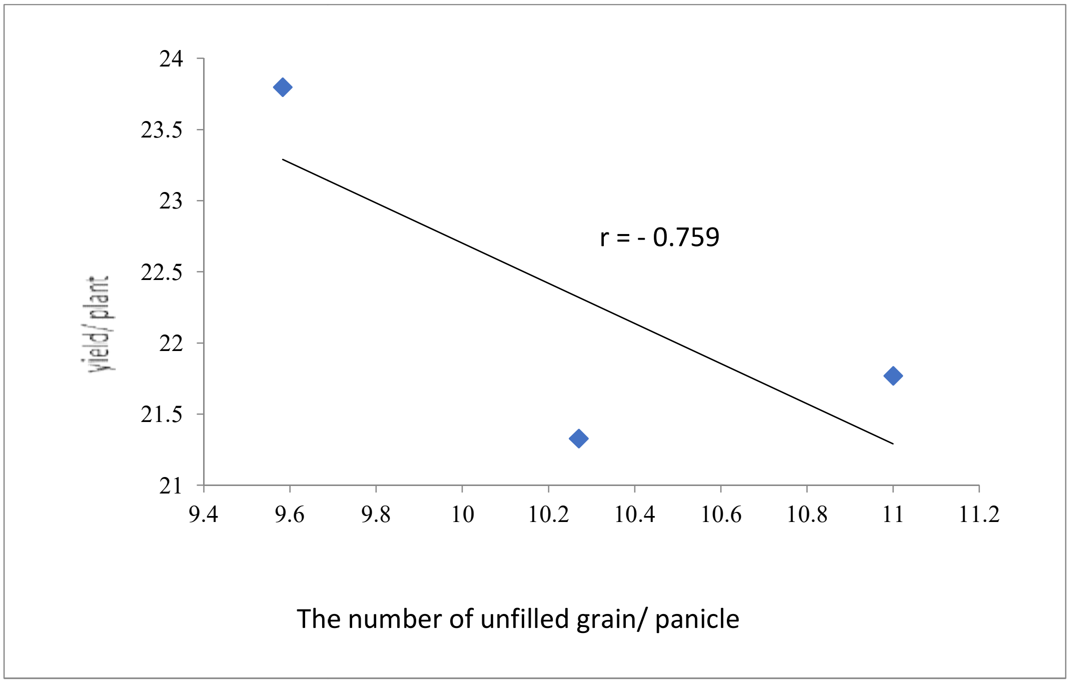


Fig. 3.9 Relationship between grain yield and number of unfilled grains (r = - 0.759)

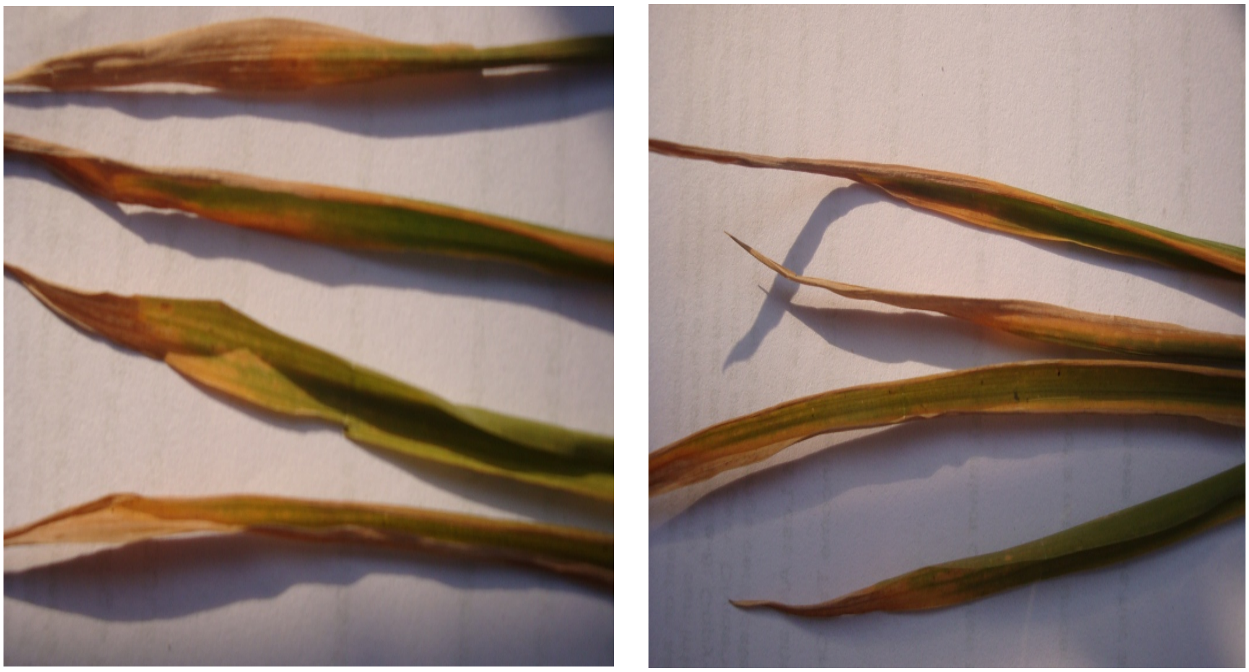


Plate 1.7: Red colour leaf (anthocyanin content) of different rice genotypes after drought condition

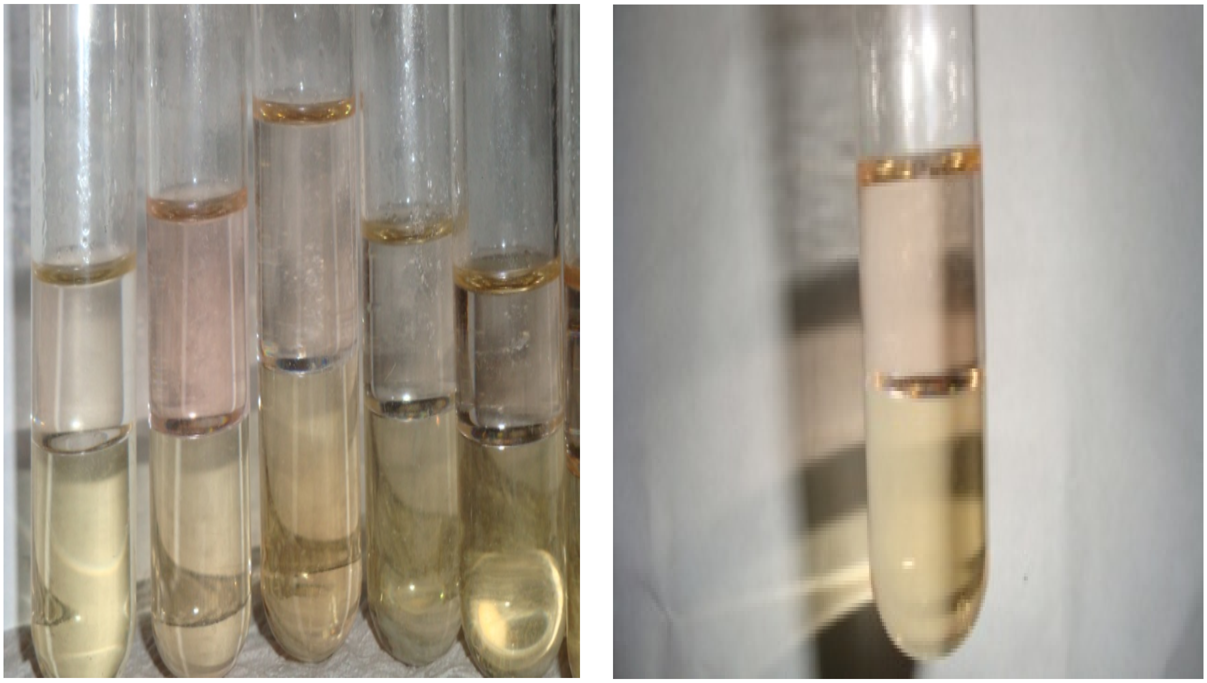


Plate 1.9 Prolene analysis of different rice genotypes after drought condition

CHAPTER 5

SUMMERY AND CONCLUSION

The agroecosystem of Bangladesh are facing various environmental stresses. Among the abiotic stress, drought is a major abiotic environmental stress factor that affects the growth and development of rice. There are many scientific evidence of climate change that will increase the intensity and severity of drought. BRRI (Bangladesh Rice Research Institute) has released drought tolerant rice genotypes. Further improvement of those and other rice varieties are required in order to meet up the future rice demand. Considering the above statement three experiments (with laboratory works) were carried out during September 2012 to July, 2014. Different morphological, physiological and biochemical characters of rice genotypes under water deficit duration were studies. The results of the three experiments have been summarized below.

In the present study 10 BRRI materials were BR21, BR24, BRRI dhan42, BRRI dhan43, BRRI dhan48, BRRI dhan55 and lines BR 6976-11-1, OM1490, BR 6976-2B-15 and tolerant check (Hashikalmi) considering 3 replication, 3 treatment (7 days, 10 days and 15 days water stress) (90 pots) were screened against drought stress for their growth and development. Genotypes were grown in the earthen pots containing sandy loam soil under rain protected shelter under natural light condition. When water stress implies before plant growth, plant height hamper. Plant height of different rice genotypes under drought condition was significant reduction compared with control. At 7, 15 days drought stress the highest plant height was found in Hashikalmi followed by BRRI dhan 55 and the lowest plant height was found in BR21 and BR 6976-11-1 which was statistically significant different among the genotypes and relative plant height was recorded 81% in Hashikalmi and 88% in by BRRI dhan 55 compared to control (no stress). Under drought condition at 7 and 15 days drought stress the highest leaf area was found in Hashikalmi followed by BRRI dhan55 and the lowest leaf area was found in BR21, BRRI dhan43 which was significantly different among the genotypes. At 15 days drought stress the highest leaf area in Hasihkalmi and the lowest leaf area in BR21 which was significantly different among the treatment. In this study leaf area varied significantly under water stress condition. At vegetative stage the plant first response to limit leaf expansion under drought condition, less water was lost through transpiration. Total number of tillers per plant of different rice genotypes was influenced by drought condition. The results showed that number of tillers of different rice genotypes was decreased under drought condition. In this result the highest number of tiller per plant was in BRRI dhan55 at 7 days stress, the second highest was in Hashikalmi and the lowest number of tiller per plant was found in BRRI dhan43 which was significantly different among the genotypes. Due to drought stress conditions root, shoot, leaf and panicle dry weight were decreased, as a result the total dry matter became lower. In this study, at 15 days stress the highest total dry matter per plant was in BRRI dhan55 the second highest total dry matter per plant was 29% in Hashikalmi and the lowest total dry matter per plant was 13% in BR24 compared to control which was significantly different among the genotypes and at no stress the highest total dry matter per plant was in BRRI dhan55, which was significantly different among the genotypes. At 7 days drought stress the highest dry weight of panicle per was found in BRRI dhan55 and at 15 days drought stress the highest was in Hashikalmi and BRRI dhan55 and the lowest was found in BR21 which was significantly different among the genotypes. Total dry matter per hill was highest in Hasikalmi and lowest was found in BR21 and BR24 in different days of drought stress. Total number of tillers per plant of different rice genotypes was influenced by drought condition. The results showed that number of tillers of different rice genotypes was decreased under drought condition. In this result 7 days stress the highest number of tiller per plant was found in BRRI dhan55, the second highest was found in Hasikalmi and the lowest panicle length was 25.67 in BRRI dhan43 which was significantly different among the genotypes. At 7 days stress the highest panicle length was obtains in Hasikalmi, followed by BRRI dhan55. At 15 days stress the highest panicle length was obtains in Hasikalmi and the lowest was in BR21, BR24 respectively. There were remarkable differences on panicle length among the genotypes under drought condition. Hashikalmi produced the largest panicle in all stress condition. Largest length of panicle contains more grain which was high weight than small length of panicle. Under water stress condition some genotype showed the small length of panicle. Thousand grain weights (g) of different rice genotypes under drought condition were different among the genotypes. At no stress the thousand grain weights was obtain in Hashikalmi, the second thousand grain weight was obtain in BRRI dhan55 and the lowest thousand grain weight was obtain in BR 6976-11-1 which were significantly different among the genotypes. In this study, genotype Hashikalmi had the highest thousand grain weight in all stress condition. At 7 and 15 days stress the highest days to maturity was obtains in BRRI dhan55, the second highest was in BR 6976-2B-15 and the lowest was obtains in BRRI dhan43 and the lowest was obtains in OM 1490. At 7, 15 and no stress days drought stress the highest harvest index was found in BRRI dhan55 and the lowest was found in BR21, BR24. At 7 days stress the highest dry matter partitioning (shoot) was found 120% in Hashikalmi, lowest in BR21 and BR24 compared to control and at 15 days stress the highest was found 45% in BRRI dhan42, lowest in BR24 compared to control.

In the second study three genotypes were screened out according to their yield and other growth performance. Among the genotypes leaf area varied significantly under water stress condition. Due to drought stress the the highest leaf area was found in Hashikalmi which was significantly different among the genotypes. The lowest leaf area was in BRRI dhan55. In case of treatment affect the highest leaf area and the lowest leaf area. The highest length of panicle was found in Hashikalmi followed by BRRI dhan55 (V_1) and the lowest panicle length was found in BR 6976-2B-15 which was significantly different among the genotypes. SPAD value represents the greenness of the leaf. SPAD value was recorded from the flag leaf of all tillers and the average value was taken during the grain filling period after 7 days interval from vegetative, anthesis and maturity stage. Under drought conditions lower SPAD value was recorded. In this present study, SPAD value was recorded ranging from 37 to 40 BRRI dhan55 during anthesis. After anthesis SPAD value slightly increased and then gradually decreased with advanced towards maturity and in sharp decreased in SPAD value which occurs at a SPAD reading around 30 to 40. Due to drought condition, in this study the highest SPAD value was in BRRI dhan55 (V1) followed by Hashikalmi and the lowest was in BR 6976-2B-15 (V2) which was not significantly different from other genotypes. Higher SPAD values as well as higher chlorophyll content in tolerant genotype contributed to higher photosynthesis and increased total dry matter content in BRRI dhan55 and Hashikalmi. A decrease of total chlorophyll content with drought stress implies a lowered capacity for light harvesting. It depends on the duration and severity of drought level. This result indicate that in case of varietal effect the highest shoot height was obtained in BRRI Dhan55 (V_1) and the lowest was obtained in BR 6976-2B-15 (V_2) which was significantly different from each genotype. In case of varietal effect the highest root dry weight was obtained in V_3 Hashikalmi and BRRI Dhan55 (V_1) and the lowest was obtained in BR 6976-2B-15 (V_2). Under drought condition, the root shoot ratio was lower and the root shoot ratio was obtained higher in drought tolerant genotype. In the study the highest root shoot ratio was obtained in

BRRI dhan55 (V_1) followed by Hashikalmi (V_3) and the lowest root shoot ratio was obtained in BR 6976-2B-15 (V_2). Due to drought stress conditions root, shoot, leaf and panicle dry weight decreased, as a result the total dry matter became lower. In case of varietal effect the highest total dry weight per plant was in Hashikalmi followed by in BRRI dhan55 (V_1) in and the lowest total dry weight per plant was in BR 6976-2B-15 (V_2). Weight of thousand grains of different rice genotypes was different under drought condition which depends on the individual grain weight. In this study tolerent check Hashikalmi posses the highest weight of thousand grains. Under drought conditions BR 6976-2B-15 was mostly source limited during grain filling stage. This effect the translocation of assimilates to the sink as well as the developing grain. As result grain weight decreased under drought condition. So, in this present study it was observed that under water stress treatment sensitive genotypes reduced lowest grain weight. In case of varietal effect the highest harvest index was 70.78% in Hasikalmi and 58.56% was in BRRI dhan55 (V_1) and the lowest was 48.67% in BR 6976-2B-15 (V_2) which were significantly different among the genotypes. In case of treatment effect the highest harvest index was 66.93% and the lowest was 35.09% which was significantly different among the treatment. In case of interaction effect the highest was 71.37% and the lowest was 34.00 % which were significantly different with each others. So, it was observed that harvest index was different in different genotypes under drought condition. In case of varietal effect the highest number of effective tillers/ plant was found in BRRI dhan55 (V_1) and the lowest were found in Hashikalmi (V_3). In severe drought stress condition increase number of ineffective tiller. In case of varietal effect the highest number of tillers/ plant were found in Hashikalmi (V_3) followed by BRRI dhan55 (V_1) and the lowest number of tillers/ plant was fund in BR 6976-2B-15 (V_2). The highest number of effective tiller was obtained in Hashikalmi, the lowest was 8.33. The highest number of ineffective tiller was 3.36 in Hashikalmi, the lowest was 2.55 in BRRI dhan55 and in case of treatment effect the highest ineffective tiller was 4.33 in Hashikalmi, the lowest was 2.22 in BR 6976-2B-15 V2. The highest number of tillers per hill was 19.67 and the lowest number of tillers per hill was 8.33 which were significantly different with each others. Another results indicate that the highest wt of 1000 grains was 30.70 in BR 6976-2B-15 (V2) and the lowest wt of 1000 grains was 19.21 in BRRI dhan55 (V1). In this present study the highest days to maturity was 115.1 in BR 6976-2B-15 (V2) and the lowest days to maturity in Hashikalmi (96).

The highest dry matter partitioning of shoot was 54.62 in BRRI dhan55, lowest dry matter partitioning of shoot was 53.76 in Hasikalmi. The highest dry matter partitioning of root was 17.86 in Hasikalmi and the lowest was 14.60 in BRRI dhan55 which were significantly different among the genotypes. In case of treatment effect the highest dry matter accumulation shoot was 57.32 and the lowest was 31.97 (Table 2.23) and in case of interaction effect the highest dry matter accumulation shoot was 60.44 and the lowest was 44.85 (Table 2.24) which was not significantly different with each others.

Due to drought stress in third experiment the highest leaf area was in Hashikalmi followed by BRRI dhan55 the lowest leaf area was in BR 6976-2B-15. In this study leaf area varied significantly under water stress condition. In case of treatment effect the highest leaf area was found in 5th stress and the lowest was found in 6th stress. When water deficit occurs, the plant first response to limit leaf expansion, less water is lost through transpiration. At the beginning of this experiment stomata conductance of 1st to 3rd stress was high in all varieties and gradually decreases at the end of the experiment. The highest leaf temperature was at 8.00am and at 12.00am leaf temperature was high in all genotype. Leaf humidity of different rice genotypes under drought condition was different. Before drought condition leaf humidity was high in all varieties at the starting stage of drought treatment and gradually decreases after water stress treatment. Leaf humidity was high before stress and was low in after stress. In all the genotypes, due to drought treatments plants accumulated anthocyanin, proline, starch and sugar. The highest anthocyanin content was found in BRRI dhan55 followed by 0.402 in Hasikalmi and the lowest in BR6976 2B-15. Due to drought condition the highest accumulation of proline found in BRRI dhan55 (V1) and in most of the treatment (2nd to 4th) and comparetively lowest proline accumulation in BR6976 2B-15 which was significantly different among the genotypes. Considering all the genotype and drought treatments proline accumulation was higher compared to low tolerant genotypes. Due to water stress conditions, soluble sugar content of leaf of different rice genotypes was found significantly higher in BRRI dhan55 and tolerant check Hashikalmi and the lowest soluble sugar content was in BR 6976-2B-15 (V2). Higher degradation of chlorophyll and lower light under water stress might responsible for lower soluble sugar content. In every treatment the soluble sugar content was better in BRRI dhan55 and tolerant check Hashikalmi. Due to water stress treatments starch content of different rice genotypes was significantly different among the genotypes. But the reduction was comparatively lower in BR 6976-2B-15 (V2) compared to other genotypes. Among the genotypes, in drought plant, the starch content was also found significantly highest in BRRI dhan55 among the genotypes. Stomata conductance of tolerant check Hashikalmi was always high compare to other varieties. In this present study, SPAD value was recorded ranging from 37 to 40 BRRI dhan55 during anthesis. After anthesis SPAD value slightly increased and then gradually decreased with advanced towards maturity and in sharp decreased in SPAD value which occurs at a SPAD reading around 30 to 40. Due to drought condition in this study the highest SPAD value was found in V3 (Hasikalmi) follwed by BRRI dhan55 (V1)) and the lowest SPAD value was 34.25 in BR 6976-2B-15 (V2) which was not significantly different among the genotypes. In this study. genotypes BRRI dhan55 (V1), had higher RWC content while genotypes BR 6976-2B-15 (V2) had lower RWC. Plants were grown under drought conditions showed a lower RWC than those of grown under non stress condition. RWC were significantly reduced at different growth stage. Water stress significantly reduced RWC due to higher evaporation resulting from increased temperature and light intensity. Due to drought stress conditions root, shoot, leaf and panicle dry weight decreased, as a result the total dry matter became lower. In this tudy, the highest total dry weight per plant was found in Hasikalmi followed by BRRI dhan55 and the lowest weight was found in BR 6976-15-2B V2. Weight of thousand grains of different rice genotypes was different under drought condition which depends on the individual grain weight. In this study tolerent check Hashikalmi posses the highest weight of thousand grains. Under drought conditions BR 6976-2B-15 was mostly source limited during grain filling stage. In all the genotypes the total yield per plant was recorded the highest yield/ pot in BRRI dhan55 followed by tolerant check Hashikalmi and the lowest yield pot was in BR 6976-2B-15. But the reduction in total grain yield per pot due to drought treatment was much lower 77.67g in Treatment T_4, 106 in T_3 and 126g in T_5 treatment. 32.30 g in V1T4 which was significantly different from each other. In this study drought stress greatly reduced filled grain and increased the number of unfilled grain. Due to water stress, the current stomatal conductance decreased, as a result the current photosynthesis became lower, insufficient assimilates production and its distribution to grains insufficient, all the spikelets did not get sufficient assimilates which results increased the empty grains and decreased filled grain ultimately yield losses. In case of varietal effect the highest reduction percentage of unfilled grain was found 42.60% in Hashikalmi (V_3) followed by 41.50% in BR 6976-2B-15 (V_2) and the lowest reduction percentage of unfilled grain was 38.53% in BRRI dhan55. In case of treatment effect on the highest reduction percentage of unfilled grain was 52.83% and the lowest unfilled grain content was 37.38 which were significantly different among the treatment. In case of combination effect of the highest percentage of unfilled grain was 91.67 and the lowest percentage of unfilled grain was 26.49 (Table 4.21) which was significantly different from each other.

Reduction in grain yield due to drought condition depends on genotypes and the duration of drought treatment. A significant decrease in panicle number and filled grain per plant, numbers of effective tillers, dry matter content, increased in number of unfilled grain were the main causes of yield decline due to drought treatment. Total number of spikelet per panicle was recorded highest in BRRI dhan55 (V1) followed by Hashikalmi. In case of treatment effect T2, T3, T4, T5, T6 produced the highest number of total grain. The total number of spikelet per panicle was recorded much lower in BR 6976-2B-15. Due to drought stress, the number of spikelet per panicle or seed setting rate decreased. After drought condition the tolerent genotype would quickly recover their biomass, leaves and then develop new growth. The susceptable genotype could lose their biomass, dry matter, number of effective tillers, filled grains, total number of spikelet per panicle, total grain yield and take much longer time to recover and then develop new organ.

CONCLUSIONS

The overall results of the present experiment, lead to conclude the following changes in respect of morphological, physiological, bio-chemical and yield attributes due to water stress treatment in drought plant and in control plant of different rice genotypes. From the results of the experiments the following conclusion may be drawn-

1. BRRI dhan55 and Hasikallmi showed the better performance among the most of parameters for which and BRRI dhan55 and Hasikallmi were drought tolerant genotype and BR 6976-2B-15, BR 6976-11-1 was the susceptible genotypes.

2. BRRI dhan48 also drought tolerant genotype. Hashikalmi produced the largest panicle. BRRI dhan55 produced the highest number of tillers per plant. It revealed that Hashikalmi showed significantly taller plant throughout growing period.

3. The grain yield per plant recorded was the highest at control treatment and gradually decreased with increasing water stress duration in all the genotypes. But the grain yield was less affected due to water stress treatment in BRRI dhan55 and Hashikallmi compared to other genotypes

4. Water deficit generally accelerates senescence in susceptible genotypes (BR 6976-2B-15, BR 6976-11-1) and this might due to relative water content, stomatal conductance and higher leaf rolling. But the tolerant genotype (BRRI dhan55, BRRI dhan48 and Hashikalmi) was less affected under water stress treatment compared to other genotypes, this might be due to lower reduction in RWC, chlorophyll content, stomatal conductance and lower leaf rolling.

5. Among the biochemical parameters, estimation of soluble sugar, starch, proline content and anthocyanin content was found to be more effective to assess drought tolerance in BRRI dhan55, BRRI dhan48 and Hashikalmi. Under water stress condition anthocyanin and proline were significantly accumulated and soluble sugar and starch decreases.

6. Stomatal conductance was high in all the varieties (1st to 3rd drought stress) and gradually decreases towards maturity at 4th to 6th drought stress.

7. In water stress conditions the highest grain yield was found in tolerent check genotypes BRRI dhan55 and Hashikalmi compaired to susceptable genotypes. Yield reduction due to water stress condition causes due to reduction of root-shoot dry matter content, panicle weight, panicle number and filled grain number, number of effective tillers, RWC and stomatal conductance.

RECOMMENDATION

1. Need to be repeating this type of research work.
2. More research facilities on this aspect are required.
3. Physiological potentiality and drought tolerance rice varieties are required.
4. Agricultural technology related to crop production has to be developed according to specific location suiting its agro- ecology including weather, climate, altitude, latitude, longitude etc. Multi-location adaptive trial may be conducted to perform their performance under drought condition.
5. Future studies should be carried out the changes in the plant water status to incorporate the drought tolerant gene to our high yielding Aus rice genotypes.

CHAPTER 6

REFERENCES

Abaaszadeh, P., Sharifi, A., Lebaschi, H. and Moghadasi, F. (2007). Effect of drought stress on proline, soluble sugars, chlorophyll and RWC level in *Melissa oggicinalis*. *Iranian J. Medicinal Plants Res*. **23**. 504-513.

Abd Allah, A., Shimaa, A., Badawy, A., Zayed, B.A. and El. Gohary, A.A. (2010). The Role of Root System Traits in the Drought tolerance of Rice (*Oryza sati*va L.) *World Academy of Sci. Engin. Tech*.,**44 :** 1388-1392.

Acevedo, E., Hsiao, T.C. and Henderson, D.W. (1971). Immediate and subsequent growth response of maize leaves to changes in water status. *Plant Physiol*. **48**: 631-636.

Acosta-Gallegos, J. A. and Adams, M.W. (1991). Plant traits and yield stability of dry bean (Phaseolus vulgaris) cultivars under drought stress. *J. Agric. Sci.* **117(**02): 213-219.

Aggarwall, P.K. and Kodundal, K.R. (1988). Relative sensitivity of some physiological characteristics to plant water deficits in wheat. *Plant Physiol. Biochem*. **15**(1): 161-168.

Ahmadi, A. and Baker, D.A. (1999). Effects of abscisic acid (ABA) on grain filling processes in wheat. *Plant Growth Regul*. **28**: 187-197.

Akram, N.A. and Ashraf, M. (2013). Regulation in plant stress tolerance by a potential plant growth regulator, 5-aminolevulinic acid. *J. Plant Growth Regul*. **32**(3): 663-679.

Amin, B., Mahleghah, G., Mahmood, H.M.R. and Hossein, M. (2009). Evaluation of interaction effect of drought stress with ascorbate and salicylic acid on some of physiological and biochemical parameters in okra (*Hibiscus esculentus* L.). *Res. J. Biol. Sci*. **4**(4): 380-387.

Anderson, O.M. and Jordheim, M. (2006). The anthocyanins. **In**: Flavonoids: Chemistry, Biochemistry and Applications. O.M. Anderson and K.R. Markham, (eds.). CRC Press, Boca Raton. pp. 471-553.

Andrew, J.S., Moreau, H., Kuntz, M., Pagny, G., Lin, C., Tanksley, S. and McCarthy, J. (2008). An investigation of carotenoid biosynthesis in *Coffeacanephora and Coffeaarabica*. *J. Plant Physiol*. **165**: 1087-1106.

Anjum, F., Yaseen, M., Rasul, E. Wahid, A. and Anjum, S. (2003). Water stress in barley (*Hordeum vulgare* L.). II. Effect on chemical composition and chlorophyll contents. *Pakistan J. Agric. Sci*. **40**(1-2**)**: 45-49.

Anonymous. (1988a). The Year Book of Production. FAO, Rome, Italy.

Anjum, S., Xie, X., Wang, L., Saleem, M., Man, C. and Lei, W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. *J. African. Agril. Res.* **6**(9): 2026-2032.

Anonymous. (1988b). Land Resources Appraisal of Bangladesh for Agricultural Development repoport no. 2. Agroecological Regions of Bangladesh, UNDP and FAO. pp. 472-496.

Anonymous. (2004). Annual report for 2003. IRRI, Los Banos, Philippines, pp. 81–88.

1.1.1 Anonymous. (2015). The geography of east Asia. http://afc.easia.columbia.edu.

Aragon, E.L. (1987). Increased lowland rice yield through improved fertilizer and water management practices. Scientific Meeting of the Federation of Crop Science Societies of the Philippines, College, Laguna (Philippines). pp. 28-30.

Arjenaki, F.G., Jabbari, R. and Morshedi, A. (2012). Evaluation of Drought Stress on Relative Water Content, Chlorophyll Content and Mineral Elements of wheat (*Triticum aestivum* L.) varieties. *Intl. J.Agric. Crop Sci*., **1:** 726-729.

Asch , F., Dingkuhn, M., Sow, A. and Audebert, A. (2005). Drought-induced changes in rooting patterns and assimilate partitioning between root and shoot in upland rice. *Field Crops Res.*. 93(2-3): 223-236.

Ashraf, M.Y., Azmi, A.R., Khan, A.H. and Ala, S.A. (1994). Effect of water stress on total phenols, peroxidase activity and chlorophyll content in wheat (*Triticum aestivum* L.) genotypes under soil water deficits. *Acta Physiol. Plant*. **16**: 185-191.

Astorga, G.I. and Melendez, L.A. (2010). Salinity effects on protein content, lipid peroxidation, pigments,and proline in *Poulownia imperialis* and *Paulownia fortune* grown *in vitro. Electronic J. Bitechnol*. **13**(5): 1- 15.

Bandurska, H. and Jozwiak, W. (2010). A comparison of the effects of drought non prolin accumulation and peroxidases activity in leaves of *Festuca rubral* L. and *Lolium perenne* L. *Plant Physiol*. **2**: 111-116.

Barsa, A. (1997). Mechanism of environmental stress resistance in plant. Harward Acad. Publisher. p. 407.

Bates, L.S., Waldern, R. and Teare, I.D. (1973). Rapid determination of free proline for water stressed studies. *Plant Soil.* **39**: 205-207.

Bayoumi, T.Y., Manal H.E. and Metwali, E.M. (2008). Application of physiological and biochemical indices as a screening technique for drought tolerance in wheat genotypes. *African J. Biotech*. **7:**14.

BBS. (2002). Statistical Pocketbook 2000, Bangladesh Bureau of Statistics, Ministry of Planning, Bangladesh, Dhaka.

Beaudoin, N., Serizet, C., Gosti, F. and Giraudat, J. (2000). Interactions between abscisic acid and ethylene signaling cascades. *Plant Cell*. **12:** 1103-1115.

Begum, F.A. (1992). Effect of different levels of light and drought stress on individual spikelet filling in rice. Ph.D. thesis, Univ. Philippines, Los Banos, College Laguna, Philippines.

Begum, S. and Paul N.K. (2007). Relative leaf water and chlorophyll contents in cassava (*Manihot esculenta* Crantz.) under different planting dates. *J. Asiatic soc. Bangladesh.* **33**: 45.

Beinsan, C., Camen, D., Sumalan, R. and Babau, M. (2003). Study concerning salt stress effect on leaf area dynamicsand chlorophyll content in four bean local landraces from Banat ares. *Fac. Hortic*. **119:** 416- 419.

Bhatt, R.M., and Srinivasa Rao, N.K. (2005). Influence of pod load on response of okra to water stress. *Indian J. Plant Physiol.* **10**(1): 54-59.

Biswal, A.K. and Kohli, A. (2013). Cereal glag leaf adaptations for grain yield under drought: Knowledge status and gaps. *Mol. Breed*., **31**(4): 749-766.

Blum, A. (2000). Drought resistance, water-use efficiency and yield potential-are they compatible, dissonant or mutually exclusive. *Australian J. Agril. Res*. **56:** 1159-1168.

Blum, A., Zhang, J. X. and Nguyen, H. T. (1999). Consistent differences among wheat cultivars in osmotic adjustment and their relationship to plant production. *Field Crops Res*. **64:** 287-291.

Blum, A. (1996). Constitutive traits affecting plant performance under stress. **In**: Developing drought and low N tolerant maize. Proc. Symp. Mexico D.F.: CIMMYT. pp.131-35.

Blum, A. (1988). Plant breeding for Stress environments. CRC.Inc., Florida. USA.

BRRI. (2012). Annual internal review for 2011-2012. Bangladesh Rice Research Institute, Gazipur, Bangladesh.

Blum, A. (1982). Evidence for genetic variability in drought resistance and its implications for plant breeding. **In**: Drought resistance in crops with emphasis on rice. IRRI, The Philippines. pp. 53-68.

Bokul, M.R., Akter, M.S., Islam, M.N., Chowdhury, M.M.A.A. and Amin, M.H.A. (2009). Water stress effects on morphological characteristics and yield attributes in some mutants T-Aman rice lines. *Bangladesh Res. Pub. J.* 3(2): 934-944.

Bonetta, D. and Mccourt, P. (1998). Genetic analysis of ABA signal transduction pathways. *Trends Plant Sci.* 3: 1360-1385.

Boyer, J.S. (1982). Plant productivity and environment. *Science.* 218: 443-445.

Boyer, J.S. (1970). Different sensitivity of Photosynthesis to low water potentials in corn and soybean. *Plant Physiol*. (46): 236-239.

Boonjung, H. and Fukai, S. (1996). Effect of soil water at different growth stages on rice growth and yield under upland conditions: II. Phenology, biomass production and yield. *Field Crops Res.* 48 (1): 47-55.

BRRI. (1991). Annual Report for 1988. Bangladesh Rice Research Institute, Gazipur, Bangladesh. pp. 40-42.

BRRI. (1990). Annual International Review for 1989. Bangladesh Rice Research Institute, Gazipur, Bangladesh. pp. 11-12.

BRRI. (1989). Annual Report for 1988-89. Bangladesh Rice Research Institute, Gazipur, Bangladesh. pp. 11-12.

BRRI. (1985). Annual Report for 1984-1985. Bangladesh Rice Research Institute, Gazipur, Bangladesh. p. 237.

Burger, J. and Edwards, G.E. (1996). Photosynthetic efficiency and photodamage by UV and visible radiation. In red versus green leaf coleus Varieties. *Plant Cell Physiol*. **37**: 395-399.

Carter, T.E.Jr. (1989). Breeding for drought tolerance in soybean: where do we stand. **In**: World Research Conference. Association Argentina Dela Soja, Buenos Aires Argentina.

Castilo, E., Siopongco, J., Buresh, R.J., Ingram, K.T. and De Datta, S.K. (1987). Effect of nitrogen timing and water deficit on nitrogen dynamics and growth of lowland rice. . IRRI Saturday, Laguna, Phillippines.

Chang, T.T., Lorest, G.C. and Tagumpay, O. (1972). Agronomic and growth characteristics of upland and lowland varietics. **In**: Rice breeding, IRRI, Los Banos, Philippines. pp. 645-661.

2 Chaves, M.M., Pereira, J.S., Maroco, J., Rodrigues, M.L., Ricardo, C.P.P., Osorio, M.L., Carvalho, I. Faria, T. and Pinheiro, C. (2002). How plants cope with water stress in the field? Photosynthesis and Growth. *Annals Bot*. **89**(7): 907-916.

Chowdhury, R.S. and Chowdhury, M.A. (2009). Hydrogen peroxide metabolism as an index of water stress tolerance in jute. *Physiol. Plant*. **65**: 503-507.

Constable, G.A. and Hearn, A.B. (1978). Agronomic and Physiological response of soybean and sorghum crops to water deficits. I. Growth, development and yield. *Australian J.Plant Physiol.* **5**(2): 159-167.

Cornic, G. and Massacci, A. (1996). Leaf photosynthesis under drought stress. **In:** Photosynthesis and the Environment. N.R. Baker, (ed.). Kluwer Academic, New York.. pp. 347-366.

Davies, K.M. (2004) Important rare plant pigments. **In**: Plant pigments and their manipulation. K.M. Davies, (ed.). Annual plant reviews, Blackwell, Oxford, UK. pp. 214-247.

3 DellaPenna, D. and Pogson, B.J. (2006). Vitamin synthesis in plants: tocopherols and carotenoids. *Ann. Rev Plant Biol*. **57**: 711-38.

4 Dingkuhn, M. M., Cruz, R.T., O'Toole, J.C. and Rffling, K. D. (1989). Net photosynthesis, water use efficiency, leaf water potential and leaf rolling as affected by water deficit in tropical upland rice. *Australian J. Agril. Res.* **40**(6): 1171-1181.

Djibril, S., Mohamed, O.K., Diaga, D. Diegane, D., Abaye, B.F., Maurice, S and Alain, B. (2005). Growth and development of date palm (*Phoenix dactylifera* L.) seedlings under drought and salinity stresses. *African J. Biotechnol*. **4(**9): 968-972.

Donald, C.M. (1963). Competition among crops and pasture plants. *Adv. Agon*. **15**: 11-18.

Dong , B., Rengel, Z. and Graham, R.D. (1995). Root morphology of wheat genotypes differing in Zn efficiency. *J. Plant Nutr*. **18:** 2761-2773.

Edward, D. and Wright, D. (2008). The effects of winter water-logging and summer drought on the growth and yield of winter wheat (*Triticum aestivum* L.). *European J. Agron*. **28:** 234–244.

Eastham, J., Oosterhuis, D.M. and Walker, S. (1984). Leaf water and tugor potential threshold values for leaf growth of wheat. *Agron. J*. **76**: 841-847.

Ekanayake, I.J., O'Toole, J.C., Garrity, D.P. and Masajo, T.N. (1987). Inheritance of root characters and their relations to drought resistance in rice. *Crop Sci.* **25**: 927-933.

Ekanayake, I. J., O'toole, J. C., Garrity, D. P., & Masajo, T. M. (1985). Inheritance of root characters and their relations to drought resistance in rice. *Crop Science*. **25**(6): 927-933.

Estill, K., Delaney, R.H., Smith, W.K. and Ditterline, R.L. (1991). Water relations and productivity of alfalfa leaf chlorophyll variants. *Crop Sci.* **31**: 1229-1233.

FAO (2002). Crops and drops making the best use of water for agriculture. Food and Agriculture Organization of the United Nations. Rome.

Farahani, H., Valadabad, A., Daneshian, J. and Khalvati, M. (2009). Medicinal and aromatic plants farming under drought conditions. *J. Hort. Forestry*. **1**(6): 86-92.

Farooq, M., Basra, S.M.A, Wahid, A., Cheema, Z.A., Cheema, M.A. and Khaliq, A. (2008). Physiological role of exogenously applied glycinebetaine in improving drought tolerance of fine grain aromatic rice (*Oryza sativa* L). *J. Agron. Crop Sci.* **194**: 325-333.

Farooq, M., Wahid, A. Kobayashi, N., Fujita, D. and Basra, S.M.A. (2009). Plant drought stress: effects, mechanisms and management. *Agron. Sustain. Dev.* **29:** 185–212.

Fedina, I.S., Georgieva, K. Grigorova, I. (2002). Light-dark changes in proline content of barley leaves under salt stress. *Biologia Plantarum.* **45**(1): 59-63.

Fisher, R.A. and Turner, R. (1978). Drought resistance in spring wheat cultivars. Grain yield responses in spring wheat. *Australian J. Agric. Sci*. **29**: 892- 912.

Fraser, T., Silk, W. and Rosr, T. (1990). Effect of low water potential on cortical cell length in growing region on maize roots. *Plant Physiol*. **93**: 648-651.

Fukai, S. and Cooper, M. (1995). Development of drought-resistant cultivars using physio morphological traits in rice. *Field Crops Res*. **40**(2): 67-86.

Gana, A.S. (2011) Screening and resistance of traditional and improved cultivars of rice to drought stress at Badeggi, Niger State. *Agric Biol. J. North Am*., **2**(6)**:** 1027-1031.

Girousse, C., Bournoville, R. and Bonnemain, J.L. (1996). Water deficit-induced changes in concentrations in proline and some other amino acids in the phloem sap of alfalfa. *Plant Physiol.* **111**(1): 109-113.

Gomez, K.A. and Gomez, A.A. (1984). Statistical procedure for agricultural research. Second Edn. International Rice Research Institute. John Wiley and Sons. New York. pp. 1-340.

Guo, S.W., Yi, Z.H.O.U., Na, S.O.N.G. and Shen, Q.R. (2006). Some physiological processes related to water use efficiency of higher plants. *Agril. Sci.China.* **5**(6): 403-411.

Ha, C.V., Leyva-Gonzalez, M.A., Osakabe, Y., Tran, U.T., Nishiyama, R., and Watanabe, Y. (2014). Positive regulatory role of strigolactone in plant responses to drought and salt stress. Proc. Nalt. Acad. Sci. U.S.A. **111:**581-856

Hansen, H. and Dorffling, K. (2006). Changes of free and conjugated abscisic acid and phaseic acid in xylem sap of drought stressed sunflower plants. *J. Expt. Bot*. **50:** 1599-1605.

Hatier, J.H.B., and Gould, K.S. (2008). Foliar anthocyanins as modulators of stress signals. *J. Theol. Biol*. **253**(3): 625-627.

Havaux, M. (1998). Carotenoids as membrane stabilizers in chloroplasts. *Trends Plant Sci*. **3**: 147–151.

Hede, R., Skovmand, B., Reynolds, M.P., Crossa, J., Vilhelmsen, A.L. and Stolen, O. (1999). Evaluating genetic diversity for heat tolerance traits in Mexican wheat landraces *Genet. Res. Crop Evol*. **46**: 37-45.

Henry, A. (2011). IRRI's drought stress research in rice with emphasis on roots: accomplishments over the last 50 years. *Plant Root*. **7**: 92-106.

Henry, A., Baños, L. and Laguna, P. (2013). IRRI's drought stress research in rice with emphasis on roots: accomplishments over the last 50 years. *Plant Root*. **7**: 5-19.

Heuer, B., Nadler, A. (1995) Growth and development of potatoes under salinity and water deficit. *Australian J. Agril. Res.* **46:** 1477-1486.

Hirasawa, T., and Hsiao, T.C. (1999). Some characteristics of reduced leaf photosynthesis at midday in maize growing in the field. *Field Crops Res.* **62**(1): 53-62.

Hossain, M.A. (2001). Growth and yield performance of some boro rice cultivars under different soil moisture regimes. M.S. thesis, BAU, Mymensingh, Bangladesh.

Hsiao, T.C. (1973). Plant responses to water stress. *Ann. Rev. Plant Physiol*. **24:** 519-570.

Hussain, S.S. (2006). Molecular breeding for abiotic stress tolerance: drought perspective. *Proc. Pakistan Acad. Sci.* **43(**3): 189-210.

Iannucci, A. (2000). Physiological responses to water stress following a conditioning period in berseem clover. *Plant soil*. **223**(1-2): 219-229.

IRRI. (2005). Annual Report for 2004. International Rice Research Institute, Los Banos, Leguna, Philippines.

IRRI. (1980). Annual Report for 1979. International Rice Research Institute, Loss Banos, Leguna, Philippines.

IRRI. (1979). Annual Report for 1978. International Rice Research Institute, Loss Banos, Leguna, Philippines.

IRRI. (1978). Annual Report for 1977. International Rice Research Institute, Loss Banos, Leguna, Philippines.

IRRI. (1977). Annual Report for 1976. International Rice Research Institute, Loss Banos, Leguna, Philippines.

IRRI, (1976). Annual Report for 1975. International Rice Research Institute, Los Banos, Philippines

Islam, M.T. and Salam M.A. (1994). Growth and yield performance of some rice genotypes under different soil moisture regimes. *Bangladesh J. Trg. Dev*. 7(2): 57-62.

Islam, M.T., Salam M.A., and Kauser, M. (1994). Effect of soil water stress at different growth stages of rice on yield components and yield. *Progr. Agric*. 5 (2): 151-152.

Islam, M. J., & Mondal, M. K. (1992). Water management strategy for increasing monsoon rice production in Bangladesh. *Agril. water managet.* **22**(4), 335-343.

Jaleel, C.A., Manivannan, P., Wahid, A., Farooq, M., Somasundaram, R. and Panneerselvam, R. (2009). Drought stress in plants: a review on morphological characteristics and pigments composition. *Intl. J. Agric. Biol.* **11**: 100-105.

Jaleel, C.A., Gopi, R. and Panneerselvam, R., (2008a). Growth and photosynthetic pigments responses of two varieties of *Catharanthus roseus* to triadimefon treatment. *Comp. Rend. Biol.* **331**: 272–277.

Jaleel, C.A., Gopi, R., Sankar, B., Gomathinayagam, M. and Panneerselvam, R. (2008b). Differential responses in water use efficiency in two varieties of *Catharanthus roseus* under drought stress. *Comp. Rend. Biol.* **331**: 42-47.

Jaleel, C.A., Manivannan, P., Murali, P.V., Gomathinayagam, M. and Panneerselvam, R. (2008c). Antioxidant potential and indole alkaloid profile variations with water deficits along different parts of two varieties of *Catharanthus roseus*. *Colloids Surf. B. Biointerfaces.* **62**: 312-318.

Jaleel, C.A., Manivannan, P.G., Lakshmanan, .M.A., Gomathinayagam, M. and Panneerselvam, R.(2008d). Alterations in morphological parameters and photosynthetic pigment responses of *Catharanthus roseus* under soil water deficits. *Colloids Surf. B. Biointerfaces.* **61**: 298-303.

Kage, H., Kochler , M. and Stützel, H. (2004). Root growth and dry matter partitioning of cauliflower under drought stress conditions: measurement and simulation. *European J. Agron.* **20** : 379-394.

Kamara, A.Y., Menkir, A. Badu-Apraku, B. and Ibikunle, O. (2003). The influence of drought stress on growth, yield and yield components of selected maize genotypes. *J. Agric. Sci.* **141**: 43-50.

Kanbar, A. and Shashidhar, H.E. (2004). Correlation and path analysis for root morphological taits in indica x indica population of rice (*Oryza sativa* L.). *Crop Res.* **27**(1): 94-98.

Karamanos, A.S. (1980). Water stress and leaf growth of field bean (*Vicia faba*) in the field: Leaf number and total area. *Annals. Bot*. **42:** 1393-1402.

Kiani, S.P., Maury, P., Sarrafi, A. and Grieu, P. (2008). QTL analysis of chlorophyll fluorescence parameters in sunflower (*Helianthus annuus* L.) under well-watered and water-stressed conditions. *Plant Sci*. **175**: 565-573.

Korir, P.C., Nyabundi, J.O. and Kimurto, P.K. (2006). Genotypic response of common bean (*Phaseolus vulgaris* L.) to moisture stress conditions in Kenya. *Asian J. Plant Sci*. **5(**1): 24-32.

Kramer, P.J. (1982). Plant and soil water relationships. A modern synthesis. Mc Grao –Hill, New York. p. 482.

Kramer, P.J., and Boyer, J.S. (1995). The absorption of water and root and stem pressures. **In**: Water Relations of Plants and Soils. Academic Press Inc . San Diego, USA. pp. 167-200.

Krol, M., Gray, G.R., Hurry, V.M., Malek, L. and Huner, N.P.A. (1995). Low temperature stress and photoperiod affect an increased tolerance to photoinhibition in *Pinus bonksiana* seedlings. *Canadian. J. Bot*. **73**: 1119-1127.

Kuixian, J., Wang, Y., Sun, W., Lou, Q., Hanwei, M., Shen, S. and Chen, H. (2012). Drought responsive mechanism in rice genotypes with contrasting drought tolerance during reproductive stage. *J. Plant Physiol*. **169**: 336-344.

Kulkarni, M., Borse, T. and Chaphalkar, S. (2008). Mining anatomical traits: A novel modelling approach for increased water use efficiency under drought conditions in plants. *Czech J. Genet. Plant Breed.* **44**(1): 11–21.

Kumar, R., Sarawgi, A.K., Ramos, C., Amarante, S.T., Ismai, A.M. and Wade, L.J. (2006). Partitioning of dry matter during drought stress in rainfed lowland rice. *Field Crops Res*. **98***:* 1-11.

Kusaka, M., Ohta, M. and Fujimura, T. (2005). Contribution of inorganic components to osmotic adjustment and leaf folding for drought tolerance in pearl millet. *Physiol. Plant*. **125**: 474-489.

Lafitte, H.R., Yongsheng, G., Yan, S. and Li, Z.K. (2007). Whole plant responses, key processes and adaptation to drought stress: the case of rice. *J. Expt. Bot*. **58**: 169-175.

Laureano, R.G., Lazo, Y.O., Linares, J.C., Luque, A., Martínez, F., Seco, J.I. and Merino, J. (2008). The cost of stress resistance: construction and maintenance costs of leaves and roots in two populations of Quercus ilex. Tree physiol. **28**: 1721-1728.

Lawlor, D.W. and Cornic, G. (2002). Photosynthetic carbon assimilation and associate metabolismin relation towater deficits in higher plants. *Plant Cell Environ*. **25**: 275-294.

Lawson, T., Oxborough, K. Morison, J.I.L. and Baker, N.R. (2003). The responses of guard and mesophyll cell photosynthesis to CO2, O2, light and water stress in a range of species are similar. *J. Expt. Bot*. **54**: 1743-1752.

Levitt, J. (1980). Responses of plants to environmental stresses. Volume II. Water, radiation, salt, and other stresses. No. Ed. 2. Academic Press. Los Banos, Laguna, Phillippines.

Lilley, J.M. and Fukai, S. (1994). Effect of timing and severity of water deficit on four diverse rice cultivars. 1. Rooting pattern and soil water extraction. Field Crops Res.,**37**: 205-213.

Liu, F. and Stütze, H. (2004). Biomass partitioning, specific leaf area, and water use efficiency of vegetable amaranth (*Amaranthus* spp.) in response to drought stress. *Scientia Horticulturae.* **102**(1): 15-27.

Liu, F., Jensen, C.R., and Andersen, M.N. (2006). Pod set related to photosynthetic rate and endogenous ABA in soybeans subjected to different water regimes and exogenous ABA and BA at early reproductive stages. *Annals Botany*. **94**(3): 405-411.

Luan, S. (2002). Signalling drought in guard cells. *Plant cell environ*. **25(**2): 229-237.

Ludlow, M.M. and Muchow, R.C. (1990). A critical evaluation of traits for improving yield in water limited environments. *Adv. Agron*. **43**: 107-153.

Lum, M.S. (2014). Effect of drought stress on growth, proline and antioxidant enzyme activities of upland rice. *J. Animal Plant Sci*. **24**(5): 1487-1493.

Mafakheri, A., Siosemardeh, A., Bahramnejad, B., Struik, P.C. and Sohrabi, Y. (2010). Effect of drought stress on yield, proline and chlorophyll content in three Chickpea cultivars. *J. Australian Crop Sci.* **4**(8): 580-585.

Mahajan, S. and Tuteja, N. (2005). Cold, salinity and drought stresses: an overview. *Archi. Biochem. biophysics.* **444** (2): 139-158.

Maji, A.T. (1994). Vegetative stage drought tolerance and agronomic characteristics of *Oryza glaberrima* accessions. Msc Thesis, University of Ibadan, pp. 156.

Manivannan, P. (2007). Growth, biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought stress. *Colloids and Surfaces B. Biointerfaces* **59**(2): 141-149.

Marron, N., Dreyer, E., Boudouresque, E., Delay, D., Petit, J.M., Delmotte, F. M. and Brignolas, F. (2003). Impact of successive drought and re-watering cycles on growth and specific leaf area of two Populus canadensis (Moench) clones,“Dorskamp”and “Luisa_Avanzo”. Tree physiol. **23**: 1225-1235.

Masuduzzaman, A.S.M. (2011). Rice production and mechanization. Annual Report. Plant Breeding Division, BRRI, Gazipur, Bangladesh.

5 Mayaki, W.C., Teare, I.D. and Stone, I.R. (1976). Top and root growth of irrigated and Nonirrigated Soybeans. *Crop Sci.* **162**: 92-94.

Mckersie, B.D., and Leshem, Y.Y. (1994). Water and drought stress. **In**: Stress and stress coping in cultivated plants. Springer Science+Business Media Dordrecht. Originally published by Kluwer Academic Publishers. pp. 148-180.

Mehrtens, F., Kranz, H., Bednarek, P. and Weisshaar, B. (2005). The Arabidopsis transcription factor MYB12 is a flavonol-specific regulator of phenylpropanoid biosynthesis. *Plant Physiol.* **138**: 1083-1096.

Mittler, R. (2006). Abiotic stress, the field environment and stress combination. *Trends in plant Sci.* 11(1). 15-19

Mohammadian, R. (2005). Effect of early season drought stress on growth characteristics of sugar beet genotypes. *Turkish J. Agric. Forestry*. **29**(5): 357.

Mohammadkhani., N. and Heidari, R. (2008). Drought induced accumulation of soluble sugars and proline in two maize varieties. *World Appl. Sci. J.* **3**(3): 448-453.

Monneveux, P. (2006). Drought tolerance improvement in tropical maize source populations. *Crop Sci.* **46**(1): 180-191.

Morgan, P.W. (1990). Effects of abiotic stresses on plant hormone systems. **In**: Stress plants: adaptation and acclimation mechanisms. Wiley-Liss, Inc. pp. 113-146.

Morinaga, T. (1955). The genealogy of Japanese rice. *Agr. Hort.* **30**: 1275-1277.

Muchow, R.C. (1989). Comparative productivity of maize, sorghum and pearl millet in a semi-arid tropical environment II. Effect of water deficits. *Field Crops Res.* **20**(3): 207-21.

Murty, K.S. (1987). Drought in relation to rainfed upland rice. *J. Agric. Res*. **2**(1): 1-8.

Mwanamwenge, J., Loss, S.P., Siddique, K.H.M. and Cocks, P.S. (1999). Effect of water stress during floral initiation, flowering and podding on the growth and yield of faba bean (*Vicia faba* L.). *European. J. Agron*. **11:** 1-11.

Naidu, B.P., Leslie, G.P. and Graham P. J. (1992). Nitrogenous compatible solutes in drought-stressed *Medicago* spp. *Phytochemistry*. **3(**4): 1195-1197.

Nakayama, N. (2007). Response of growth, photosynthetic gas exchange, translocation of 13C-labelled photosynthate and N accumulation in two soybean (*Glycine max* L.) Merrill cultivars to drought stress. *Intl. J. Agric. Biol*. **9**: 669-674.

Ndung'u, C.K., Shimizu, M., Okamoto, G. and Hirano, K. (1997). Abscisic acid, carbohydrates, and nitrogen contents of Kyoho grapevines in relation to bud break induction by water stress. *American. J. Enol. Vitic*. **48**: 115-120.

Niyogi, K.K. (1999). Photoprotection revisited: genetic and molecular approaches. *Ann. Rev. Plant Physiol. Plant Mol. Biol.* **50**: 333-359.

Noodén LD (1988) The phenomena of senescence and aging. In: Senescence and aging in plants. (Eds LD Noodén and AC Leopold) pp. 1–50.

O'Toole, J.C. and Moya, T.B. (1981). Water deficit and yield in upland rice. *Field Crops Res.* **4**(3): 247-259.

O'Toole, J.C., Chang, T.T. and Cruz, R.T. (1979). Leaf rolling and transpiration. *Plant Sci*. **16**: 111-114.

Oosterhuis, D.M., and Cartwright, P.M. (1983). Spike differentiation and floret survival in semidwarf spring wheat as affected by water stress and photoperiod. *Crop Sci.* **23**(4): 711-717.

O'Toole, J.C. (1982). Adaptation of rice to drought prone environments. **In:** Drought resistance in crop with emphasis on rice. International Rice Research Institute, Los Banos. pp. 195-213.

Pandey, V. and Shukla, A. (2015). Acclimation and Tolerance Strategies of Rice under Drought Stress. *Rice Sci.,***22**(4): 147-161.

Pandey, S. and Bhandari, H. (2008). Drought: economic costs and research implications. Drought frontiers in rice: Crop improvement for increased rainfed production. World Scientific, Singapore; International Rice Research Institute, Los Baños, Philippines. pp: 3-17.

Pantuwan, G., Fukai, S., Cooper, M., Rajatasereekul, S., and O'Toole, J.C. (2002). Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed lowlands. Plant factors contributing to drought resistance. *Field Crops Res*.**73**.181-200.

Park, S.C., Kim, Y.H., Jeong, J.C., Kim, C.Y., Lee, H.S., Bang, J.W. and Kwak, S.S. (2011). Sweetpotato late embryogenesis abundant 14 (IbLEA14) gene influences lignification and increases osmotic-and salt stress-tolerance of transgenic calli. *Planta.* **233**(3): 621-634.

Passioura, J.B. (1982). Water in the soil-plant-atmosphere continuum. **In**: Physiological Plant Ecology II. O.L. Lange, P.S. Nobel, C.B. Osmond, H. Ziegler, (eds.). Springer Berlin Heidelberg. pp. 5-33.

Paul, N.K. and Aman, R. (2000). Genotypic variation in physiological characters and grain yield of wheat under low soil moistures. *Ann. Bangladesh Agric*. **10**: 195-201.

Peleg, Z. and Blumwald, E. (2011). Hormone balance and abiotic stress tolerance in crop plants. *Curr Opin Plant Biol.* **14**: 290–295.

Peterson, A. M., Mao, L., Jett, L. E., Story, R. N., Hammond, , J. K., & Labonte, D. R. (2004). Influence of drought stress on sweetpotato resistance to sweetpotato weevil, Cylas formicarius (Coleoptera: Apoinidae), and storage root chemistry. *Florida Entomologist*. **87**(3): 261-267.

6 Petropoulos, S.A., Daferera, D., Polissiou, M.G. and Passam, H.C. (2008). The effect of water deficit stress on the growth, yield and composition of essential oils of parsley. *Scientia Horticulturae*. **115**(4): 393-397.

Pinheiro, C. and Chaves, M.M. (2011). Photosynthesis and drought: can we make metabolic connections from available data. *J. Expt. Bot*. **62(**3): 869-882.

Pireivatloum, J., Qasimov, N. and Maralian, H. (2010). Effect of soil water stress on yield and proline content of four wheat lines. *African. J. Biotechnol*. **9**: 36-40.

Popp, M.P., Keisling, T.C., Oliver, L.R. and Wallace, D. (2002). Planting date, cultivar and tillage system effects on dry land soybean production. *Agric. J.* **94**: 81-88.

Prabhudeva, T.V. (1998). Soil moisture stress and drought susceptibility index in sunflower. *Indian Agric.* **42**: 287-289.

Prochazkova, D., Sairam, R. K., Srivastava, G.C., and Singh, D.V. (2001). Oxidative stress and antioxidant activity as the basis of senescence in maize leaves. *Plant Science.* **161**(4), 765-771.

Puckridge, D.W. and O'Toole, J. (1981). Dry matter and grain production of rice, using a line source sprinkler in drought studies. *Field Crops Res*. **3**: 303-319.

Rahdari, P. and Hoseini. S.M. (2012). Drought Stress: A Review. *Intl. J. Agron. Plant Prod.* **3**(10): 443-446.

Rontein, D., Basset, G., Hason, A.D. (2002). Metabolic engineering of osmoprotectant accumulation in plants. *Metab. Eng*. **4**: 49-56.

Reddy, A.R., Chaitanya, K.V. and Vivekanandan, M. (2004). Drought induced responses of photosynthesis and antioxidant metabolism in higher plants. *J. Plant Physiol*. **161**: 1189-1202.

RRDI. (1999). Effect of water deficit. Rice Research and Development Institute. http:/www/rice.ac.lk/research disciples 41.html. Department of Agriculture , Batalagoda , Ibbagamuwa, Sri lanka.

Russell, M.B. (1959). Water and its relation to soils and crop. *Adv. Agron*. **11**: 11-22.

Sacks, M.M., Silk, W.K. and Burman, P. (1997). Effect of water stress on cortical cell division Rates within the Apical Meristem of Primary Roots of Maize. *Plant Physiol.* **114**(2):519-527.

Sadras, V.O. and Milroy, S.P. (1996). Soil-water thresholds for the responses of leaf expansion and gas exchange: A review. *Field Crops Res.* **47**(2): 253-266.

Sairam, R.K. and Srivastava, G.C. (2001). Water stress tolerance of wheat (*Triticum aestivum* L.): Variations in hydrogen peroxide accumulation and antioxidant activity in tolerant and susceptible genotypes. *J. Agron. Crop Sci*. **186**(1): 63-70.

Sankar, B., Jaleel, C.A., Manivannan, P., Kishorekumar, A., Somasundaram, R. and Panneerselvam, R. (2008). Relative efficacy of water use in five varieties of *Abelmoschus esculentus* (L.) Moench. under water-limited conditions. Colloids and *Surfaces B. Biointerfaces*. **62**(1): 125-129.

Sankar, B., Jaleel, C.A., Manivannan, P., Kishorekumar, A., Somasundaram, R. and Panneerselvam, R. (2007). Effect of paclobutrazol on water stress amelioration through antioxidants and free radical scavenging enzymes in Arachis hypogaea L. *Colloids Surf B. Biointerfaces.* **60**(2): 229-235.

Sarkar, P. K. (2014). Growth and yield of wheat (Triticum aestivum) under deficit . *Bangladesh Journal of Agricultural Research.* **38(**4): 719-732.

Schonfeld, M.A., Johnson, R.C., Carver, B.F. and Mornhinweg, D.W. (1988). Water relations in winter wheat as drought resistance indicator. *Crop Sci.* **28**: 526-531.

Schwinn, K.E. and Davies, K.M. (2004). Flavonoids. *In.* KM Davies, ed, Plant Pigments and Their Manipulation, *Ann.Plant Rev.***14**: 92-149.

Scott, L.C. (1999). Invited review environmental significance of anthocyanins in plant stress responses. Photochem. Photobiol. **70**(1): 1-9.

Sellammal, R., Robin, S. and Raveendran, M. (2014). Association and Heritability Studies for Drought Resistance under Varied Moisture Stress Regimes in Backcross Inbred Population of Rice, *Rice Sci.,* **21**(3): 150-161.

Shao, H.B., Chu, L.Y., Shao, M.A., Jaleel, C.A. and Hong-Mei, M. (2008). Higher plant antioxidants and redox signaling under environmental stresses. *Comp. Rend. Biol*. **331**(6): 433-441.

Sharp, R.E. Poroyko, V., Hejlek, L.G., Spollen, W.G., Springer, G.K., Bohnert, H.J. and Nguyen, H.T. (2004). Root growth maintenance during water deficits: physiology to functional genomics. *J. Expt. Bot.* **55**(407): 2343-2351.

Shaw, R.H. (1988). Climate requirement. **In**: Corn and Corn Improvement. G.F. Sprague and J. W. Dudley, (eds). gronomy Series: no.18.ASA.Madison, Wisconsin, USA. pp 609-633.

Siddique, M.R.B., Hamid, A. and Islam**,** M.S. (1999). Drought stress effects on water relations of wheat. Institute of Postgraduate Studies in Agriculture, Gazipur-1703, Bangladesh.

Sikuku, P.A., Netondo, G.W., Onyango, J.C. and Musyimi, D.M. (2010). Chlorophyll fluorescence, protein and chlorophyll content of three NERICA rainfed rice varieties under varying irrigation regime. *Agril. Biol. Sci.* **5**(2): 19-25.

Sinclair, T.R. and Ludlow, M.M. (1985). Who taught plants thermodynamics? The unfulfilled potential of plant water potential. *Funct. Plant Biol*. **12**(3): 213-217.

Singh, J.S., Milchunas, D.G. and Lauenroth, W.K. (1998). Soil water dynamics and vegetation patterns in a semiarid grassland. *Plant ecol.* **134(**1): 77-89.

Smirnoff, N. (1993). The role of reactive oxygen in the response of plants to water deficit and desiccation. *J. New Phytol*. **125**: 27-30.

Specht, J. E. (2001). Soybean response to water. *Crop Sci.* **41**(2): 493-509.

Stoyanov, Z. (2005). Effects of water stress on leaf water relations of young bean plant. *J. Central European Agric*. **6(**1): 35-56.

Subbarao, G.V., Johansen, C. Slinkard, A.E., Nageshwara Rao, R.C., Saxena, N.P. and Cjhauhan, Y.S. (1995). Strategies and scope for improving drought resstance in grain legumes. *Crit. Rev. Plant Sci.* **14**(6): 469-523.

Subrahmanyam, D., Subash, N., Haris, A., and Sikka, A. K. (2006). Influence of water stress on leaf photosynthetic characteristics in wheat cultivars differing in their susceptibility to drought. *Photosynthetica*. **44**(1): 125-129.

Synerri, C.L.M., Pizino, C. and Navariizzo, F. (1993). Chemical changes and O2 production in thylakoid membrane under water stress. *Plant Physiol*. **87**: 211-216.

Tabaeizadeh, Z. (1998). Drought-induced responses in plant cells. *Intl. Rev. Cytol*. **182**: 193-247.

Tahir, M.H.N., Imran, M. and Hussain, M.K. (2002). Evaluationof sunflower (*Helianthus annuus* L.) inbred lines for drought tolerance. *Intl. J. Agric. Biol***. 3:** 398-400.

Tahkokorpi, M., Taulavuori, K. Laine, K. and Taulavuori, E. (2007). After effects of drought-related winter stress in previous and current year stems of *Vaccinium myrtillus* L. *Environ. Expt. Bot*. **61:** 85-93.

Taiz, L. and Zieger, E. (1998). Stress physiology. **In**: Plant physiology. 2nd edn. Sinauer Associates, Inc., Sunderland, M.A. pp. 725-757.

Tanaka, R., Oster, U., Kruse, E., Rudiger, W. and Grimm, B. (1999). Reduced activity of geranylgeranyl reductase leads to loss of chlorophyll and tocopherol and to partially geranylgeranylated chlorophyll in transgenic tobacco plants expressing antisense RNA for geranylgeranyl reductase. *Plant Physiol.* **120**(3): 695-704.

Tevini, M. (1994). UV. Effect of terrestrial plants and aquatic organisms. *Prog. Bot*. **55**: 174-190.

Ting, Y. (1949). Origination of the rice cultivation in China. *Agron. B. Sun Yatsen U.Ser*.**7**:1-8.

Tsuda, M. and Takami, S. (1991). Changing in heading date and panicle weight in rice subjected to water stress during the early stage of panicle development. *Japanese J. Crop Sci*. **60**: 2-64.

Tuong, T. and Bouman, B. (2003). Rice production in water scarce environment. In: J. Kljine, R. Barker and Modden, D. (eds). Water productivity in agriculture: Limits and opportunities for improvement. pp. 53-67.

Turner, N.C. Hearn, A.B., Begg, J.E. and Constable, G.A. (1986). Cotton (*Gossypium hirsutum*

L.) physiological and morphological responses to water deficits and their relationship to yield. *Field Crops Res.***14:** 153-170.

Turk, K.J., Hall, A.E. and Asbell, C.W. (1980). Drought adaptation of cowpea. I. Influence of drought on seed yield. *Agron. J.* **72**(3): 413-420.

Unyayar, S., Aktoklu, E. and Büyükasik, Y. (2004). The response to exogenous abscisic acid of the roots of notabilis and its wild-type tomato under drought stress. *Israel J. Plant Sci.* **52**(4): 294-299.

Usman, M., Raheem, Z.F., Ahsan, T. Iqbal, A. Sarfaraz, Z. N. and Haq, Z. (2013). Morphological, physiological and biochemical attributes as indicators for drought tolerance in rice (*Oryza sativa* L.). *European J. Biol. Sci*. **5** (1): 23-28.

Vijrabhaya, M., Kumpun, W. and Chadehawan, S.(2000). The solute accumulation. mechanism for drought tolerance in RD23 rice (*Oryza sativa*). *Lines. Sci. Asia*. **27**: 93-97.

Vile, D., Garnier, E., Shipley, B., Laurent, G., Navas, ML., Roumet, C., Lavorel, S. and Díaz, S. (2005). Specific leaf area and dry matter content estimate thickness in laminar leaves. Annals Bot. *96 (6): 1129-1136.*

Wade, L.J., McLaren, C.G., Quintana, L., Harnpichitvitaya, D., Rajatasereekul, S., Sarawgi, A.K., Kumar, A., Ahmed, H.U., Sarwoto Singh, A.K., Rodriguez, R., Siopongco, J. and Sarkarung, S. (1999). Genotype by environment interactions across diverse rainfed lowland rice environments. *Field Crops Res.* **64**: 35-50.

Webber, M., Barnett, J., Finlayson, B. and Wang, M. (2006). Pricing China's Irrigation water. Working paper. School of Anthropology, Geography and Environmental Studies. The University of Melbourne, Victoria, Australia.

Whiteman, P.C. and Wilson, G.L. (1965). Effects of water stress on the productive developmentof Sorghum vulgare pers. **4**(14): 233-234

Wu, Q.S., Xia, R.X. and Zou, Y.N. (2008). Improved soil structure and citrus growth after inoculation with three arbuscular mycorrhizal fungi under drought stress. *European J. Soil Biol.* **44**(1): 122-128.

Wullschleger, S.D., Yin, T.M., DiFazio, S.P., Tschaplinski, T.J. Gunter, L.E., Davis, M.F. and Tuskan, G.A. (2005). Phenotypic variation in growth and biomass distribution for two dvanced-generation pedigrees of hybrid poplar. *Canadian J. Res*. **35**: 1779-1789.

Yamboo, E.B. and Ingram, K.T. (1988). Drought stress index for rice Philippines. *J. Crop Sci.* **13** (20): 105-111.

Yang G., Ristic, Z. and Shailendra, K.B. (1999). Two-dimensional gel analysis of 45 ku heat shock proteins from a drought and heat resistant maize line. *J. plant physiol*. **154** (2): 264-268.

Yang, J. (2001). Water deficit–induced senescence and its relationship to the remobilization of pre-stored carbon in wheat during grain filling. *Agron. J.* **93 (**1): 196-206.

Yang, X. (2006). Tolerance of photosynthesis hybridization line and its parents grown under field conditions. *Plant Sci.* **171**: 389-397.

Yokota, A., Takahara, K. and Akashi, K. (2006). Water stress physiology and molecular biology of stress tolerance in plants. Springer Netherlands. pp. 15-39.

Yordanov, I., Velikova, V. and Tsonev, T. (2003). Plant responses to drought and stress tolerance. Bulg. *J. Plant Physiol*. 187-206.

Yoshida, S. (1972). Physiological aspect of grain yield. *Ann. Rev.Plant physiol*.**23:** 437-464.

Yoshida, S., & Hasegawa, S. (1982). The rice root system: its development and function. Drought resistance in crops with emphasis on rice, 10.

Yoshida, S. (1985). Fundamentals of rice crop science. IRRI, Philippines. pp. 1-41.

Yoshida, S., Forno, D.A. Cook, J.H. and Gomez, K.A. (1975). Routine procedure for growing rice plant in culture solution. **In**: Laboratory manual for physiological studies for rice. IRRI, Los Banos, Philippines. p.61- 66.

Zeigler, R.S. and Puckridge, D.W. (1995). Improving sustainable productivity in rice based rainfed lowland systems of south and Southeast Asia. *Geo. J.* **35:** 307-324.

Zhang, J., James, Z., Robert, A., Creelman and Zhu, J.K. (2004). From laboratory to field. Using information from Arabidopsis to engineer salt, cold, and drought tolerance in crops. *Plant Physiol.* **135(**2): 615-621.

Zhang, J., Kirkham, M.B. (1996). Antioxidant response to drought in Sunflower and Sorghum seedlings. *New Phytol*. **132**: 361-373.

Zhao, C.X, L.Y. Guo, C.A. Jaleel,. Shao, H.B and Yang, H.B. (2008). Prospects for dissecting plant-adaptive molecular mechanisms to improve wheat cultivars in drought environments. *Comp. Rend. Biol*. **331**: 579-586.

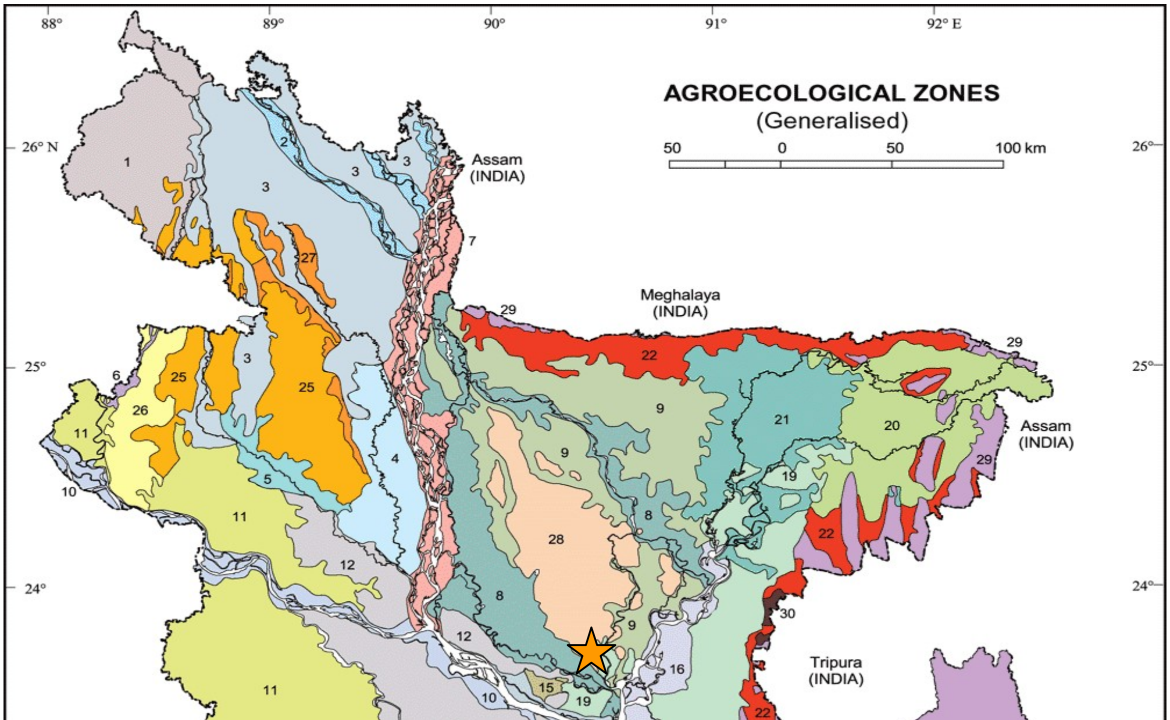
Zubaer, M.A., Chowdhury, A.K.M.M.B., Islam, M.Z., Ahmed, T. and Hasan, M.A. (2007). Effects of water stress on growth and yield attributes of Aman rice genotypes. *Intl. J. Sus. Crop Prod.* **2**(6): 25-30.

Zulkarnain, W.M. (2009). Rice growth and yield under rain shelter house as influenced by different water regimes. *Intl. J. Agric. Biol*. **11**: 566-570.

CHAPTER-7

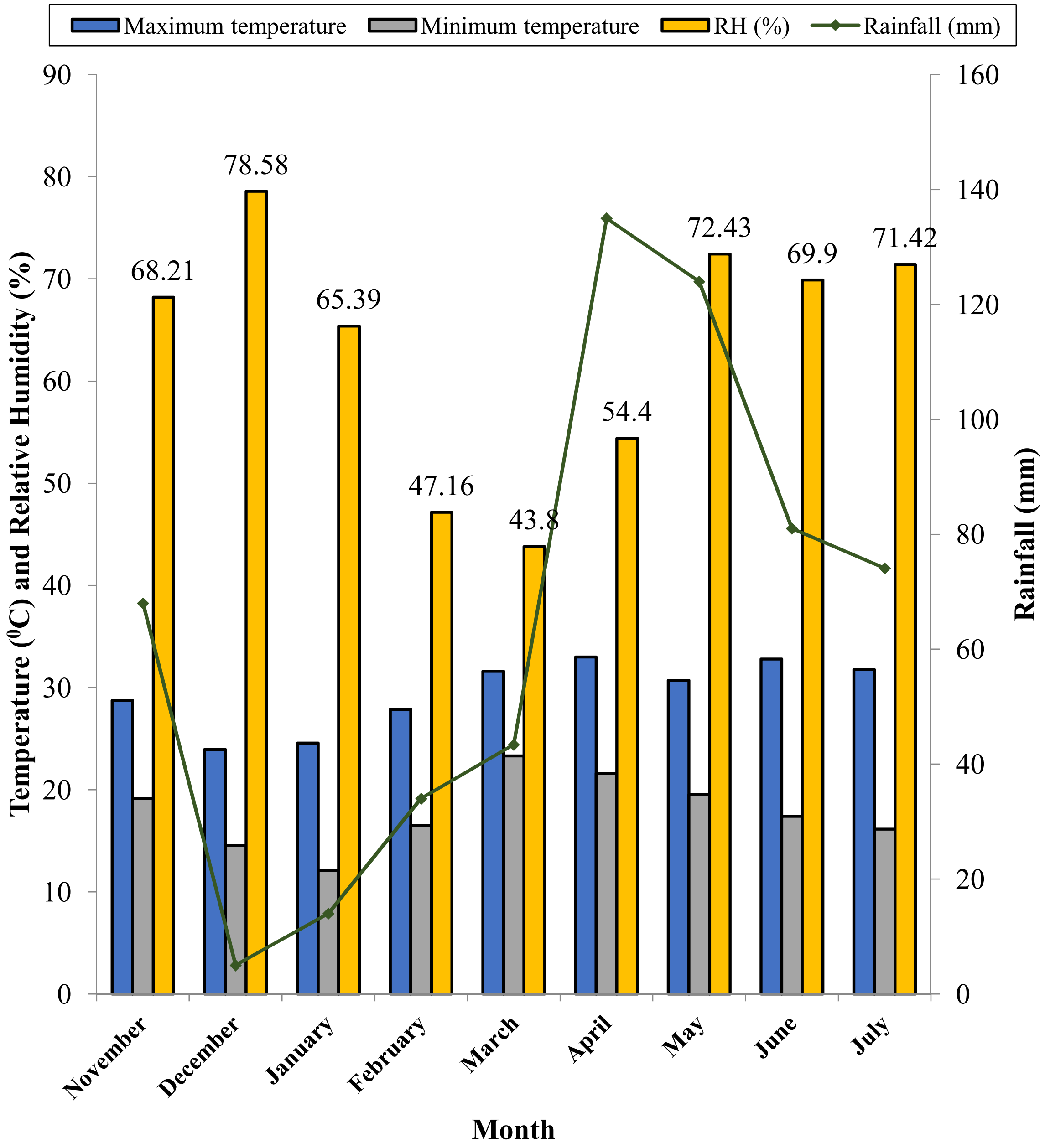
APPENDICES

Appendix I. Map showing the experimental sites under study

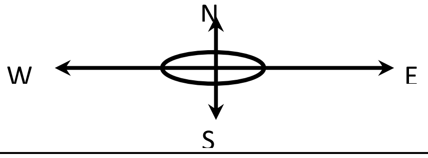


The experimental site under study

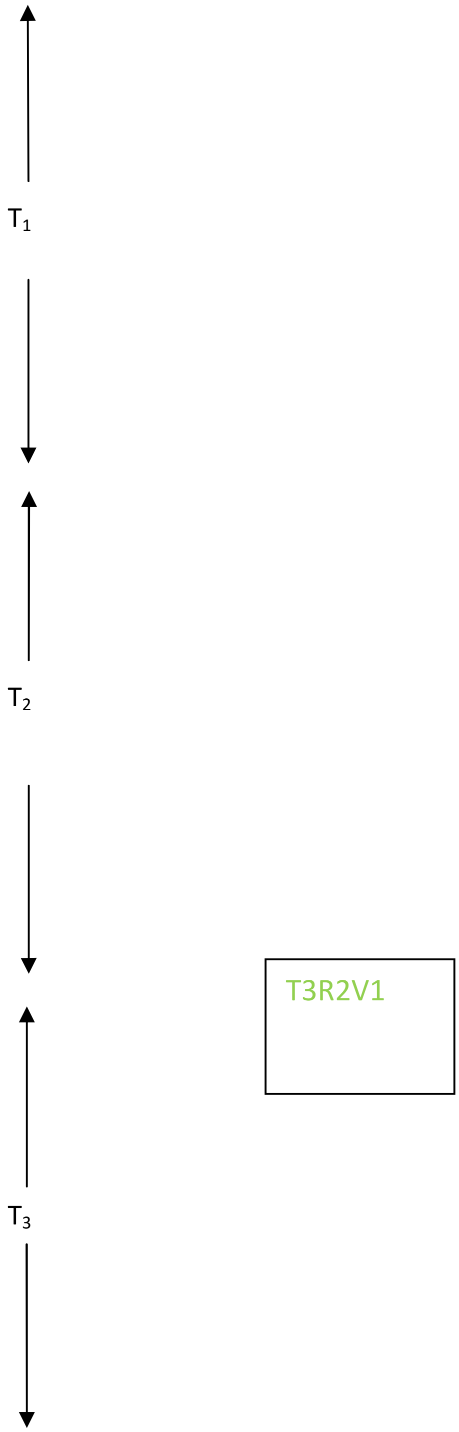
Appendix II. Monthly record of average air temperature, relative humidity and total rainfall of the experimental site during the period from November 2012 to July 2013



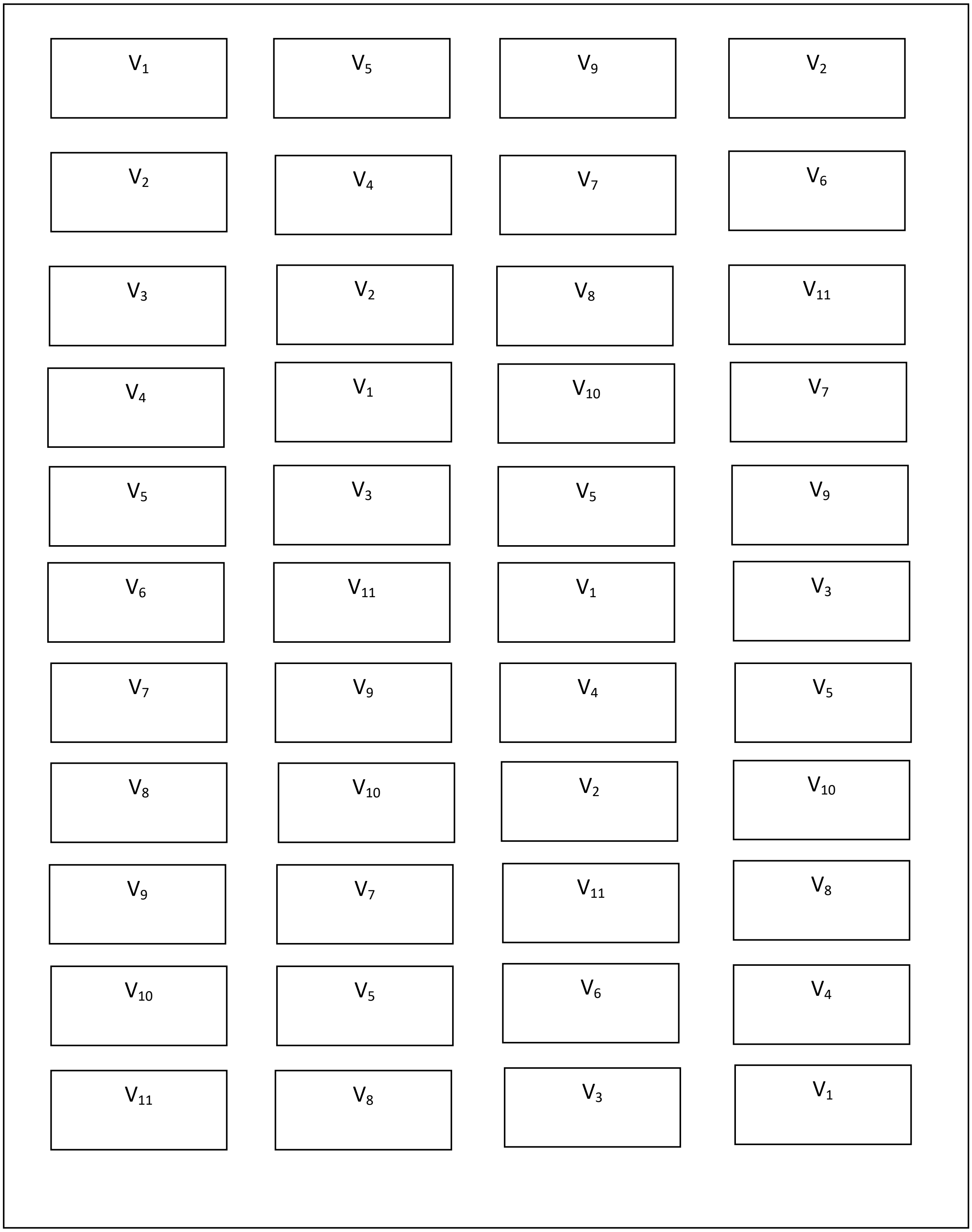
Appendix III: Lay out of the experiment- 3 with randomization



T1R1V1	T1R2V1	T1R3V1	T4R1V1	T4R2V1	T4R3V1

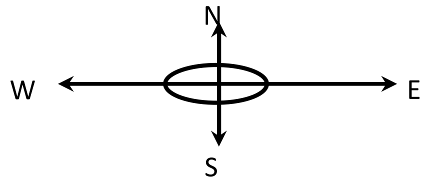


Appendix IV. Lay out of the experiment-1 with randomization


V_1 V_5 V_9 V_2
V_2 V_4 V_7 V_6
V_3 V_2 V_8 V_{11}
V_4 V_1 V_{10} V_7
V_5 V_3 V_5 V_9
V_6 V_{11} V_1 V_3
V_7 V_9 V_4 V_5
V_8 V_{10} V_2 V_{10}
V_9 V_7 V_{11} V_8
V_{10} V_5 V_6 V_4
V_{11} V_8 V_3 V_1

Appendix V. Lay out of the experiment- 1 with randomization

Variety	**Treatment-1 (control)**			**Treatment-2 (7 days stress)**			**Treatment-3 (15 days stress)**		
	R1	R2	R3	R1	R2	R3	R1	R2	R4
V1	V10 R1	V4 R2	V6R3	V1R1	V4 R2	V6R3	V10 R1	V4 R2	V6R3
V2	V3 R1	V2 R2	V4 R3	V3 R1	V2 R2	V4 R3	V3 R1	V2 R2	V4 R3
V3	V5 R1	V3 R2	V1 R3	V5 R1	V3 R2	V6 R3	V5 R1	V3 R2	V1 R3
V4	V9 R1	V1R2	V9 R3	V9 R1	V1R2	V9 R3	V9 R1	V1R2	V9 R3
V5	V2R1	V5 R2	V7 R3	V2R1	V5 R2	V7 R3	V2R1	V5 R2	V7 R3
V6	V8 R1	V6 R2	V3 R3	V8 R1	V6 R2	V3 R3	V8 R1	V6 R2	V3 R3
V7	V1R1	V7 R2	V5 R3	V10 R1	V7 R2	V5 R3	V1R1	V7 R2	V5 R3
V8	V6 R1	V8 R2	V10 R3	V6 R1	V8 R2	V10 R3	V6 R1	V8 R2	V10 R3
V9	V4 R1	V9 R2	V2 R3	V4 R1	V9 R2	V2 R3	V4 R1	V9 R2	V2 R3
V10	V7 R1	V10 R2	V8 R3	V7 R1	V10 R2	V8 R3	V7 R1	V10 R2	V8 R3



Appendix VI. Lay out of the experiment-2

Treatment	R1	R2	R3
T1	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T2	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T3	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T4	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T5	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T6	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T7	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T8	R1V1	R2V1	R3V1

	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T9	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
10	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3
T11	R1V1	R2V1	R3V1
	R1V2	R2V2	R3V2
	R1V3	R2V3	R3V3

Appendix VI : Proline standard curve

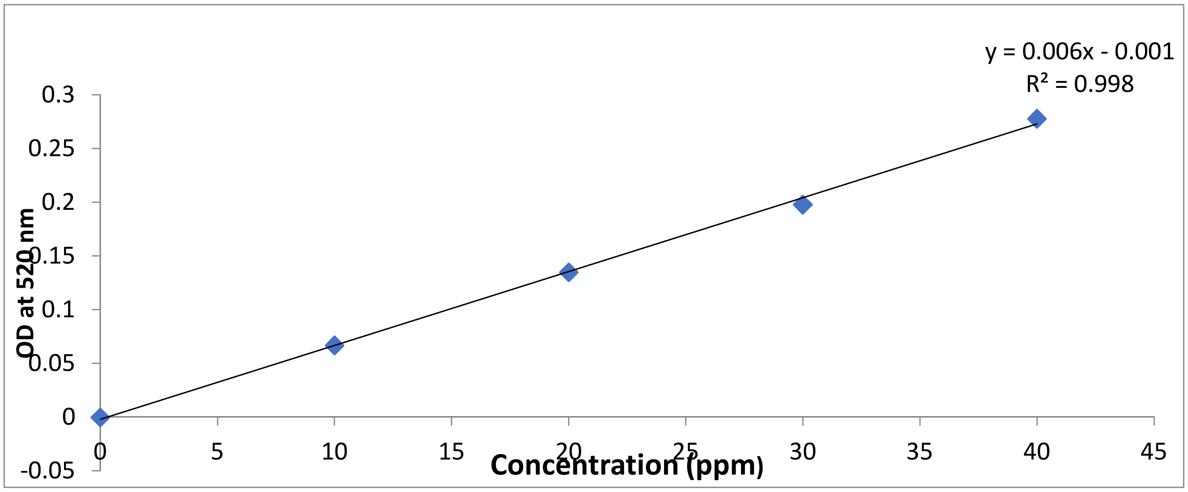


Table 1.6. Root dry weight (g) at first ten cm to seventy cm depth in soil of eleven rice Genotypes under drought conditions for their rooting ability

CHAPTER-8

PLATES

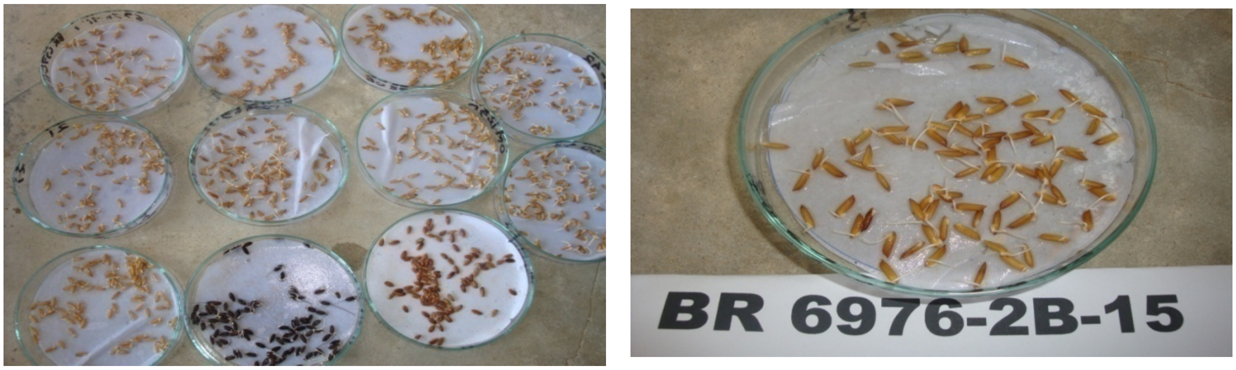


Plate 1.10. Seed germination in the petridish

Plate 1.11 Preparation of sand and soil mixture and seedling in root elongation tube

1.10 Leaf rolling of rice genotypes under drought condition

Plate 1.11: Leaf rolling of rice genotypes under drought condition


V_1
V_2
V_3

Plate 1.12: Plant height of three rice genotypes under drought condition

Plate 1.13: Different rice genotypes before water stress treatment at seedling stage

Plate 1.14: Different rice genotypes after water stress treatment at seedling stage

Plate 1.15: Different rice genotypes after water stress treatment at maturity stage

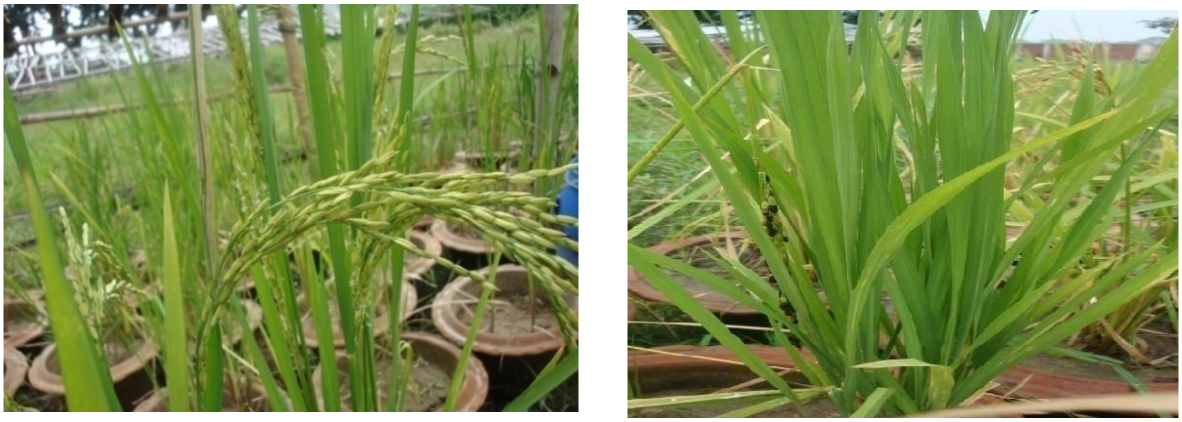


Plate 1.16 : Different rice genotypes before water stress treatment at panicle stage

Plate 1.17 Leaf proline and anthocyanine analysis of different rice genotypes under drought

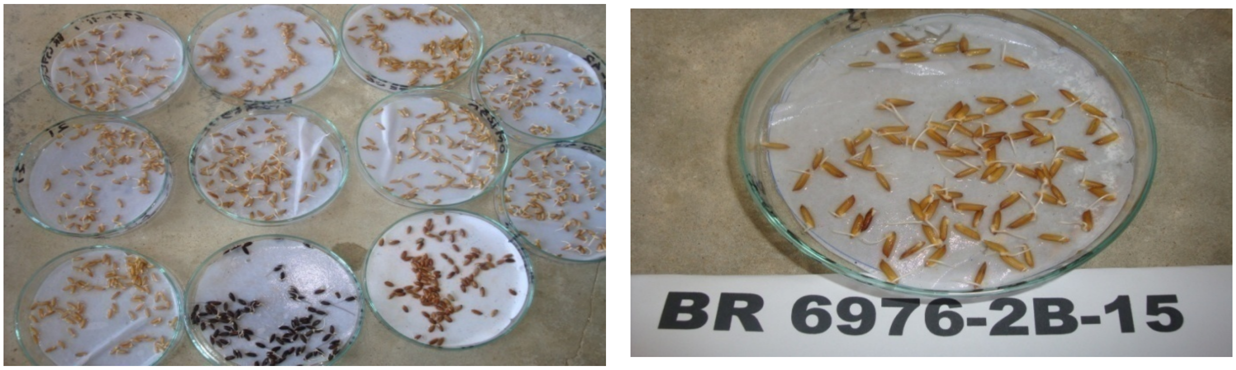


Plate 1.10. Seed germination in the petridish

Plate 1.11 Preparation of sand and soil mixture and seedling in root elongation tube

1.

12 Root spread in sand under drought conditions