SUSCEPTIBILITY AND RECOVERY POTENTIAL OF HYBRID RICE VARIETIES TO DROUGHT STRESS AT DIFFERENT GROWTH STAGES

SABHIA ALI

DEPARTMENT OF AGRICULTURAL BOTANY

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

DHAKA-1207

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By

SABIHA ALI

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APPROVED BY:

…………………………………	……………………………………
Supervisor	**Co-supervisor**
Prof. Dr. Md. Moinul Haque	**Prof. Dr. Kamal Uddin Ahamed**
Department of Agricultural Botany	**Department of Agricultural Botany**
SAU, Dhaka	**SAU, Dhaka**

..…………………………………….
Dr. Kamrun Nahar
Associate Professor
Chairman
Examination Committee

DEPARTMENT OF AGRICULTURAL BOTANY
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

Ref. No:Date:

CERTIFICATE

This is to certify that the thesis entitled “**SUSCEPTIBILITY AND RECOVERY POTENTIAL OF HYBRID RICE VARIETIES TO DROUGHT STRESS AT DIFFERENT GROWTH STAGES’** ‘submitted to the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.)** in **AGRICULTURAL BOTANY**, embodies the results of a piece of bona fide research work carried out by **SABIHA ALI**, Registration No. **12-04740**, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma in any other institution.

I further certify that any help or sources of information received during the course of this investigation has duly been acknowledged**.**

Dated: June, 2018
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Prof. Dr. Md. Moinul Haque
Supervisor

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ABSTRACT

An experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Dhaka-1207 during the *boro* season of the year 2017-18 to evaluate the susceptibility and recovery potential of five hybrid rice varieties to drought stress at different growth stages**.** The two factorial experiment was laid out in a split plot design with three replications. Factor A: Different levels of drought stress [T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering), T_2 = Drought stress at 80-85 days after transplanting (flowering)] and Factor B: Hybrid rice varieties [V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4= Moyna, V_5 = BRRI hybrid dhan3]. Significant variation was observed on growth, yield and yield contributing parameters. In case of drought stress, the highest plant height at different days after transplanting (29.84 cm, 49.77 cm, 69.60 cm and 89.42 cm respectively), leaves hill^{-1} (75.05), leaf area index (4.13), tillers hill^{-1} (6.40, 9.87, 12.87 and 14.13 respectively), effective tillers hill^{-1} (12.60), panicle length (24.37 cm), filled grains panicle^{-1} (161.43), 1000 grain weight (31.39 g), grain yield (7.26 t ha^{-1}), straw yield (8.42 t ha^{-1}), biological yield (15.68 t ha^{-1}) and chlorophyll content (48.83) were recorded from T_0 and lowest from T_2. In case of hybrid rice varieties, the highest plant height at different days after transplanting (25.83 cm, 43.97 cm, 61.72 cm and 78.07 cm respectively), leaves hill^{-1} (59.89), leaf area index (4.25), tillers hill^{-1} (5.08, 8.42, 11.00 and 12.75 respectively), effective tillers hill^{-1} (10.67), panicle length (22.57 cm), filled grains panicle^{-1} (156.53), 1000 grain weight (29.67 g), grain yield (6.88 t ha^{-1}), straw yield (7.98 t ha^{-1}), biological yield (14.86 t ha^{-1}) and chlorophyll content (41.89) were recorded from V_3 and lowest from V_2. In interaction, highest plant height at different days after transplanting (31.77 cm, 50.77 cm, 70.80 cm and 90.23 cm respectively), number of leaves hill^{-1} (90.67), leaf area index (4.68), tillers hill^{-1} (7.33, 11.67, 14.67 and 16.33 respectively), effective tillers hill^{-1} (15.33), panicle length (26.50 cm), filled grains panicle^{-1} (173.30), 1000 grain weight (31.07 g), grain yield (8.58 t ha^{-1}), straw yield (9.96 t ha^{-1}), biological yield (18.55 t ha^{-1}) and chlorophyll content (49.33) were recorded from T_0V_3 and lowest from T_2V_2. Thus, V_3 (Heera2) showed better performance under drought stress and V_2 (Nobin) showed comparatively more susceptibility to drought stress.

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LIST OF ABBREVIATIONS

%	Percent
@	At the rate of
^0C	Degree Celsius
AEZ	Agro-Ecological Zone
BRRI	Bangladesh Rice Research Institute
Cm	Centimeter
CV%	Percentage of Coefficient of Variance
DAT	Days After Transplanting
e.g.	As for example
et al.	and others
g	Gram
ha	Hectare
i.e.	that is
kg	Kilogram
kg ha^{-1}	kg per hectare
LSD	Least Significant Difference
m	Meter
SAU	Sher-e-Bangla Agricultural University
t ha^{-1}	Ton per hectare

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple crop for nearly half of the global population, particularly in developing countries. Rice is popularly known as **"Global Grain"** model crop, belonging to genus *Oryza*, family Poaceae and sub family Oryzoidea. The genus *Oryza* includes 24 spp., out of which 22 are wild and two are cultivated i.e. *Oryza sativa* and *Oryza glaberrima*. There are three subspecies of *Oryza sativa*, namely: *indica, japonica* and *javanica* (Roschevicz, 1931).

It is one of the three major food crops of the world and forms the staple diet of about half of the world's population, But at the same time, it is also the single largest consumer of fresh water. Asia can be considered as **“Rice Basket”** of the world as 90 per cent of world’s rice is grown and consumed with 60 per cent of population which constitutes, about two-thirds of world’s poor (Khush and Virk, 2000).

Rice is grown under a wide range of agro-ecological conditions in different subtropical and tropical countries. To fulfill the future food demand of ever-increasing world population, there is an urgent need to take necessary steps for increasing the productivity of this crop (Ram *et al*., 2007). Rice provides nutrition for more people in the world than other crops, especially in developing countries (Phillips *et al*., 2005).

Rice farming is considered as one of the world′s most sustainable and productive cropping system as it is adapted to wide range of environment ranging from tropical low lands to mountains and from deep water swamp to uplands. In general, rice crop is semi aquatic and can thrive well in waterlogged soil and hence its production system relies on ample water supply. Based on the availability of water, rice can be grown in different ecological conditions such as rain-fed lowland, lowland irrigated, deep water and upland. All these ecosystems, to a variable extent, face the threat posed by climate change. However, conditions in rain-fed environments are particularly unstable. In general, rain-fed environments may be classified into four different categories i.e. rain-fed uplands, rain-fed shallow lowlands, rain-fed medium lowlands, and deep water ecosystems.

Rice production and food security largely depend on the irrigated lowland rice system, whose sustainability is threatened by fresh water scarcity, water pollution and competition for water use. Flooded and irrigated rice systems consume two-three times more water than other cereals, such as maize or wheat. Future predictions on water scarcity limiting agricultural production have estimated that by 2025, about 2 million ha of Asia's irrigated rice fields will suffer from water shortage in the dry season especially since flood-irrigated rice uses more than 45% of 90% of total freshwater used for agricultural purposes (Bouman, 2001 and Peng *et al*., 2006).

To feed the fast increasing global population, the world's annual rice production must be increased to 760 million tons by the year 2020 (Kundu and Ladha, 1995). It plays a vital role in the economy of Bangladesh providing significant contribution to the GDP, employment generation and food availability. In Bangladesh, rice is the most extensively cultivated cereal crop. It provides about 75% of the calories and 55% of the protein in the average daily diet of the people of our country (Bhuiyan *et al.,* 2002).

The climatic and edaphic conditions of Bangladesh are favorable for rice cultivation throughout the year. It provides nearly 48% of rural employment, about two-third of total calorie supply and about one-half of the total protein intakes of an average person in the country (BBS, 2013). About 75% of the total cropped area and over 80% of the total irrigated area is planted to rice. Thus, rice plays a vital role in the livelihood of the people of Bangladesh. Among the rice growing countries, Bangladesh occupies third position in rice area and fourth position in rice production (BRRI, 2012).

Drought or moisture stress is a meteorological term and is commonly defined as the inadequacy of water availability including period without significant rainfall and soil moisture storage capacity. According to Hanson *et al*. (1995) drought is defined as a period of no rainfall or no irrigation that affects the crop growth. Drought has been recognized as the primary constraint to rain-fed rice production (De Datta *et al*., 1975).

Drought is the major environmental constraints to rice productivity in rain fed areas (Serraj *et al*., 2009). At all stages of rice growth and development, drought is the major stress, but it has the greatest impact during flowering, where grain formation is suppressed. This results in considerable yield losses for rain fed ecosystems. Rice sensitivity to drought stress is more pronounced during reproductive stage; even moderate stress can result in drastic reduction in grain yield (Venuprasad *et al*., 2009).

Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. It is estimated that drought stress can potentially reduce nearly 20% of crop yield around the World (Bouman *et al*., 2002). Global climatic changes such as dry spell, heat waves and uneven precipitation patterns limit water availability for farming. However, factors such as timing, intensity and duration of stress have detrimental effect on plant growth. Water is needed at every phase of plant growth from seed germination to plant maturation and any degree of imbalance in the uptake would pose a serious threat to agriculture by adversely affecting the growth and grain yield (Wang *et al*., 2007). Further, water deficit could occur at any time of growing seasons. However, severity of stress on productivity depends on distribution of rainfall. Different developmental stages of rice such as tillering phase, panicle initiation and heading responds differently to drought stress (Kamoshita *et al*., 2004). However, Liu *et al*. (2006) reported that reproductive stage during flowering is more vulnerable to stress and may cause spikelet sterility to different degrees.

It is also observed that apart from direct losses in income and production, drought also leads to loss in income in normal years. Apart from this, the abiotic stresses associated with drought makes the rice more vulnerable to biotic stresses, leading to further decline in crop production. For example, there are more diseases (e.g. rice blast and brown spot) in drought-affected fields than the fields with proper water supply. Drought is the predominant abiotic stress that affects crop production in the rain-fed environment. Dry spells at the reproductive stage are particularly damaging as the crop is most prone to yield loss at this stage. Developing drought tolerant varieties is one of the possible solutions to increase rice production in such areas. Despite above mentioned facts, majority of the rain-fed areas are planted with high-yielding varieties preferred by farmers and consumers. Those varieties were not developed for tolerance to stresses such as drought and farmers face severe crop losses in the event of a drought. On global scenario, irrigated rice is considered as productive farming system and accounts for 55% of total harvested area with a contribution of 75% of total productivity. Further, annual productivity of irrigated rice is estimated to be 5% more than that of rain-fed rice (Dobermann and Fairhurst, 2000).

The water shortage at the grain filling stage may cause drastically seed yield loss. The performance of rice varieties varies under water stress conditions at different growth stages have been evaluated by many workers. 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 low in gain weight and increases empty grains (Davatgara *et al*., 2009).

Considering the above facts, the present study was undertaken with the following objectives:

- To assess the effects of drought stress on morphological and growth attributes and
- To investigate the drought stress effect on yield components and yield traits in hybrid rice.

CHAPTER II

REVIEW OF LITERATURE

Growth and yield of rice plants are greatly influenced by the environmental factors i.e. air, day length or photoperiod, temperature, variety and agronomic practices like transplanting time, spacing, number of seedlings, depth of planting, fertilizer management etc. and abiotic stresses like salinity, drought, flood, contamination by heavy metals etc. Yield and yield contributing characters of rice are considerably influenced by different levels of drought stresses. The available relevant review related to drought stress in rice is abundant in the context of Bangladesh as well as in the World. Some of the recent past information on drought stress in rice have been reviewed under the following headings:

2.1 Effect of drought stress

Cutler *et al*. (1980) observed various responses of rice plants to drought stress include reduced production of new tillers and leaves, reduced leaf elongation, rolling of existing leaves leading to leaf death.

Christiansen (1982) stated that in rain fed agriculture, the short term drought (10-20 days) is very common and it reduces productivity. Seed germination and seedling growth responses of plants to drought stress are considered critical for the establishment of the crop and consequently constitute important criteria for the evaluation of drought tolerance of germplasm. Thus evaluation at an early stage of growth could prove useful to differentiate tolerant and susceptible genotypes of rice.

Cruz and O'Toole (1984) reported that drought stress at panicle development to anthesis stage was found highly critical since it can severely affect grain yield of rice. Drought stress at anthesis leads to very high sterility of florets and hence lowering the percentage of filled grains. In most cases, drought stress delayed flowering in rice.

Turner (1986) stated that plant processes that depend on cell volume enhancement are particularly sensitive to water deficit. Leaf expansion and leaf gas exchange rates are two such sensitive processes.

Inthapan and Fukai (1988) reported that drought stress may delay the phenological development of the rice plant and affect physiological processes like transpiration, photosynthesis, respiration and translocation of assimilates to the grain.

Ekanayake *et al*. (1989) stated that the response of paddy yield to drought stress depends on the timing of the drought because the sensitivity of the plant varies at different growth stages.

Widawsky and O'Toole (1990) stated that drought stress is most severe limitation to the productivity of rice. Drought stress is a meteorological term and is commonly defined as the inadequacy of water availability including period without significant rainfall that affects the crop growth and soil drought storage capacity and it occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Drought stress has been recognized as the primary constraint to rain fed rice production.

Bray (1993) stated that drought stress is one of the main environmental stresses responsible for reducing crop productivity in the dry lands as it affects growth through various physiological and metabolic processes of plant. Vital biochemical processes including photosynthesis, respiration, protein synthesis and assimilation of organic nitrogen have been demonstrated to be adversely affected by drought stress.

Zeigler *et al.* (1994) found that rice is particularly susceptible to water deficit at the reproductive stage and drought causes the greatest reduction in grain yield when stress coincides with the irreversible reproductive process. The booting stage and anthesis through flowering are the most sensitive stages. Yield reduction related to water deficit after anthesis occurs due equally to reduced panicle numbers and increased sterility.

Blum (1996) reported that drought stress is less detrimental to grain yield when occurring early in the crop cycle. It is well known that drought during seed germination and seedling stage has an influence on seedling vigor, which ultimately reflects the number and size of the plant. Drought stress affects every aspect of plant growth and metabolism. He also stated that drought stress is a multidimensional stress that affects different plant growth stages. The impact of drought stress on total green plant surface and plant response to drought stress are very intricate because it reflects combination of stress impacts and plant response in all essential levels of plant over time and place. Drought stress is a major stress factor affecting crop production systems and a major constraints causing yield loss in rice. About one third of world′s rice area is rainfed and these are all drought stress prone, it was estimated that around 50% of the world rice production areas is affected by drought stress.

Wopereis *et al.* (1996) found that the occurrence of drought during transplanting and two weeks after transplanting results in no yield reduction compared to drought stress that occurs at the reproductive stage in rice. They also observed that young rice plants respond better to drought stress at a lower soil water status than the older plants and the first effect of drought stress in the vegetative phase results in leaf expansion phase compared to well watered plants.

Sarkarung *et al*. (1997) reported that drought stress on plants has been reported to reduce the rice growth, adversely affect the photosynthesis, seedling biomass, stomatal conductance, plant water relation such as nutrient uptake and starch metabolism.

Tabaeizadeh (1998) reported that reduction of photosynthetic activity, accumulation of organic acids and osmolytes, and changes in carbohydrate metabolism, are typical physiological and biochemical responses to drought stress.

Hirasawa (1999) reported that rice is a notoriously drought stress susceptible crop due in part to its small root system, rapid stomatal closure and little circular wax during mild drought stress.

Price and Courtois (1999) reported that rice can experience soil drought stress in different growth stages and the response of rice genotypes to this stress varies depends on the characteristics of drought stress environment.

Pantuwan *et al*. (2000) reported that the grain yield of some rice genotypes could be reduced by up to 81% under drought stress, depending on the timing, duration and severity of the plant water deficit. They also reported that drought stress close to the booting stage resulted in disturbance of floret initiation whereas the number of unproductive tillers was increased. Furthermore, panicle trap within the flag leaf sheath and an increased amount of spikelet sterility due to anther dehiscence failure, or suppression of starch accumulation in pollen grains was observed at drought stress close to booting.

Tripathy *et al*. (2000) reported that drought stress induces reduction in plant growth and development of rice. Due to the reduction in turgor pressure under stress, cell growth is severely impaired.

Bouman and Toung (2001) stated that drought stress is a major constraint for about 50% of the world production area of rice. Yield losses from drought in lowland rice can occur when soil water contents drop below saturation. Rice crops are susceptible to drought stress, which causes large yield losses in many Asian countries; however, some genotypes are more drought stress resistance than others, out-yielding those exposed to the same degree of drought stress.

Zhu (2002) stated that water deficit and salt stresses are global issues to ensure survival of agricultural crops and sustainable food production. Conventional plant breeding attempts changed over to use physiological selection criteria since they are time consuming and rely on present genetic variability.

Bota *et al*. (2004) stated that severe drought stress conditions limit photosynthesis due to a decline in Rubisco activity, which is an enzyme of the Calvin cycle. However, the amount of Rubisco activase, which rescues Rubisco sites from dead end inhibition by promoting ATP-dependent conformational changes, enhances under the drought stress as a protective mechanism. The up-regulation of this enzyme might alleviate the damage on Rubisco by drought stress.

Turk *et al*. (2004) reported that drought stress may results in delayed and reduced seed germination or many prevent germination completely.

Hansen and Jones (2006) stated that drought stress also increases the formation of reactive oxygen species (ROS) resulting in lipid per oxidation, protein denaturation and nucleic acid damage with severe consequences on overall metabolism.

Liu *et al*. (2006**)** reported that mild drought stress during grain filling resulted in yield decreases of 11.6% to 14.7% while severe drought at panicle initiation, flowering and grain filling resulted in losses of up to 70%, 88% and 52% respectively. Reductions of 22% for the number of spikelets per panicle and 15% for 1000-grain weight were observed when drought stress was applied at 7 days before heading and 10 days after heading. They also stated that decreasing water supply affects physiological, morphological and biochemical processes in plants and if that drought occurs in critical phase of plant growth, it can decrease yield and even cause crop failure.

Jaleel *et al*. (2007) stated that drought stress is characterized by reduction of water content diminished leaf water potential, turgor pressure, stomata activity and decreasement in cell enlargement and growth. Drought stress tolerance is seen in almost all plants but its extent varies from species to species, even within the species.

Wang *et al*. (2007) studied a dynamic accumulation of ABA in response to drought stress in rice. ABA imparts drought stress tolerance in part by inducing a significant increase in antioxidant enzymes and improving protein transport, carbon metabolism and expression of resistance proteins. Exogenous ABA application in rice enhances the recovery of the net photosynthetic rate, stomata conductance and transpiration rate under drought, with increased expression of various drought responsive genes.

Jaleel *et al*. (2008a) reported that severe drought stress may result in the arrest of photosynthesis, disturbance in metabolism and finally the death of plant. It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates and nutrient metabolism and growth promoters.

Jaleel *et al*. (2008b) stated that drought is a limiting factor in agriculture production by preventing a crop from reaching the genetically determined theoretical maximum yield. In plants, a better understanding of the morphological and physiological basis of changes in drought resistance could be used to select or create new varieties of crops to obtain a better productivity under drought conditions.

Clark *et al*. (2008) reported that drought stress also hinders root branching. Under limited water supply, reduction in leaf size and leaf pubescence as well as a change in shape and leaf yellowing is observed. Furthermore, the development of new leaves and new tillers and stem expansion is slow during drought. Severe drought ends in leaf drying and finally plant death. Moreover, drought is accompanied by reduction in biomass production. All these modifications in normal status of the different tissues and organs impair with photosynthetic rate and other biochemical processes. The reduction in photosynthetic rate is due to stomatal closure that limits the diffusion of CO_2, which leads to reduction of photosynthetic enzyme activity, and loss or diminish ion of photosynthetic pigments such as chlorophyll a and b and carotenoids resulting from the impairment in their synthesis or their post synthesis degradation. Reduction of photosynthetic rate might also be caused by the loss of the chloroplast membrane.

Reynolds and Tuberosa (2008) reported that most of the high yielding popular rice varieties endowed with high yield potential and good grain quality suffers from poor adaptability to drought stress, causing substantial yield losses during years of drought. Water uptake (WU), water-use efficiency (WUE), and harvest index (HI) were considered as drivers of grain yield.

Shao *et al*. (2008) reported that drought stress affects both elongation as well as expansion growth, and inhibits cell enlargement more than cell division. It impairs the germination of rice seedlings and reduces number of tillers and plant height.

Centritto *et al*. (2009) reported that drought deficit affects rice physiology in countless ways like it affects plant net photosynthesis, transpiration rate, stomatal conductance, water use efficiency, intercellular CO_2, photosystem II (PSII) activity, relative water content and membrane stability index. All these parameters reduce under drought in rice.

Farooq *et al*. (2009) reported that a common adverse effect is the reduction in biomass production. Many studies indicate significant decrease in fresh and dry weights of shoots and roots under drought stress. Reduced fresh shoot and root weights as well as their lengths ultimately reduce the photosynthetic rate of physiology and biochemical processes of rice.

Jaleel *et al*.(2009) stated that drought stress causes many changes related to altered metabolic functions, and one of those is either loss of or reduced the 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 and yield.

Pirdashti *et al*. (2009) reported that decreases in chlorophyll content and the maximum quantum yield of PSII (Fv/Fm) on drought stressed rice. This reduction in chlorophyll content may occur due to stress-induced impairment in pigment biosynthetic pathways or in pigment degradation, loss of the chloroplast membrane, and increased lipid per oxidation.

Haq *et al.* (2010) stated that germination and seedling growth phase is of prime importance in the growth cycle of plants as it determines the successful establishment and final yield of the crop.

Anjum *et al*.(2011) stated that drought stress adversely affects plant physiological performance through reduction in gas exchange in particular stomatal conductance, photosynthetic pigments and overall crop water relations. Regardless of varieties, chlorophyll content, photochemical efficiency (*Fv*/*Fm*) and leaf relative water content (leaf RWC) are also affected when drought occurs at the vegetative, flowering or grain-filling stages.

Kato and Okami (2011) observed that the reduction in leaf water potential adversely affects the reproductive growth and canopy expansion, leading to significant yield loss.

Saragih *et al*. (2013) reported that drought stress at the early reproductive stage greatly affects the grain yield of rice. The variation in rice yield component is associated with variability in water availability at different growth stages.

Kumar *et al*. (2014) reported that under drought stress condition, contribution of dry matter partitioning from stem and leaf increased significantly under drought condition compared to well watered condition, thereby affecting grain yield.

2.2 Effect of varieties

Alvarez (1973) compared 4, 6, and 8-mm seven-day rotational irrigation treatment with 12.5 mm/day continuous flooding irrigation. The continuous flooding irrigation had higher yield than rotational irrigation treatments.

Bahattacharjee *et al*. (1973) found significant reductions in plant height and grain yield when drought was imposed at tillering stage.

Ne Smith and Ritchie (1973) reported that rice root porosity, number of roots, and root dry weight are low under severe stress. Transpiration of root plants began to decrease when 25% of the total extractable water was left in the root zone.

Begg and Turner (1976) stated that the most obvious morphological change with the onset of drought stress is a reduction in leaf area, either through a reduction in leaf size or by the shedding or death of leaves and reduction in evapotranspiration. Decreased development of leaf area also contributes to a decrease in the photosynthetic productivity of water deficient plants and may be the earliest sign of a drought deficit.

Raju (1980) observed that the flooded irrigation in reproductive stage and saturated at vegetative stage treatment had higher harvest index than flooded at vegetative stage and saturated at reproductive stage. On the other hand, continuous irrigation in 5-cm depth gave the highest grain yield, however it had the lowest harvest index.

Rawgamannar *et al*. (1978) reported that continuous irrigation in 5 cm depth gave higher grain yield than continuously saturated irrigation.

Hsiao (1982) reported that rice is particularly sensitive to drought stress during reproductive growth, even under moderate drought stress. In rice, moderate stress can be broadly characterized by a 31 to 64% loss in grain yield as compared with non-stress conditions.

Kakade and Soner (1983) observed that continuous submergence and submergence up to flowering significantly increased the rice grain yield over alternate submergence and drying, and upland conditions. Submergence up to flowering significantly increased rice straw yields over alternate submergence and drying, and upland condition treatment.

Biswas and Choudhuri (1984) reported that the decrease in plant height might be due to sensitivity of reproductive phase to water status.

Hale and Orcutt (1987) reported that the timing of drought stress conditions in relation to the stage of plant development is also important in terms of internal competition for water. Drought stress at the tillering stage reduced plant height and leaf length, induced leaf rolling or drying, and prolonged the vegetative stage even after drought stress was removed. Drought stress is especially critical during reproductive development. Drought stress at booting and flowering reduces plant height and dry matter production, delays panicle exertion, and induces uneven flowering. Photosynthetic efficiency is impaired, resulting in less dry matter accumulation and a low concentration of non-reducing sugar in the stem.

Renmin and Yuanshu (1989) reported that when the soil drought content lowers, the milled rice recovery and the brown rice protein content arc both significantly raised, but the percentage of unripened grain is decreased, meanwhile the amylose content in milled rice is decreased.

Yakan and Sürek (1990) compared continuously saturated irrigation with continuous flooded irrigation and interval irrigation in the different depths. There was no significant difference among irrigation treatment for grain yield.

Borrell (1991) compared different irrigation regimes in dry seeded rice production in Australia. Flooding irrigation from sowing to maturity gave the highest grain yield, and intermittent irrigation had lowest grain yield.

Jha and Singh (1997) studied in eight rice genotypes of their response towards simulated drought stress. It was observed that seedling growth decreased with increasing drought stress. They also observed that total sugar, reducing and non-reducing sugar decreased whereas starch and phenol contents increased in eight rice genotypes with increasing drought stress.

Beser (1997) found out significantly differences for rice grain yield among different irrigation methods. He obtained the highest yield from continuous flooding irrigation; interval and sprinkler irrigation followed it. Also, the highest values of total biological yield and harvest index achieved in continuous flooding irrigation.

Busso and Fernadez (1998) reported that the radical growth of rice was decreased under drought condition.

Watanabe *et al*. (2000) observed that drought stress generally accelerates senescence and reduces photosynthesis in susceptible varieties while water balance was maintained under tolerant varieties and keeps pace with photosynthetic activity and carbohydrate metabolism. The increases in the concentration of soluble carbohydrates in three rice cultivars leaves were founded to be remarkable during drought stress.

Hossain (2001) reported that drought might inhibit photosynthesis and produce less amount of assimilates which resulted in lower number of leaves.

Samonte *et al*. (2001) reported that the occurrence of soil drought stress affects many of the physiological processes such as photosynthesis and transpiration resulting in reduced growth and poor grain filling.

Chaves *et al*. (2002) reported least effects of drought stress on height, number of panicles per plant, panicle length and 1000-grain weight in mid-season varieties and on number of grains per panicle and harvest index in early varieties.

Pantuwan *et al*.(2002) reported that the delay in heading under stress was negatively associated with plant water status indicators and stress yields. The delay in heading is an expression of growth retardation during the drying cycle as well as upon recovery and this delay is a strong indication of susceptibility to stress.

Rahman *et al.* (2002) reported that plant height, tiller number, panicle number, panicle length, number of filled grains per panicle, 1000-grain weight, harvest index (HI), total dry matter (TDM) and yield were decreased with drought stress.

Tezara *et al*. (2002) stated that the spikelet sterility increases under drought stress condition which might be due to the reduction of many key metabolic functions and physiological processes in rice plant.

Kumar and Kujur (2003) reported that the period of delay is partly related to extent of stress, the rice genotypes experienced and those with longer delay will tend to produce less grain.

Lafitte *et al*. (2003) observed that delay usually occurs in flowering date, when rice experiences a drought deficit before flowering.

Pirdasthi *et al*. (2003) revealed that plant height increased at vegetative stage under aerobic as compared to flooded but at flowering stage the plant height decreased under water deficit condition as compared to flooded condition. They also observed that seedling growth decreased in rice genotypes with increasing drought stress.

Kamoshita *et al*. (2004) stated that rice genotypes with greater plant height are often larger in overall plant size, intercept more light and use water faster by transpiration, leading to lower plant water status.

Plaut *et al*. (2004) reported that drought stress at grain filling process induces early senescence and shortens the grain filling period but increases remobilization of assimilates (are reserved in the stems and sheaths of rice and contribute 10-40% of the final grain weight) from the straw to the grains.

Tuong *et al*. (2005) stated that drought resulted to decrease in plant height, number of tillers per plant, total biomass and grain yield.

Sharma and Dubey (2005) observed a concomitant decrease in the content of total soluble protein with an increasing level of water deficit in root as well as shoots of growing rice seedling.

Singh (2006) reported that the productivity in rain fed uplands is poor (0.8 to 1.2 t/ha) mainly because of erratic rainfall and drought stress at flowering stage.

Zubaer *et al.* (2007) evaluated effect of drought at different growth stages of different three rice genotypes at three water levels (100%, 70% and 40% Field Capacity). Plant height, numbers of tillers/hill, no. of filled grains /panicle, total dry matter/hill, 1000 grain weight, grain yield and harvest index decreased with increasing drought levels. They also conducted a pot experiment and found that at booting (106.8), flowering (85) and maturity (58.11) stage, the highest number of leaves was found in 100% FC. The number decreased gradually with increasing soil drought stress and 40%FC produced the lowest number of leaves per hill in all growing stages. They carried out a pot experiment to evaluate the performance of the genotypes under varying drought stress. Results showed that the 1000 grain weight was reduced with reduced soil drought levels. It was anticipated that the lower soil drought might had decreased translocation of assimilates to the grain which lowered grain size. But the degree of reduction in 1000 grain size weight was different in different genotypes. Percent reduction was lower in BINA Dhan 4 (4.14 to 6.37%) than in Basmoti (6.75to 12.5%) and RD 2585 (4.57 to 14.64%).

Sarvestani and Pirdashti (2008) evaluated the effect of drought stress on the yield and yield component of four rice cultivars. The different drought stress conditions were drought stress during vegetative, flowering and grain filling stages. Drought stress at vegetative stage significantly reduced plant height of all cultivars. Drought stress at flowering stage had a greater grain yield reduction than drought stress at other times. The reduction of grain yield largely resulted by the reduction in fertile panicle and filled grain percentage. Total biomass, harvest index, plant height, filled grains unfilled grains and 1000 grain weight were reduced under drought stress in all the cultivars. Drought stress at vegetative stage effectively reduced total biomass due to decrease of photosynthesis rate and dry matter accumulation.

Sarvestani *et al*. (2008) reported that drought at flowering stage had a greater grain yield reduction than drought at other times. The reduction of grain yield largely resulted from the reduction in fertile panicle and filled grain percentage. Water deficit during vegetative, flowering and grain filling stages reduced mean grain yield by 21, 50 and 21% on average in comparison to control respectively. The yield advantage of two semi-dwarf varieties; Fajr and Nemat, were not maintained under drought stress.

Mostajeran and Eichi (2009) observed a decline of total, reducing and non-reducing sugar in rice seedling under drought stress. The decrease was relatively more in susceptible varieties compared to the tolerant.

Cheng and Kato (2010) found a decrease in protein content and yield of rice under drought stress condition and PEG (6000) treatment also resulted in chlorophyll loss and protein degradation in detached rice leaves. Drought induced significant decrease in endogenous level of protein contents in leaves at soft dough stage.

Das and kalita (2010) conducted an experiment with five rice cultivars. They found that seedling length and vigor index decreased with increasing drought stress.

Guan *et al*. (2010) documented that biomass production (plant height and number of tillers per plant) is more affected under vegetative stage stress whereas severe effects on sink size (spikelet fertility, 1000-grain weight and seed yield) under reproductive stage stress would be resulted.

Sikuku *et al*. (2010) reported that panicle length was affected by water deficit as NERICA 4 had the most pronounced reduction in panicle length at the highest water deficit compared to control. They also reported that protein content decreased under drought stress conditions in rice genotypes due to the disturbed protein synthesis system. They also found that drought stress affects the days to maturity and grain yield by decreasing tiller number, panicle length and field grain percentage of rice varieties.

Zhao *et al.* (2010) observed reduced grain yield by 60%, harvest index by 50%, plant height by 12 cm and delayed flowering by 3 days under drought stress in rice.

Majeed *et al*.(2011) reported that drought stress induced significant decrease in endogenous level of sugar in leaves at soft dough stage; whereas in grains, drought stress induced decreases in sugar in both cultivars.

Kamoshita *et al*. (2004) reported that drought stress during vegetative growth, flowering and terminal period of rice cultivation, can interrupt floret initiation (which cause spikelet sterility) and grain filling, respectively. On the other hand, it has been proposed that grain filling is closely linked to the whole-plant senescence process.

Sokoto and Muhammad (2014) conducted a dry season pot experiment indicated that drought stress had no significant ($P < 0.05$) effect on plant height at 3 weeks after planting (WAP). But at tillering resulted to significant ($P < 0.05$) reduction in plant height at 6, 9, 12 and 15 WAP. Control (unstressed) was statistically ($P < 0.05$) similar with drought stress at flowering and grain filling. The reduction in plant height was as a result of drought stress imposed at tillering stage. This was because imposing drought stress resulted in low leaf water potentials and reductions in photosynthesis; photosynthetic activity declines because of decreased stomatal opening and the inhibition of chloroplast activity; this reduced the length of the internodes at jointing stage which follows tillering stage. At the time when drought stress was imposed at flowering and grain filling, the jointing stage had taken place and plants had reached their maximum height, thus the effect of drought stress was ineffective.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials and methods of the experiment with a brief description on experimental site, climate, soil, land preparation, planting materials, experimental design, land preparation, fertilizer application, transplanting, irrigation and drainage, intercultural operation, data collection and their analysis. The details of the materials and methods have presented below:

3.1 Experimental site

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka , Bangladesh. The experimental site is situated between 23º41' N latitude and 90º22' E longitude at an altitude of 8.6 meter above the sea level.The location of the experimental site has been shown in Appendix I.

3.2 Soil

The soil of the experimental area belonged to the Modhupur tract (AEZ No. 28). It was a medium high land with non-calcareous dark grey soil. The pH value of the soil was 5.6. The physical and chemical properties of the experimental soil have been shown in Appendix II.

3.3 Climate

The experimental area was under the subtropical climate and was characterized by high temperature, high humidity and heavy precipitation with occasional gusty winds during the period from April to September, but scanty rainfall associated with moderately low temperature prevailed during the period from October to March. The detailed meteorological data in respect of air temperature, relative humidity, rainfall and sunshine hour recorded by the meteorology center, Dhaka for the period of experimentation have been presented in Appendix III.

3.4 Planting materials

In this research work, five samples of hybrid rice varieties were used as planting materials. The rice varieties used in the experiments were BRRI dhan29, Nobin, Heera2, Moyna and BRRI hybrid dhan3. The seeds were collected from the

Bangladesh Rice Research Institute (BRRI) and Supreme Seed Company Ltd. and Lal Teer Seed Company Ltd. respectively.

3.5 Treatments of the experiment

The experiment consisted of two factors as mentioned below:

Factor A: Different levels of drought stress

i. T_0= Control
ii. T_1 =Drought stress at 40-45 days after transplanting (tillering)
iii. T_2 =Drought stress at 80-85 days after transplanting (flowering)

Factor B: Hybrid rice varieties

i. V_1 = BRRI dhan29
ii. V_2 = Nobin
iii. V_3 = Heera2
iv. V_4 = Moyna
v. V_5 = BRRI hybrid dhan3

3.6 Experimental design

The experiment was laid in split plot design with three replications (block). Each replication was first divided into 15 subplots where treatment combinations were assigned. Thus the total number of unit plots was 15×3=45. The layout of the experiment was prepared for distributing the variety. There were 45 plots of size 2 m × 1.5 m in each of 3 replications. The treatments of the experiment were assigned at random into each replication following the experimental design. There were 0.75 m width and 10 cm depth for drains between the blocks. Each treatment was again separated by drainage channel of 0.5 m width and 10 cm depth.Two seedlings hill^{-1} were used during transplanting.The layout of the experimental field has been shown in Appendix IV.

3.7 Growing of crops

3.7.1 Seed collection

The seeds of the test crops were collected from Bangladesh Rice Research Institute (BRRI) and Supreme Seed Company Ltd. and Lal Teer Seed Company Ltd. respectively.

3.7.2 Seedling raising

The seedlings were raised at the wet seed bed in SAU farm. The seeds were sprouted by soaking for 72 hours. The sprouted seeds were sown uniformly in the well-prepared seed bed in 15th November, 2017.Appropriate care was taken to raise the seedlings in the nursery bed. Irrigation was done but no manuring and fertilization was done and weeds were removed from the nursery bed, as per necessity.

3.7.3 Preparation of the main field

The plot selected for the experiment was opened in 17th December, 2017 with a power tiller and was exposed to the sun for a week, after which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubble were removed, and finally obtained a desirable tilth of soil for transplanting of seedlings.

3.7.4 Fertilizers application

The following doses of manure and fertilizers were used.

Fertilizers	Dose (kg ha^{-1})
Cow dung	5000
Urea	220
Triple Super Phosphate (TSP)	165
Muriate of Potash (MP)	180
Gypsum	70
Zinc sulphate	10

Whole amount of cow dung, TSP, MP, Gypsum, Zinc sulphate and one third of urea were applied at the time of final land preparation at broadcasting method. Half of the rest two third of urea was applied at 20 DAT and the rest amount of urea was applied at 45 DAT.

3.7.5 Uprooting of seedlings

The nursery bed was made wet by application of water one day before uprooting the seedlings. The seedlings were uprooted on December 26, 2017 without causing much mechanical injury to the roots.

3.7.6 Transplanting of seedlings

The seedlings were transplanted in the main field on December 27, 2017 and the rice seedlings were transplanted in lines each having a line to line distance of 20 cm and plant to plant distance was 15 cm for all test varieties in the well prepared plot.

3.7.7 Intercultural operations

The details of different intercultural operations performed during the course of experimentation are given below:

3.7.8 Irrigation and drainage

The experimental field was irrigated with sufficient water which was maintained throughout the crop growth period. Flood irrigations were given when was necessary to maintain 3-5 cm water in the rice field. For immediate release of excess rainwater and to top-dress urea, a good drainage facility was maintained in the field.

3.7.9 Gap filling

Gap filling was done for all of the plots at 7-10 days after transplanting (DAT) by planting same aged seedlings.

3.7.10 Weeding

Three weeding done on 10, 30, 45 days after transplanting to keep the crops free from weeds.

3.7.11 Plant protection

The plants were infested with rice stem borer, leaf roller and rice bug to some extent; to control them insecticides such as Diazinon and Ripcord @ 10 ml/10 liter of water for 5 decimal lands were applied both in plot and in pot. During the grain-filling period, for controlling birds proper watching was done, especially during morning and afternoon.

3.8 Harvesting, threshing and cleaning

The rice plant was harvested depending upon the maturity of grains and harvesting was done manually from each plot. Maturity of crop was determined when 80-90% of the grains become golden yellow in color.Ten pre-selected hills per plot from which different data were collected and 3 m^2 areas from middle portion of each plot was separately harvested and bundled, properly tagged and then brought to the threshing floor. Enough care was taken for harvesting, threshing and also cleaning of rice seed. Fresh weight of grain and straw were recorded plot wise. Finally the weight was adjusted to a drought content of 12-14%. The straw was sun dried and the yields of grain and straw plot^{-1} were recorded and converted to t ha^{-1}.

3.9 Data recording

3.9.1 Plant height

The height of plant was recorded in centimeter (cm) by measuring the distance from base of the plant to the tip of the flag leaf at 30, 60, 90 DAT and at harvest; and finally averaged.

3.9.2 Leaves hill^{-1}

The leaves hill^{-1} was recorded at harvest by counting total leaves as the average of same 10 hills pre-selected at random from the inner rows of each plot.

3.9.3 Leaf area index

Leaf area index (LAI) was estimated manually at the time of harvest. Data were collected as the average of 10 plants selected from middle of each row. Final data were calculated multiplying by a correction factor 0.75.

3.9.4 Tillers hill^{-1}

The tillers hill^{-1} was counted from each plot at 30, 60, 90 DAT and at harvest and finally averaged.

3.9.5 Effective tillers hill^{-1}

The effective tillers hill^{-1} were counted from the plants of the plots after harvesting and finally averaged.

3.9.6 Non-effective tillers hill^{-1}

The non-effective tillers hill^{-1} were counted from the plants of the plots after harvesting and finally averaged.

3.9.7 Panicle Length

Panicle length was measured from basal node of the rachis to apex of each panicle. Each observation was an average of 10 panicles.

3.9.8 Filled grains panicle^{-1}

The filled grains panicle^{-1} were counted from each plot. Lack of any food materials inside the spikelets were denoted as unfilled grains.

3.9.9 Unfilled grains panicle^{-1}

The unfilled grains panicle^{-1} were counted from each plot. Lack of any food materials inside the spikelets were denoted as unfilled grains.

3.9.10 Weight of 1000 grain

One hundred grains (g) were randomly collected from each plot and were sun dried and weighed by an electronic balance and then multiplied by 10.

3.9.11 Grain yield

Grains obtained from each plot were sun-dried and weighed carefully. The dry weight of grain of the respective plot was recorded carefully and converted to t ha^{-1}.

3.9.12 Straw yield

Straw obtained from each plot were sun-dried and weighed carefully. The dry weight of straw of the respective plot was recorded carefully and converted to t ha^{-1}.

3.9.13 Biological yield

Grain yield and straw yield were all together regarded as biological yield. Biological yield was calculated with the following formula:

$$\text{Biological yield (t/ha)} = \text{Grain yield (t/ha)} + \text{Straw yield (t/ha)}$$

3.9.14 Chlorophyll content

Flag leaves were sampled at 6 days after flowering and a segment of 20 mg from middle portion of leaf was used for chlorophyll analysis. Chlorophyll content was measured on fresh weight basis extracting with 80 % acetone and used doubled beam spectrophotometer (Model: U-2001, Hitachi, Japan) according to Witham *et al.* (1986). Amount of chlorophyll was calculated using following formulae.

Chlorophyll a= [12.7 (OD_{663})-2.69 (OD_{645})] $\times \frac{V}{1000\ W}$

Chlorophyll b = [12.9 (OD_{663})-4.68 (OD_{645})] $\times \frac{V}{1000\ W}$

Where,

OD = Optical density of the chlorophyll extract at the specific wave length.

V = Final volume of the 80% acetone chlorophyll extract (ml)

W = Fresh weight in gram of the tissues extracted.

The total chlorophyll content was estimated by adding chlorophyll a and chlorophyll b.

3.10 Statistical Analysis

The data obtained for different characters were statistically analyzed following the analysis of variance techniques by using MSTAT-C computer package program. The significant differences among the treatment means were compared by Least Significant Different (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

A study was undertaken during the *boro* season of December-June (2017-18) to evaluate the susceptibility and recovery potential of hybrid rice varieties to drought stress at different growth stages. The results of the study regarding the susceptibility and recovery potential of hybrid rice varieties to drought stress at different growth stages has been presented with possible interpretations under the following headings:

4.1 Plant height

Effect of drought stress

Different levels of drought stress showed significant difference on the plant height of hybrid rice varieties at 30, 60, 90 DAT and at harvest (Figure 1 and Appendix V). The result revealed that at 30, 60, 90 DAT and at harvest, the highest plant height (29.84 cm, 49.77 cm, 69.60 cm and 89.42 cm respectively) were recorded from the treatment $T_0$and; the lowest height (18.82 cm, 31.90 cm, 43.95 cm and 54.87 cm respectively) were recorded from the treatment T_2. Tuong *et al*., (2005) stated that water stress resulted to decrease in plant height, number of tillers per plant, total biomass and grain yield.

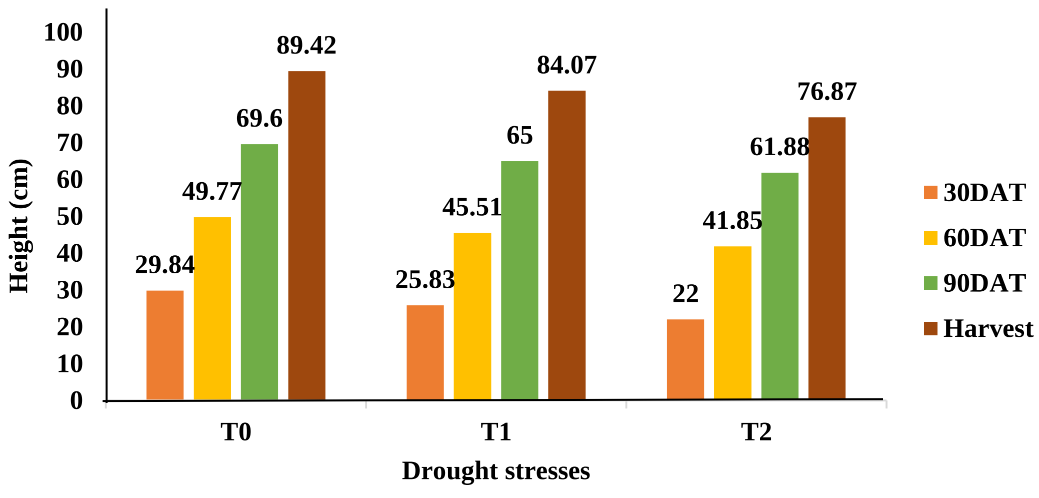

Figure 1: Effect of drought stress on plant height at different days after transplanting

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The plant height (cm) of hybrid rice varieties were significantly influenced by varieties at 30, 60, 90 DAT and at harvest (Figure 2 and Appendix VI). The results revealed that at 30, 60, 90 DAT and at harvest, V_3 produced the tallest plant (25.83 cm, 43.97 cm, 61.72 cm and 78.07 cm respectively)and V_2 produced the shortest plant (22.81 cm, 40.93 cm, 58.88 cm and 74.97 cm respectively).

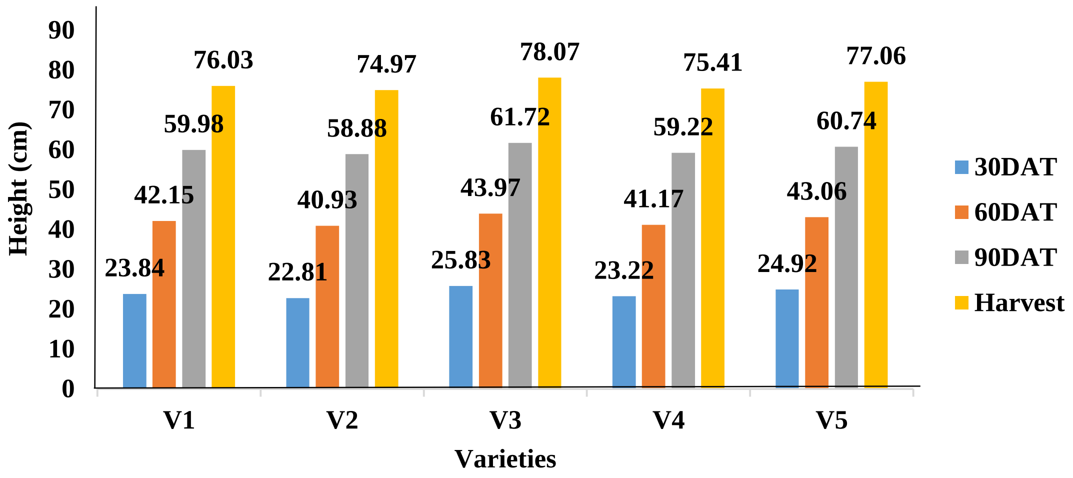

Figure 2: Effect of variety on plant height at different days after transplanting

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on plant height at 30, 60, 90 DAT and at harvest (Table 1). At 30 DAT, the highest plant height (31.77 cm) was observed from the T_0V_3 treatment and the lowest plant height (20.50 cm) was observed from T_2V_2 treatment which was statistically similar with T_2V_5 (23.07cm). At 60 DAT, the highest plant height (50.77 cm) was observed from the T_0V_3 treatment which was statistically similar with T_0V_1 (50.37 cm) and T_0V_5 (50.67 cm) whereas; the lowest plant height (40.53 cm) was observed from the treatment T_2V_2. At 90 DAT, the highest plant height (70.80 cm) was observed from the T_0V_3 treatment and the lowest plant height (60.53 cm) was observed from T_2V_2. At harvest, the highest plant height (90.23 cm) was observed from the T_0V_3 treatment which was statistically similar with T_0V_1 (89.80 cm) and T_0V_5 (89.83 cm) whereas; the lowest plant height (75.47 cm) was observed from T_2V_2.

Table 1: Interaction effect of different levels of drought stress and variety on plant height at different days after transplanting

Treatments		Plant height (cm)			
		30 DAT	60 DAT	90 DAT	Harvest
T_0	V_1	29.83 c	50.37 a	70.10 b	89.80 a
	V_2	28.33 d	48.43 bc	68.47 c	88.47 b
	V_3	31.77 a	50.77 a	70.80 a	90.23 a
	V_4	28.63 d	48.63 b	68.50 c	88.77 b
	V_5	30.63 b	50.67 a	70.13 b	89.83 a
T_1	V_1	25.20 f	45.17 e	64.57 f	83.33 e
	V_2	24.03 g	43.40 f	63.23 g	81.57 g
	V_3	28.23 d	48.07 c	67.37 d	87.13 c
	V_4	24.37 g	43.60 f	63.43 g	82.10 f
	V_5	27.33 e	47.33 d	66.40 e	86.20 d
T_2	V_1	21.77 i	41.57 h	61.67 i	76.50 j
	V_2	20.50 j	40.53 i	60.53 j	75.47 k
	V_3	23.23 h	43.43 f	63.13 gh	78.47 h
	V_4	21.43 i	41.10 h	61.40 i	76.37 j
	V_5	23.07 h	42.60 g	62.67 h	77.57 i
LSD $_{(0.05)}$		0.65	0.48	0.49	0.51
CV		5.63	4.69	5.50	6.40

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

4.2 Leaves hill^{-1}

Effect of drought stress

Different levels of drought stress showed significant difference on leaves hill^{-1} of hybrid rice varieties at harvest (Figure 3 and Appendix V). The result revealed that at harvest, the highest number of leaves hill^{-1} (75.05) were recorded from the treatment T_0 and the lowest number of leaves hill^{-1} (45.7) were recorded from the treatment T_2 which was statistically similar with T_1 (46.08). Similar result was reported by Hossain (2001) who observed that water stress might inhibit photosynthesis and produce less amount of assimilates which resulted in lower number of leaves.

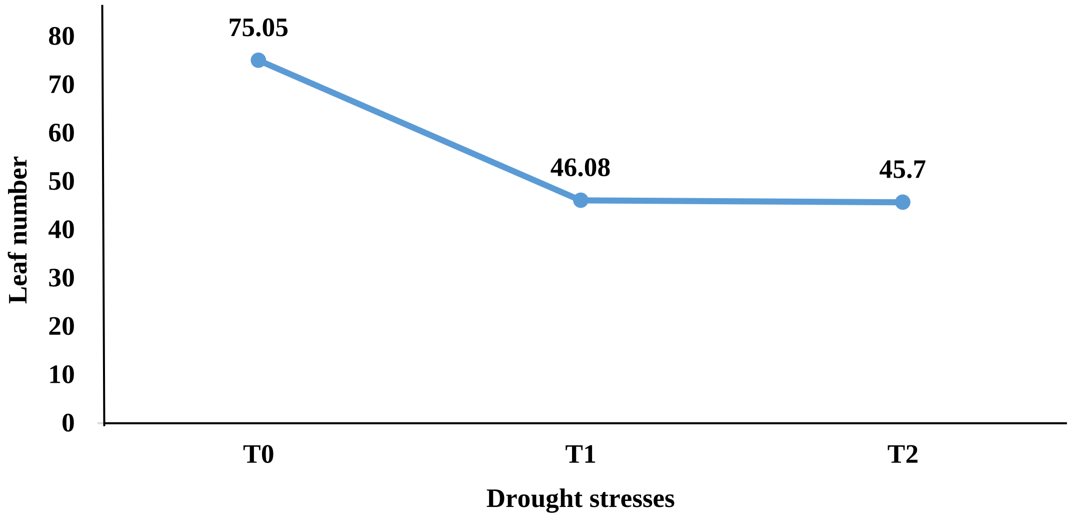

Figure 3: Effect of drought stress on leaves hill^{-1} at harvest

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The leaves hill^{-1} of hybrid rice varieties were significantly influenced by varieties at harvest (Figure 4 and Appendix VI). The results revealed that at harvest, the highest leaves hill^{-1} (59.89) were recorded from V_3 which was statistically similar with V_5 (59.41) and V_1 (57.67) whereas; the lowest leaves hill^{-1} (50.56) were recorded from V_2. The results substantiate with the findings of Luh (1991) who observed highest tiller and leaf number in rice occurred at 40 to 60 days after transplanting, depending upon the tillering capacity of the variety, the spacing used and the fertility level.

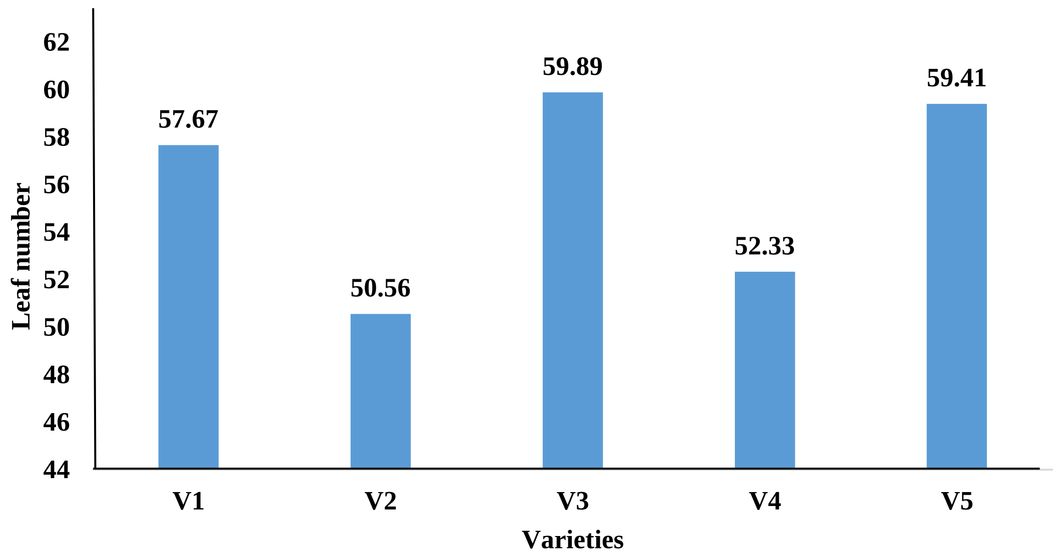

Figure 4: Effect of variety on leaves hill^{-1} at harvest

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on leaves hill^{-1} at harvest (Table 2). The result showed that the highest leaves hill^{-1} at harvest (90.67) was observed from the T_0V_3 treatment and the lowest leaves hill^{-1} at harvest (42.33) was observed from T_2V_2 treatment which was statistically similar with T_2V_4 (43.33) and T_2V_1 (43.67).

4.3 Leaf area index

Effect of drought stress

Different levels of drought stress showed significant difference on leaf area index (Figure 5 and Appendix V). The result revealed that highest leaf area index (4.13) was recorded from the treatment T_0 which was statistically similar with T_1 (4.01) and the lowest leaf area index (3.73) was recorded from the treatment T_2.

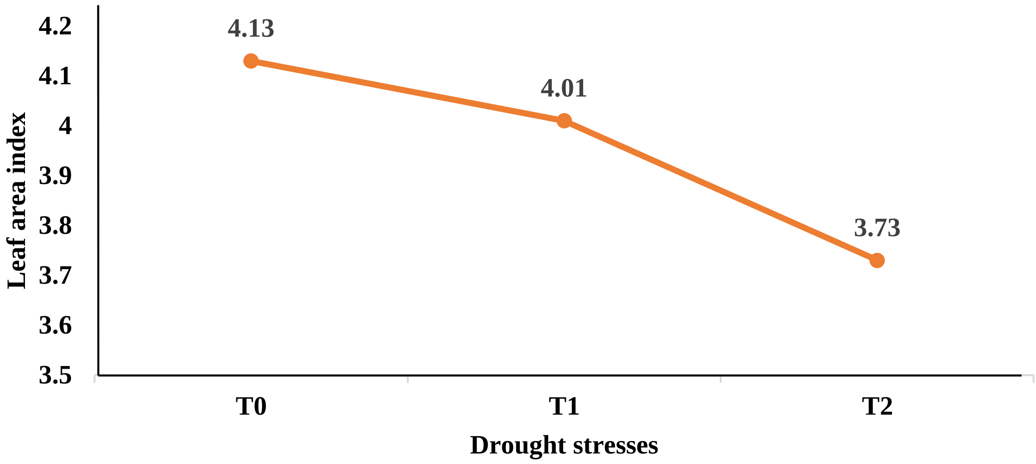

Figure 5: Effect of drought stress on leaf area index

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The leaf area index of hybrid rice varieties were significantly influenced by varieties (Figure 6 and Appendix VI). The results revealed that highest leaf area index (4.25) was recorded from V_3 which was statistically similar with V_5 (4.08) and V_1 (3.96) whereas; the lowest leaf area index (3.56) were recorded from V_2.

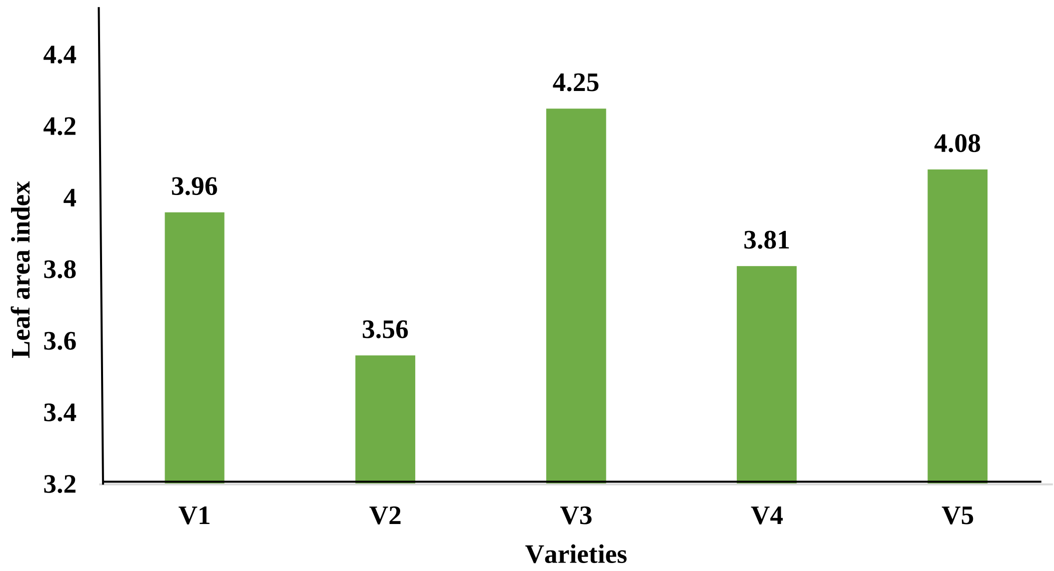

Figure 6: Effect of variety on leaf area index

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Table 2: Interaction effect of different levels of drought stress and variety on leaves hill^{-1} and leaf area index

Treatments		Leaves hill^{-1}	Leaf area index
T_0	V_1	73.67 c	4.45 ab
	V_2	56.67 e	4.38 abc
	V_3	90.67 a	4.68 a
	V_4	67.33 d	4.43 ab
	V_5	86.90 b	4.65 a
T_1	V_1	47.67 f	3.93 bcde
	V_2	46.67 fgh	3.80 cde
	V_3	53.67 e	4.25 abcd
	V_4	47.00 fg	3.81 cde
	V_5	48.00 f	3.96 bcde
T_2	V_1	43.67 ghi	3.48 e
	V_2	42.33 i	3.36 e
	V_3	46.33 fgh	3.64 de
	V_4	43.33 hi	3.40 e
	V_5	45.67 fgh	3.48 e
LSD $_{(0.05)}$		3.05	0.55
CV		10.35	4.18

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on leaf area index (Table 2). The result showed that the highest leaf area index (4.68) was observed from the T_0V_3 treatment which was statistically similar with T_0V_5 (4.65), T_0V_1 (4.45), T_0V_4 (4.43), T_0V_2 (4.38) and T_1V_3 (4.25) whereas; the lowest leaf area index (3.36) was observed from T_2V_2 treatment which was statistically similar withT_2V_4 (3.40), T_2V_5 (3.48), T_2V_1 (3.48), T_2V_3 (3.64), T_1V_2 (3.80), T_1V_4 (3.81), T_1V_1 (3.93), T_1V_5 (3.96) and T_1V_3 (4.25).

4.4 Tillers hill^{-1}

Effect of drought stress

Different levels of drought stress showed significant difference on tillers hill^{-1} at 30, 60, 90 DAT and at harvest (Figure 7 and Appendix VII). The result revealed that at 30, 60, 90 DAT and at harvest, the highest tillers hill^{-1} (6.40, 9.87, 12.87 and 14.13 respectively) were recorded from the treatment T_0 and; the lowest tillers hill^{-1} (4.00, 6.13, 8.27 and 9.33 respectively) were recorded from the treatment T_2. This results are in conformity with Rahman *et al.* (2002) who reported that plant height, tiller number, panicle number, panicle length, number of filled grains per panicle, 1000-grain weight, harvest index (HI), total dry matter (TDM) and yield were decreased with drought stress.

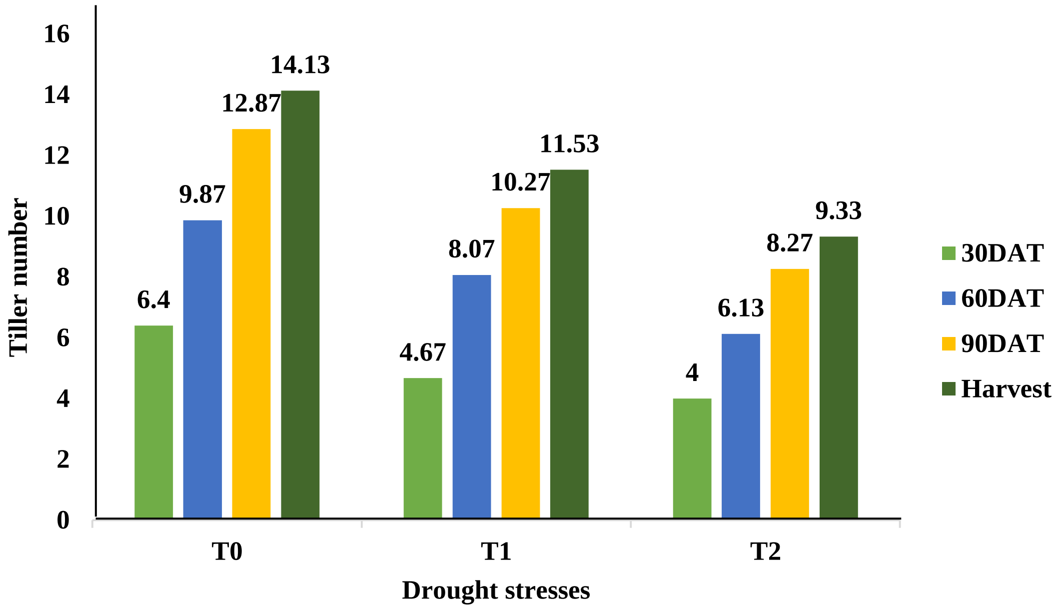

Figure 7: Effect of drought stress on tillers hill^{-1} at different days after transplanting

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The tillers hill^{-1} of hybrid rice varieties were significantly influenced by varieties at 30, 60, 90 DAT and at harvest (Figure 8 and Appendix VIII). The results revealed that at 30, 60, 90 DAT and at harvest, V_3 produced the highest tillers hill^{-1} (5.08, 8.42, 11.00 and 12.75 respectively) and V_2 produced the lowest tillers hill^{-1} (3.67, 5.50, 7.75 and 9.17 respectively).

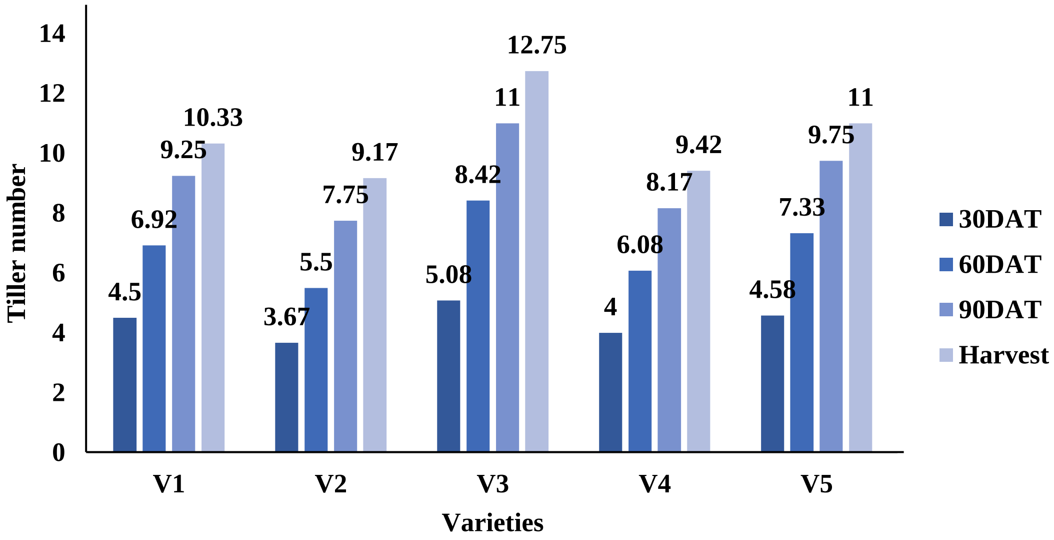

Figure 8: Effect of variety on tillers hill^{-1} at different days after transplanting

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on tillers hill^{-1} at 30, 60, 90 DAT and at harvest (Table 3). At 30 DAT, the highest tillers hill^{-1} (7.33) was observed from T_0V_3 treatment and the lowest tillers hill^{-1} (3.33) was observed from T_2V_2 treatment which was statistically similar with T_2V_4 (3.67) and T_2V_1 (4.00). At 60 DAT, the highest tillers hill^{-1} (11.67) was observed from the T_0V_3 treatment and the lowest tillers hill^{-1} (5.00) was observed from the treatment T_2V_2 which was statistically similar with T_2V_4 (5.33), T_2V_1 (6.00) and T_2V_5 (6.67). At 90 DAT, the highest tillers hill^{-1} (14.67) was observed from the T_0V_3 treatment and the lowest tillers hill^{-1} (7.00) was observed from T_2V_2 which was statistically similar with T_2V_4 (8.33), T_2V_1 (8.67) and T_2V_5 (9.00). At harvest, the highest tillers hill^{-1} (16.33) was observed from the T_0V_3 treatment and the lowest tillers hill^{-1} (8.33) was observed from T_2V_2 which was statistically similar with T_2V_4 (8.67), T_2V_1 (9.00) and T_2V_5 (9.67).

Table 3: Interaction effect of different levels of drought stress and variety on tillers hill^{-1} at different days after transplanting

Treatments		Tillers hill^{-1}			
		30 DAT	60 DAT	90 DAT	Harvest
T_0	V_1	6.33 b	10.33 b	13.33 b	14.33 b
	V_2	5.67 bc	8.00 bc	11.33 bc	12.67 bc
	V_3	7.33 a	11.67 a	14.67 a	16.33 a
	V_4	6.00 b	8.67 b	11.67 b	14.33 b
	V_5	6.67 b	10.67 b	13.67 b	15.00 b
T_1	V_1	4.67 cd	8.00 cd	11.00 cd	11.67 cd
	V_2	4.33 d	7.33 d	10.33 d	10.67 d
	V_3	5.33 c	9.67 c	11.33 c	12.33 c
	V_4	4.67 cd	7.67 cd	10.67 cd	11.00 cd
	V_5	5.00 cd	8.33 cd	11.00 cd	11.67 cd
T_2	V_1	4.00 de	6.00 de	8.67 de	9.00 de
	V_2	3.33 e	5.00 e	7.00 e	8.33 e
	V_3	4.33 d	7.00 d	9.67 d	10.00 d
	V_4	3.67 e	5.33 e	8.33 e	8.67 e
	V_5	4.33 d	6.67 de	9.00 de	9.67 de
LSD $_{(0.05)}$		1.77	1.49	1.94	1.99
CV		5.26	3.91	2.84	6.57

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

4.5 Effective tillers hill^{-1}

Effect of drought stress

Different levels of drought stress showed significant difference on effective tillers hill^{-1} (Figure 9 and Appendix VII). The result revealed that the highest effective tillers hill^{-1} (12.60) were recorded from the treatment T_0 and the lowest effective tillers hill^{-1} (6.53) were recorded from the treatment T_2.

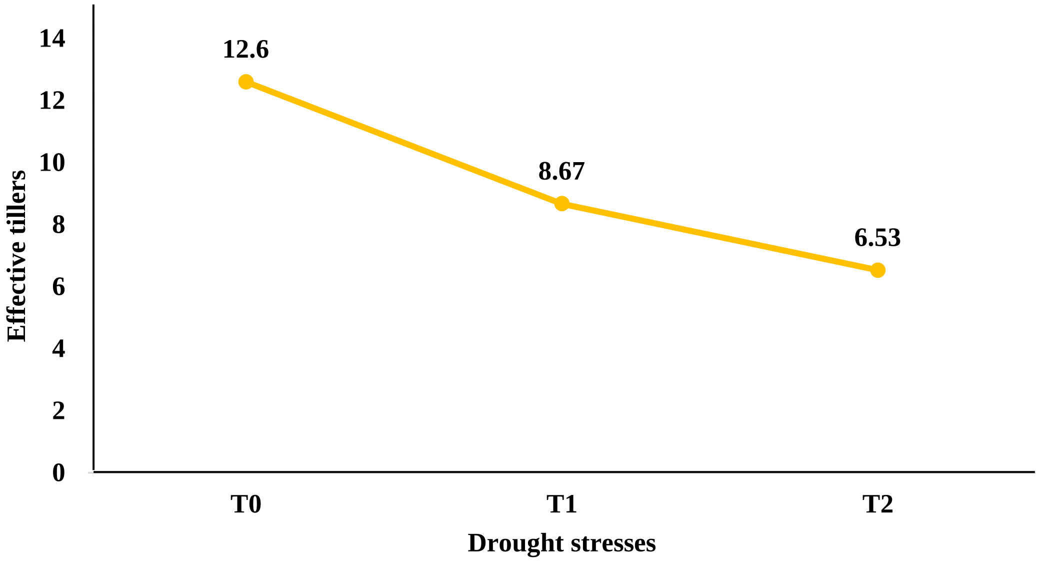

Figure 9: Effect of drought stress on effective tillers hill^{-1}

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The effective tillers hill^{-1} of hybrid rice varieties were significantly influenced by varieties (Figure 10 and Appendix VIII). The results revealed that V_3 produced the highest effective tillers hill^{-1} (10.67) and V_2 produced the lowest effective tillers hill^{-1} (5.83).

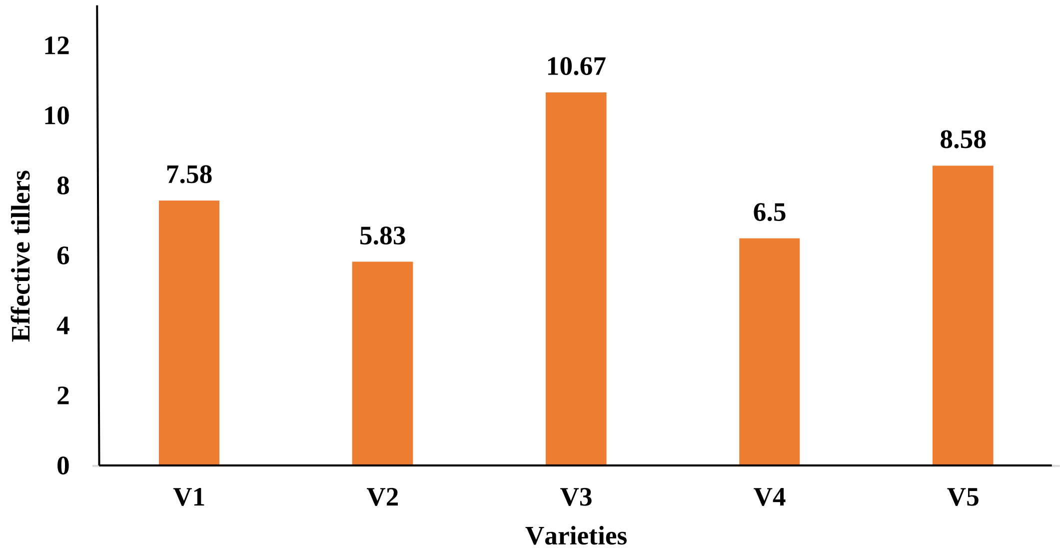

Figure 10: Effect of variety on effective tillers hill^{-1}

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on effective tillers hill^{-1} (Table 4). The results revealed that the highest effective tillers hill^{-1} (15.33) was observed from T_0V_3 treatment and the lowest effective tillers hill^{-1} (5.33) was observed from T_2V_2 treatment.

4.6 Non-effective tillers hill^{-1}

Effect of drought stress

Different levels of drought stress showed significant difference on non-effective tillers hill^{-1} (Figure 11 and Appendix VII). The result revealed that the highest non-effective tillers hill^{-1} (3.00) were recorded from the treatment T_2 and the lowest non-effective tillers hill^{-1} (1.67) were recorded from the treatment T_0.

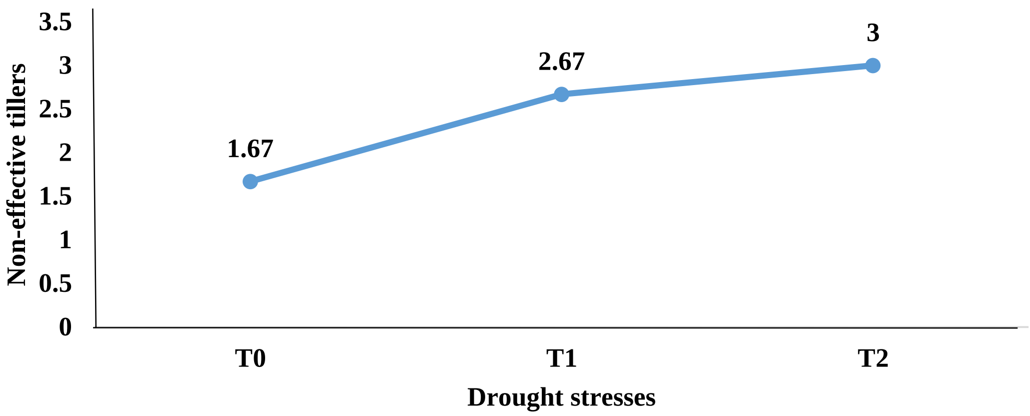

Figure 11: Effect of drought stress on non-effective tillers hill^{-1}

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The non-effective tillers hill^{-1} of hybrid rice varieties were significantly influenced by varieties (Figure 12 and Appendix VIII). The results revealed that V_2produced the highest non-effective tillers hill^{-1} (3.58) which was statistically similar with V_4 (3.08) and V_3 produced the lowest non-effective tillers hill^{-1} (2.08) which was statistically similar with V_5 (2.42).

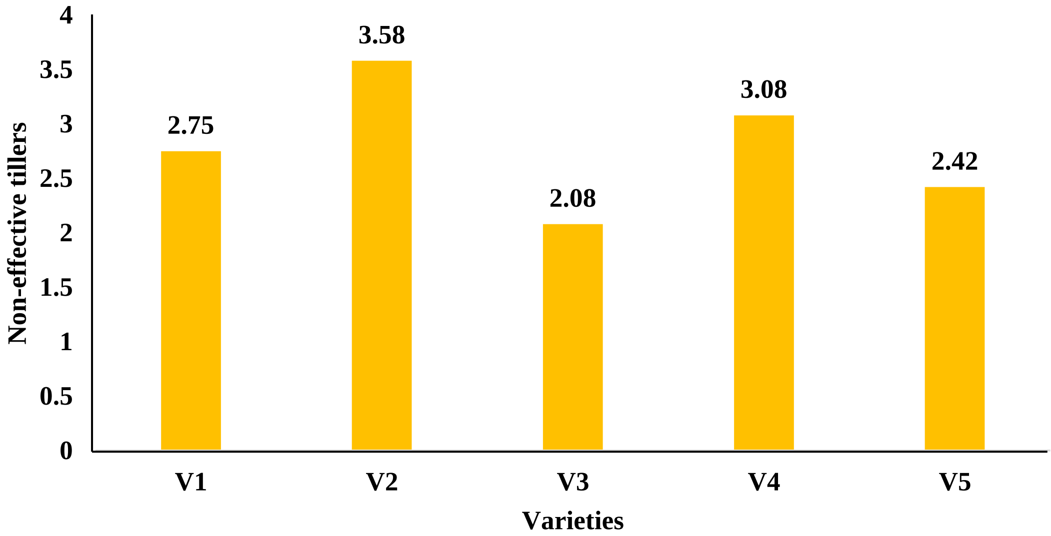

Figure 12: Effect of variety on non-effective tillers hill^{-1}

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Table 4: Interaction effect of different levels of drought stress and variety on effective tillers hill^{-1}, non-effective tillers hill^{-1}, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1}

Treatments		Effective tillers	Non-effective tillers	Panicle length (cm)	Filled grains panicle^{-1}	Unfilled grains panicle^{-1}
T_0	V_1	12.67 bc	1.67 d	22.78 b	166.30 bc	32.56 f
	V_2	11.00 c	2.33 c	21.57 bc	159.64 cd	38.56 d
	V_3	15.33 a	1.00 e	26.50 a	173.30 a	26.56 h
	V_4	12.33 bc	2.00 cd	22.52 b	163.70 c	36.79 e
	V_5	13.67 b	1.33 d	25.30 ab	169.30 b	29.54 g
T_1	V_1	9.33 de	2.33 c	20.44 c	152.44 d	37.76 de
	V_2	8.33 e	2.67 bc	19.77 d	146.39 ef	43.33 b
	V_3	11.00 c	2.00 cd	21.41 bc	156.70 cd	31.87 f
	V_4	9.33 de	2.67 bc	20.12 cd	149.55 e	41.48 c
	V_5	10.33 d	2.33 c	20.87 c	154.35 d	34.23 f
T_2	V_1	6.67 fg	3.33 ab	17.23 de	141.33 g	41.33 c
	V_2	5.33 gh	3.67 a	13.43 f	135.43 h	47.33 a
	V_3	7.67 ef	3.00 b	19.43 d	143.66 g	35.33 e
	V_4	6.00 g	3.33 ab	15.89 e	139.48 g	45.67 b
	V_5	7.00 f	3.00 b	18.12 de	142.77 fg	38.67 d
LSD $_{(0.05)}$		2.36	1.28	5.57	9.06	4.40
CV		5.47	6.23	4.12	8.28	7.05

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on non-effective tillers hill^{-1} (Table 4). The results revealed that the highest non-effective tillers hill^{-1} (3.67) was observed from T_2V_2 treatment which was statistically similar with T_2V_1 (3.33) and T_2V_4 (3.33) whereas; the lowest non-effective tillers hill^{-1} (1.00) was observed from T_0V_3 treatment.

4.7 Panicle length

Effect of drought stress

Different levels of drought stress showed significant difference on panicle length (Figure 13 and Appendix VII). The result revealed that the highest panicle length (24.37 cm) was recorded from the treatment T_0 and the lowest panicle length (18.58 cm) was recorded from the treatment T_2. Rahman *et al.* (2002) also reported the same result. They reported that plant height, tiller number, panicle number, panicle length, number of filled grains per panicle, 1000-grain weight, harvest index (HI), total dry matter (TDM) and yield were decreased with drought stress.

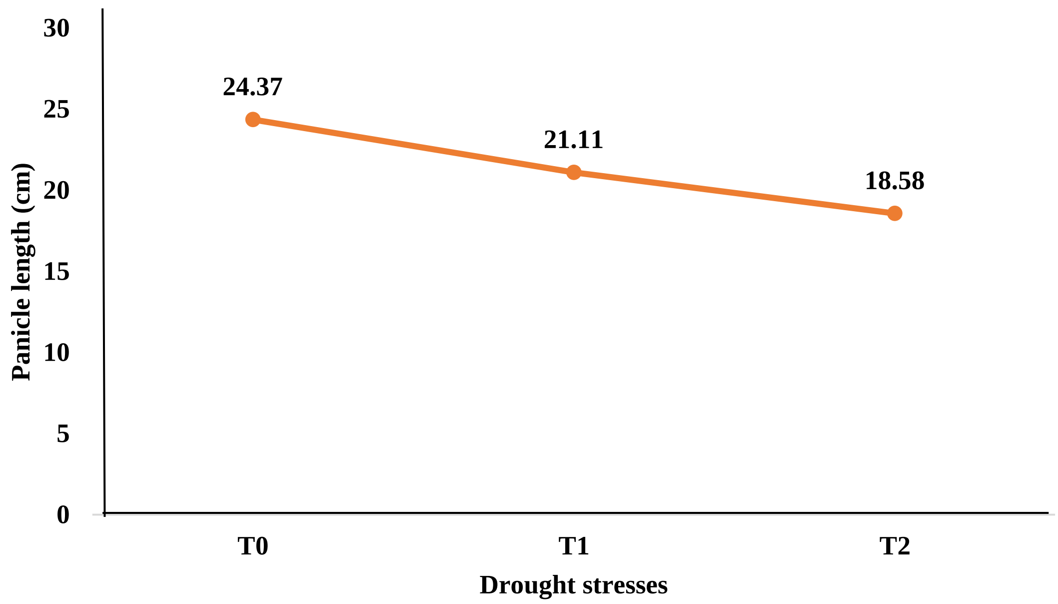

Figure 13: Effect of drought stress on panicle length

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The panicle length of hybrid rice varieties were significantly influenced by varieties (Figure 14and Appendix VIII). The results revealed that V_3 produced the highest panicle length (22.57 cm) which was statistically similar with V_5 (20.73 cm) and V_2 produced the lowest panicle length (15.43 cm).

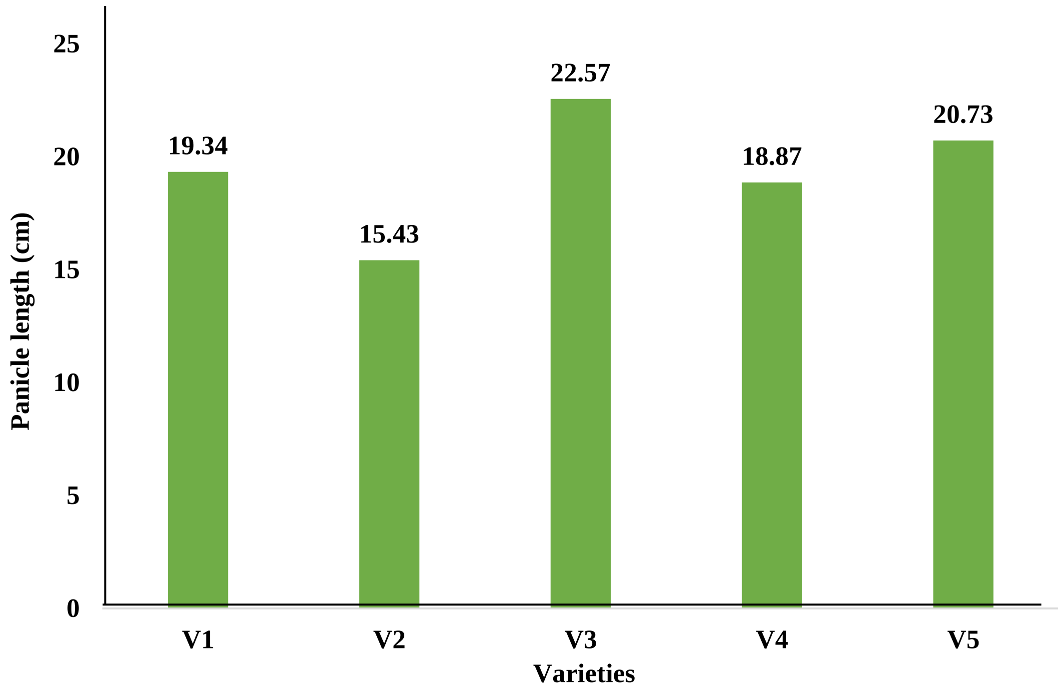

Figure 14: Effect of variety on panicle length

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on panicle length (Table 4). The results revealed that the highest panicle length (26.50 cm) was observed from T_0V_3 treatment which was statistically similar with T_0V_5 (25.30 cm) and the lowest panicle length (13.43 cm) was observed from T_2V_2 treatment.

4.8 Filled grains panicle^{-1}

Effect of drought stress

Different levels of drought stress showed significant difference on filled grains panicle^{-1} (Table 5). The result revealed that the highest filled grains panicle^{-1} (161.43) was recorded from the treatment T_0 and the lowest filled grains panicle^{-1} (154.90) was recorded from the treatment T_2. Rahman *et al.* (2002) also reported the same result. They reported that plant height, tiller number, panicle number, panicle length, number of filled grains per panicle, 1000-grain weight, harvest index (HI), total dry matter (TDM) and yield were decreased with drought stress.

Table 5: Effect of drought stress on filled grains panicle^{-1}, unfilled grains panicle^{-1} and weight of 1000 grain

Treatments	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}	Weight of 1000 grain (g)
T_0	161.43 a	17.47 c	31.39 a
T_1	157.82 b	23.22 b	28.81 b
T_2	154.90 c	26.78 a	26.17 c
LSD $_{(0.05)}$	3.72	6.46	2.78
CV (%)	6.21	4.55	4.96

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The filled grains panicle^{-1} of hybrid rice varieties were significantly influenced by varieties (Table 6). The results revealed that V_3 produced the highest filled grains panicle^{-1} (156.53) and V_2 produced the lowest filled grains panicle^{-1} (147.42).

Table 6: Effect of varieties on filled grains panicle^{-1}, unfilled grains panicle^{-1}and weight of 1000 grain

Treatments	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}	Weight of 1000 grain (g)
V_1	151.33 bc	31.39 c	27.06 bc
V_2	147.42 d	39.74 a	24.19 d
V_3	156.53 a	25.44 e	29.67 a
V_4	149.70 c	27.73 d	26.44 c
V_5	154.21 b	35.48 b	28.21 b
LSD $_{(0.05)}$	12.28	4.17	2.78
CV	3.82	6.17	6.06

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on filled grains panicle^{-1} (Table 4). The results revealed that the highest filled grains panicle^{-1} (173.30) was observed from T_0V_3 treatment and the lowest filled grains panicle^{-1} (135.43) was observed from T_2V_2 treatment.

4.9 Unfilled grains panicle^{-1}

Effect of drought stress

Different levels of drought stress showed significant difference on unfilled grains panicle^{-1} (Table 5). The result revealed that the highest unfilled grains panicle^{-1} (26.78) was recorded from the treatment T_2 and the lowest unfilled grains panicle^{-1} (17.47) was recorded from the treatment T_0.

Effect of variety

The unfilled grains panicle^{-1} of hybrid rice varieties were significantly influenced by varieties (Table 6). The results revealed that V_2 produced the highest unfilled grains panicle^{-1} (39.74) and V_3 produced the lowest unfilled grains panicle^{-1} (25.44).

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on unfilled grains panicle^{-1} (Table 4). The results revealed that the highest unfilled grains panicle^{-1} (47.33) was observed from T_2V_2 treatment and the lowest unfilled grains panicle^{-1} (26.56) was observed from T_0V_3 treatment.

4.10 Weight of 1000 grain

Effect of drought stress

Different levels of drought stress showed significant difference on weight of 1000 grain (g) (Table 5). The result revealed that the highest weight of 1000 grain (31.39 g) was recorded from the treatment T_0 and the lowest weight of 1000 grain (26.17 g) was recorded from the treatment T_2. Zubaer *et al.* (2007) reported the same result. They evaluated that plant height, numbers of tillers/hill, no. of filled grains /panicle, total dry matter/hill, 1000 grain weight, grain yield and harvest index decreased with increasing water stress levels.

Effect of variety

The weight of 1000 grain (g) of hybrid rice varieties were significantly influenced by varieties (Table 6). The results revealed that V_3 produced the highest weight of 1000 grain (29.67 g) and V_2 produced the lowest weight of 1000 grain (24.19 g).

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on weight of 1000 grain (g) (Table 9). The results revealed that the highest weight of 1000 grain (31.07 g) was observed from T_0V_3 treatment and the lowest weight of 1000 grain (17.24 g) was observed from T_2V_2 treatment.

4.11 Grain yield

Effect of drought stress

Different levels of drought stress showed significant difference on grain yield (t ha^{-1}) (Table 7). The result revealed that the highest grain yield (7.26 t ha^{-1}) was recorded from the treatment T_0 and the lowest grain yield (4.61 t ha^{-1}) was recorded from the treatment T_2. Similar result was found by Sarvestani and Pirdashti (2008) who concluded that drought stress at flowering stage had a greater grain yield reduction than drought stress at other times. The reduction of grain yield largely resulted by the reduction in fertile panicle and filled grain percentage.

Table 7: Effect of drought stress on grain yield, straw yield, biological yield and chlorophyll content

Treatments	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Chlorophyll content (SPAD value)
T_0	7.26 a	8.42 a	15.68 a	48.83 a
T_1	5.58 b	6.47 b	12.05 b	45.36 b
T_2	4.61 c	5.35 c	9.96 c	41.04 c
LSD $_{(0.05)}$	0.52	0.79	1.13	3.05
CV	5.83	8.30	7.09	6.59

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Effect of variety

The grain yield ($t\ ha^{-1}$) of hybrid rice varieties were significantly influenced by varieties (Table 8). The results revealed that V_3 produced the highest grain yield (6.88 $t\ ha^{-1}$) and V_2 produced the lowest grain yield (4.02 $t\ ha^{-1}$).

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on grain yield ($t\ ha^{-1}$) (Table 9). The results revealed that the highest grain yield (8.59 $t\ ha^{-1}$) was observed from T_0V_3 treatment and the lowest grain yield (4.12 $t\ ha^{-1}$) was observed from T_2V_2 treatment.

4.12 Straw yield

Effect of drought stress

Different levels of drought stress showed significant difference on straw yield ($t\ ha^{-1}$) (Table 7). The result revealed that the highest straw yield (8.42 $t\ ha^{-1}$) was recorded from the treatment T_0 and the lowest straw yield (5.35 $t\ ha^{-1}$) was recorded from the treatment T_2.

Effect of variety

The straw yield (t ha^{-1}) of hybrid rice varieties were significantly influenced by varieties (Table 8). The results revealed that V_3 produced the highest straw yield (7.98 t ha^{-1}) and V_2 produced the lowest straw yield (4.66 t ha^{-1}).

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on straw yield (t ha^{-1}) (Table 9). The results revealed that the highest straw yield (9.96 t ha^{-1}) was observed from T_0V_3 treatment and the lowest straw yield (4.78 t ha^{-1}) was observed from T_2V_2 treatment.

Table 8: Effect of varieties on grain yield, straw yield, biological yield and chlorophyll content

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Chlorophyll content (SPAD value)
V_1	5.23 bc	6.07bc	11.30 bc	35.41 c
V_2	4.02 d	4.66 d	8.68 d	28.35 e
V_3	6.88 a	7.98 a	14.86 a	41.89 a
V_4	4.78 c	5.54 c	10.32 c	32.28 d
V_5	5.91 b	6.86 b	12.77 b	38.11 b
LSD $_{(0.05)}$	3.57	1.76	4.72	3.83
CV	6.27	4.81	3.09	5.56

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Table 9: Interaction effect of different levels of drought stress and variety on weight of 1000 grain, grain yield, straw yield, biological yield and chlorophyll content

Treatments		Weight of 1000 grain (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Chlorophyll content (SPAD value)
T_0	V_1	27.58 bc	7.62 b	8.84 b	16.46 b	45.33 b
	V_2	25.70 c	6.68 c	7.75 c	14.43 c	43.33 c
	V_3	31.07 a	8.59 a	9.96 a	18.55 a	49.33 a
	V_4	27.26 bc	7.13 bc	8.27 bc	15.40 bc	43.48 c
	V_5	29.26 b	8.01 b	9.29 b	17.30 b	47.67 b
T_1	V_1	23.25 d	5.76 d	6.68 d	12.44 d	39.76 de
	V_2	21.19 e	5.12 e	5.94 e	11.06 e	37.33 e
	V_3	24.29 cd	6.54 c	7.59 c	14.13 c	40.67 d
	V_4	22.43 de	5.47 de	6.34 de	11.81 de	38.79 e
	V_5	23.56 d	6.02 d	6.98 d	13.00 d	40.56 d
T_2	V_1	19.71 ef	4.51 gh	5.23 gh	9.74 gh	33.87 f
	V_2	17.24 g	4.12 hi	4.78 hi	8.90 hi	28.56 h
	V_3	20.46 e	4.73 f	5.49 f	10.63 f	36.23 f
	V_4	18.48 f	4.41 h	5.12 h	9.53 h	31.54 g
	V_5	19.96 ef	4.53 g	5.25 g	9.78 g	34.56 f
$LSD_{(0.05)}$		1.36	2.13	5.57	9.06	2.20
CV		3.20	6.02	4.59	5.07	7.24

T_0 = Control, T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

4.13 Biological yield

Effect of drought stress

Different levels of drought stress showed significant difference on biological yield (t ha^{-1}) (Table 7). The result revealed that the highest biological yield (15.68 t ha^{-1}) was recorded from the treatment T_0 and the lowest biological yield (9.96 t ha^{-1}) was recorded from the treatment T_2.

Effect of variety

The biological yield (t ha^{-1}) of hybrid rice varieties were significantly influenced by varieties (Table 8). The results revealed that V_3 produced the highest biological yield (14.86 t ha^{-1}) and V_2 produced the lowest biological yield (8.68 t ha^{-1}).

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on biological yield (t ha^{-1}) (Table 9). The results revealed that the highest biological yield (18.55 t ha^{-1}) was observed from T_0V_3 treatment and the lowest biological yield (8.90 t ha^{-1}) was observed from T_2V_2 treatment.

4.14 Chlorophyll content

Effect of drought stress

Different levels of drought stress showed significant difference on chlorophyll content (SPAD value) (Table 7). The result revealed that the highest chlorophyll content (48.83) was recorded from the treatment T_0 and the lowest chlorophyll content (41.04) was recorded from the treatment T_2.

Effect of variety

The chlorophyll content (SPAD value) of hybrid rice varieties were significantly influenced by varieties (Table 8). The results revealed that V_3 produced the highest chlorophyll content (41.89) and V_2 produced the lowest chlorophyll content (28.35).

Interaction effect of drought stress and variety

Interaction of different levels of drought stress and variety showed significant variation on chlorophyll content (SPAD value) (Table 9). The results revealed that the highest chlorophyll content (49.33) was observed from T_0V_3 treatment and the lowest chlorophyll content (28.56) was observed from T_2V_2 treatment.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka from November 2017 to May 2018 to study the susceptibility and recovery potential of hybrid rice varieties to drought stress at different growth stages. The experiment comprised of two factor viz. Factor A: Different levels of drought stress [$\mathbf{T_0}$= Control, $\mathbf{T_1}$= Drought stress at 40-45 days after transplanting (tillering), $\mathbf{T_2}$ = Drought stress at 80-85 days after transplanting (flowering)] and Factor B: Hybrid rice varieties [$\mathbf{V_1}$= BRRI dhan29, $\mathbf{V_2}$=Nobin, $\mathbf{V_3}$= Heera2, $\mathbf{V_4}$= Moyna, $\mathbf{V_5}$= BRRI hybrid dhan3]. The experiment was laid out in split plot design with three replications.

Different growth and yield parameters varied significantly due to difference in drought stresses. At 30, 60, 90 DAT and at harvest; the treatment T_0 produced the tallest plant (29.84 cm, 49.77 cm, 69.60 cm and 89.42 cm respectively) and the treatment T_2 produced the shortest plant (22.00 cm, 41.85 cm, 61.88 cm and 76.87 cm respectively). At harvest, treatment T_0 produced the highest leaves hill^{-1} (75.05) and the treatment T_2 produced the lowest leaves hill^{-1} (46.08). The highest leaf area index (4.13) was recorded from the treatment T_0 and the lowest leaf area index (3.73) was recorded from the treatment T_2. At 30, 60, 90 DAT and at harvest, the treatment T_0 produced the highest tillers hill^{-1} (6.40, 9.87, 12.87 and 14.13 respectively) and the treatment T_2 produced the lowest tillers hill^{-1} (4.00, 6.13, 8.27 and 9.33 respectively). Among the treatments, the treatment T_0 produced the highest effective tillers hill^{-1} (12.60) and the treatment T_2 produced the lowest effective tillers hill^{-1} (6.53) whereas, the treatment T_2 produced the highest non-effective tillers hill^{-1} (3.00) and the treatment T_0 produced the lowest non-effective tillers hill^{-1} (1.67). The highest panicle length (24.37 cm) was recorded from the treatment T_0 and the lowest panicle length (18.58 cm) was recorded from the treatment T_2. The highest filled grains panicle^{-1} (161.43) produced by the treatment T_0 and the lowest (154.90) produced by T_2. The maximum unfilled grains panicle^{-1} (26.78) produced by the treatment T_2 and the lowest (17.47) produced by T_0. The maximum value of 1000 grain weight was produced by the treatment T_0 (31.39 g) and the lowest by T_2 (26.17 g). The maximum grain yield (7.26 t ha^{-1}) was recorded from the treatment T_0 and the minimum (4.61 t

ha^{-1}) from the T_2. The highest straw yield (8.42 t ha^{-1}) was found in the treatment T_0 and the lowest (5.35 t ha^{-1}) from the T_2. The highest biological yield (15.68 t ha^{-1}) was recorded from the treatment T_0 and the lowest (9.96 t ha^{-1}) from the T_2. The highest chlorophyll content (48.83) was found in the treatment T_0 and the lowest (41.04) from the T_2.

Different rice varieties had significant effect on growth and yield related parameters. At 30, 60, 90 DAT and at harvest, V_3 produced the tallest plant (25.83 cm, 43.97 cm, 61.72 cm and 78.07 cm respectively) and V_2 produced the shortest plant (22.81 cm, 40.93 cm, 58.88 cm and 74.97 cm respectively). At harvest, V_3 produced the highest leaves $hill^{-1}$ (59.89) and V_2 produced the lowest leaves $hill^{-1}$ (50.56). The highest leaf area index (4.25) was recorded from V_3 and the lowest leaf area index (3.56) was recorded from V_2. At 30, 60, 90 DAT and at harvest, V_3 produced the highest tillers $hill^{-1}$ (5.08, 8.42, 11.00 and 12.75 respectively) and V_2 produced the lowest tillers $hill^{-1}$ (3.67, 5.50, 7.75 and 9.17 respectively). Among the varieties, V_3 produced the highest effective tillers $hill^{-1}$ (10.67) and V_2 produced the lowest effective tillers $hill^{-1}$ (5.83) whereas; V_2 produced the highest non-effective tillers $hill^{-1}$ (3.58) and V_3 produced the lowest non-effective tillers $hill^{-1}$ (2.08). The highest panicle length (22.57 cm) was recorded from V_3 and the lowest panicle length (15.43 cm) was recorded from V_2. The highest filled grains $panicle^{-1}$ (156.53) produced by V_3 and the lowest (147.42) produced by V_2. The maximum unfilled grains $panicle^{-1}$ (39.74) produced by V_2 and the lowest (25.44) produced by V_3. The maximum value of 1000 grain weight was produced by V_3 (29.67 g) and the lowest by V_2 (24.19 g). The maximum grain yield (6.88 t ha^{-1}) was recorded from V_3 and the minimum (4.02 t ha^{-1}) from the V_2. The highest straw yield (7.98 t ha^{-1}) was found in V_3 and the lowest (4.66 t ha^{-1}) from the V_2. The highest biological yield (14.86 t ha^{-1}) was recorded from V_3 and the lowest (8.68 t ha^{-1}) from the V_2. The highest chlorophyll content (41.89) was found in V_3 and the lowest (28.35) from the V_2.

At 30, 60, 90 DAT and at harvest,T_0V_3 produced the tallest plant (31.77 cm, 50.77 cm, 70.80 cm and 90.23 cm respectively) and T_2V_2 produced the shortest plant (20.50 cm, 40.53 cm, 60.53 cm and 75.47 cm respectively). At harvest, T_0V_3 produced the highest leaves $hill^{-1}$ (90.67) and T_2V_2 produced the lowest leaves $hill^{-1}$(42.33). The highest leaf area index (4.68) was recorded from T_0V_3 and the lowest leaf area index (3.36) was recorded from T_2V_2. At 30, 60, 90 DAT and at harvest; T_0V_3 produced the highest tillers hill^{-1} (7.33, 11.67, 14.67 and 16.33 respectively) and T_2V_2 produced the lowest tillers hill^{-1} (3.33, 5.00, 7.00 and 8.33 respectively). Among the treatments, T_0V_3 produced the highest effective tillers hill^{-1} (15.33) and T_2V_2 produced the lowest effective tillers hill^{-1}(5.33) whereas; T_2V_2 produced the highest non-effective tillers hill^{-1} (3.67) and T_0V_3 produced the lowest non-effective tillers hill^{-1} (1.00). The highest panicle length (26.50 cm) was recorded from T_0V_3 and the lowest panicle length (13.43 cm) was recorded from T_2V_2. The highest filled grains panicle^{-1} (173.30) produced by T_0V_3 and the lowest (135.43) produced by T_2V_2. The maximum unfilled grains panicle^{-1} (47.33) produced by T_2V_2 and the lowest (26.56) produced by T_0V_3. The maximum value of 1000 grain weight was produced by T_0V_3 (31.07 g) and the lowest by T_2V_2 (17.24 g). The maximum grain yield (8.59 t ha^{-1}) was recorded from T_0V_3 and the minimum (4.12 t ha^{-1}) from the T_2V_2. The highest straw yield (9.96 t ha^{-1}) was found in T_0V_3 and the lowest (4.78 t ha^{-1}) from the T_2V_2.The highest biological yield (18.55 t ha^{-1}) was recorded from T_0V_3 and the lowest (8.90 t ha^{-1}) from the T_2V_2. The highest chlorophyll content (49.33) was found in T_0V_3 and the lowest (28.56) from the T_2V_2.

From the above results it can be concluded that,

- Drought stress adversely affects all the growth and yield related attributes of hybrid rice varieties.
- Treatment T_0 (Control) gave the better yield and yield contributing characters and lower by T_2 [Drought stress at 80-85 days after transplanting (flowering)].
- Heera2 produced 12.89% more yield compared to Nobin under drought stress.
- Nobin showed comparatively more susceptibility to drought stress.

From the above conclusions, the following recommendations can be made:

✓ Heera2 is recommended to cultivate under drought stress because it is stress tolerant and produce more yield than other varieties.

✓ Such studies needs more trials under farmer’s field conditions at different agro-ecological zones of Bangladesh for the conformation of the results.

CHAPTER VI

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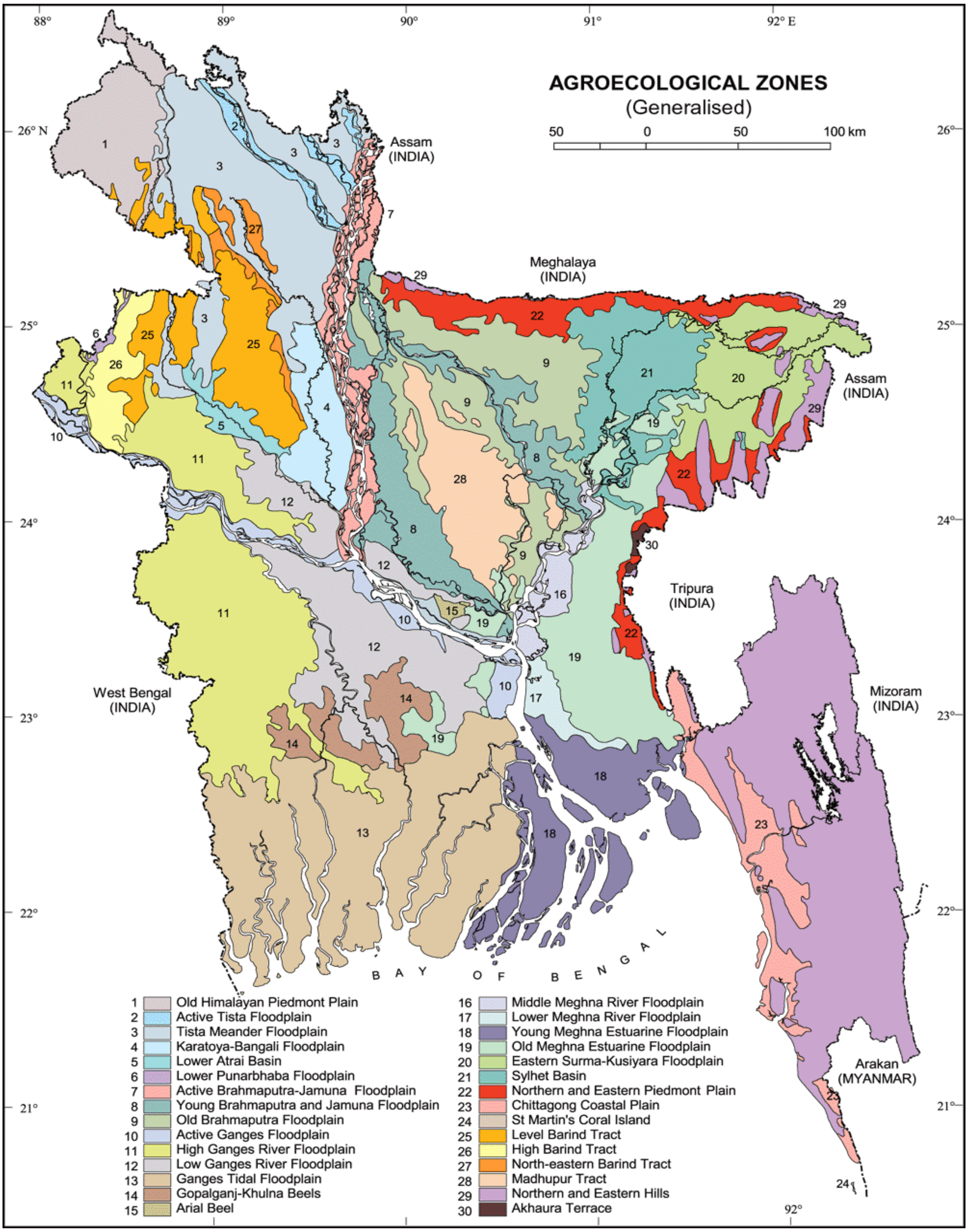
APPENDICES

Appendix I. Experimental location on the map of Agro-ecological Zones of Bangladesh



Appendix II. Morphological characteristics of the experimental field

Morphology	Characteristics
Location	SAU Farm, Dhaka
Agro-ecological zone	Madhupur Tract (AEZ- 28)
General Soil Type	Deep Red Brown Terrace Soil
Parent material	Madhupur Terrace
Topography	Fairly level
Drainage	Well drained
Flood level	Above flood level

(SAU Farm, Dhaka)

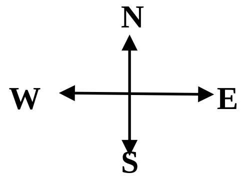
Appendix III. Initial physical and chemical characteristics of the soil

Characteristics	Value
Mechanical fractions: % Sand (2.0-0.02 mm) % Silt (0.02-0.002 mm) % Clay (<0.002 mm)	 22.26 56.72 20.75
Textural class	Silt Loam
pH (1: 2.5 soil- water)	5.9
Organic Matter (%)	1.09
Total N (%)	0.028
Available K (ppm)	15.625
Available P (ppm)	7.988
Available S (ppm)	2.066

(SAU Farm, Dhaka)

Appendix IV. Layout of the experimental field

B_1	B_2	B_3
T_2V_5	T_0V_2	T_1V_3
T_2V_4	T_0V_1	T_1V_4
T_2V_3	T_0V_5	T_1V_2
T_2V_2	T_0V_4	$T_1 V_1$
T_2V_1	T_0V_3	T_1V_5
T_1V_5	T_2V_2	T_0V_3
T_1V_4	T_2V_1	T_0V_4
T_1V_3	T_2V_5	T_0V_2
T_1V_2	T_2V_4	T_0V_1
T_1V_1	T_2V_3	T_0V_5
T_0V_5	T_1V_2	T_2V_3
T_0V_4	T_1V_1	T_2V_4
T_0V_3	T_1V_5	T_2V_2
T_0V_2	T_1V_4	T_2V_1
T_0V_1	T_1V_3	T_2V_5



Plot length = 2 m

Plot width = 1.5 m

Plot area = 2 × 1.5 = 3 m^2

T_0 = Control (no drought stress)

T_1 = Drought stress at 40-45 days after transplanting (tillering)

T_2 = Drought stress at 80-85 days after transplanting (flowering)

V_1 = BRRI dhan29

V_2 = Nobin

V_3 = Heera2

V_4 = Moyna

V_5 = BRRI hybrid dhan3

Appendix V. Effect of drought stress on plant height at different days after transplanting, leaves hill^{-1} at harvest and leaf area index

Treatments	Plant height (cm)				Leaves hill^{-1}	Leaf area index
	30 DAT	60 DAT	90 DAT	Harvest		
T_0	29.84 a	49.77 a	69.60 a	89.42 a	75.05 a	4.13 a
T_1	25.83 b	45.51 b	65.00 b	84.07 b	46.08 b	4.01 a
T_2	22.00 c	41.85 c	61.88 c	76.87 c	45.70 c	3.73 b
LSD $_{(0.05)}$	0.29	0.21	0.22	0.22	7.22	0.43
CV (%)	8.03	5.89	4.64	7.25	8.15	6.57
Significant level	*	*	*	*	*	*

* - Significant at 5% level

T_0 = Control (no drought stress), T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Appendix VI. Effect of variety on plant height at different days after transplanting, leaves hill^{-1} at harvest and leaf area index

Treatments	Plant height (cm)				Leaves hill^{-1}	Leaf area index
	30 DAT	60 DAT	90 DAT	Harvest		
V_1	23.84 b	42.15 b	59.98 b	76.03 b	57.57 ab	3.96 ab
V_2	22.81 c	40.93 c	58.88 c	74.97 c	50.56 c	3.56 c
V_3	25.83 a	43.97 a	61.72 a	78.07 a	59.89 a	4.25 a
V_4	23.22 b	41.17 b	59.22 b	77.06 b	52.33 b	3.81 b
V_5	24.92 b	43.06 b	60.74 b	77.06 b	59.41 ab	4.08 ab
LSD $_{(0.05)}$	0.32	0.24	0.25	0.25	2.06	0.56
CV (%)	3.56	4.58	2.64	6.40	10.35	5.67
Significant level	*	*	*	*	*	*

* - Significant at 5% level

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Appendix VII. Effect of drought stress on tillers hill^{-1} at different days after transplanting, effective tillers hill^{-1}, non-effective tillers hill^{-1} and panicle length

Treatments	Tillers hill^{-1}				Effective tillers hill^{-1}	Non-effective tillers hill^{-1}	Panicle length (cm)
	30 DAT	60 DAT	90 DAT	Harvest			
T_0	6.4 a	9.87 a	12.87 a	14.13 a	12.60 a	1.67 c	24.37 a
T_1	4.67 b	8.07 b	10.27 b	11.53 b	8.67 b	2.67 b	21.11 b
T_2	4.00 c	6.13 c	8.27 c	9.33 c	6.53 c	3.00 a	18.58 c
LSD $_{(0.05)}$	0.79	0.67	0.87	0.89	1.06	0.57	0.73
CV (%)	24.56	13.19	12.81	11.50	8.29	7.84	5.27
Significant level	*	*	*	*	*	*	*

* - Significant at 5% level

T_0 = Control (no drought stress), T_1 = Drought stress at 40-45 days after transplanting (tillering) and T_2 = Drought stress at 80-85 days after transplanting (flowering)

Appendix VIII. Effect of variety on tillers hill^{-1} at different days after transplanting, effective tillers hill^{-1}, non-effective tillers hill^{-1} and panicle length

Treatments	Tillers hill^{-1}				Effective tillers hill^{-1}	Non-effective tillers hill^{-1}	Panicle length (cm)
	30 DAT	60 DAT	90 DAT	Harvest			
V_1	4.50 b	6.92 b	9.25 b	10.33 b	7.58 bc	2.75 b	19.34 b
V_2	3.67 cd	5.50 cd	7.75 cd	9.17 cd	5.83 d	3.38 a	15.43 c
V_3	5.08 a	8.42 a	11.00 a	12.75 a	10.67 a	2.08 c	22.57 a
V_4	4.00 c	6.08 c	8.17 c	9.42 c	6.50 c	3.08 ab	18.87 b
V_5	4.58 b	7.33 b	9.75 b	11.00 b	8.58 b	2.42 c	20.73 a
LSD $_{(0.05)}$	0.88	0.75	0.97	0.99	1.19	0.65	1.29
CV (%)	14.51	3.29	2.11	4.58	6.92	8.74	6.77
Significant level	*	*	*	*	*	*	*

* - Significant at 5% level

V_1 = BRRI dhan29, V_2 = Nobin, V_3 = Heera2, V_4 = Moyna and V_5 = BRRI hybrid dhan3

Appendix IX. Analysis of variance on the data of plant height at different days after transplanting and leaves hill^{-1}

Source of variation	Degrees of freedom	Mean square				
		Plant height				Leaves hill^{-1}
		30 DAT	60 DAT	90 DAT	Harvest	
Replication	2	2.32	4.49	6.05	5.91	2.21
Factor A	2	363.74*	289.51*	219.58*	289.51.*	42.33*
Error	4	6.20	2.57	5.68	2.33	5.62
Factor B	4	53.14**	69.31*	49.96*	68.24*	19.07*
A × B	8	1.18*	0.88*	1.39*	4.52*	4.20*
Error	24	2.80	3.58	2.93	1.41	3.64

*Significant at 5% level
**Significant at 1% level
NS - Non Significant

Appendix X. Analysis of variance on the data of leaf area index, tillers hill^{-1} at different days after transplanting and effective tillers hill^{-1}

Source of variation	Degrees of freedom	Mean square					
		Leaf are index	Tillers hill^{-1}				Effective tillers hill^{-1}
			30 DAT	60 DAT	90 DAT	Harvest	
Replication	2	1.12	3.69	5.43	4.66	4.95	5.11
Factor A	2	98.1*	33.79*	34.92*	29.48*	7.98*	6.33*
Error	4	9.45	6.32	2.72	3.78	3.19	4.22
Factor B	4	35.21*	23.12*	15.58*	15.19*	5.27*	2.97*
A × B	8	9.57*	0.49*	0.58**	0.89*	2.51*	1.30*
Error	24	2.28	4.33	2.50	3.83	1.48	3.97

*Significant at 5% level
**Significant at 1% level
NS - Non Significant

Appendix XI. Analysis of variance on the data of non-effective tillers hill^{-1}, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1}

Source of variation	Degrees of freedom	Mean square			
		Non-effective tillers hill^{-1}	Panicle Length (cm)	Filled grains panicle^{-1}	Unfilled grains panicle^{-1}
Replication	2	2.89	6.04	4.61	5.53
Factor A	2	21.71*	42.91*	88.53*	74.03*
Error	4	4.14	2.36	5.12	3.49
Factor B	4	9.98*	5.06*	69.57*	91.92**
A × B	8	28.19*	2.18*	4.01*	5.41*
Error	24	2.87	6.43	7.71	3.74

*Significant at 5% level
**Significant at 1% level
NS - Non Significant

Appendix XII. Analysis of variance on the data of weight of 1000 grain, grain yield, straw yield, biological yield and chlorophyll content

Source of variation	Degrees of freedom	Mean square				
		Weight of 1000 grain	Grain yield	Straw yield	Biological yield	Chlorophyll content
Replication	2	2.79	3.34	6.07	7.25	4.88
Factor A	2	42.18*	62.08*	88.53*	86.59*	56.04*
Error	4	3.24	2.89	6.18	2.87	6.20
Factor B	4	28.02	44.57*	22.67*	48.21*	39.47*
A × B	8	6.89*	4.03*	4.53*	6.04*	5.45*
Error	24	2.74	3.23	4.13	6.10	1.94

*Significant at 5% level
**Significant at 1% level
NS - Non Significant