IMPACT OF WATER DEFICIT ON MORPHOLOGY AND YIELD ATTRIBUTES OF HYBRID AND INBRED RICE (*Oryza sativa* L.) VARIETIES

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CERTIFICATE

This is to certify that the thesis entitled "**IMPACT OF WATER DEFICIT ON MORPHOLOGY AND YIELD ATTRIBUTES OF HYBRID AND INBRED RICE (*Oryza sativa* L.) VARIETIES"** 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 **RAZIA SULTANA RINA**, Registration No. **19-10241**, 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: July, 2022
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Prof. Dr. Nasima Akhter
Supervisor

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IMPACT OF WATER DEFICIT ON MORPHOLOGY AND YIELD ATTRIBUTES OF HYBRID AND INBRED RICE (*Oryza sativa* L.) VARIETIES

ABSTRACT

The pot experiment was conducted at the Research Farm of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, during the period from November 2019 to May 2020 to study the impact of water deficit on morphology and yield attributes of hybrid and inbred rice varieties. The experiment comprised of two factors viz. Factor A: Variety (4), V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5; factor B: Water deficit (3), T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering). The result revealed that V_3 (Aloron) exhibited its superiority to other tested variety Heera 4, BRRI hybrid dhan5 and BRRI dhan92 in terms of seed yield. V_3 (Aloron) out-yielded over V_2 (Heera 4) by 5.08% and V_4 (BRRI hybrid dhan5) by 11.43% higher yield. V_3 (Aloron) also showed the tallest plant at harvest (91.60 cm), highest SPAD value (40.02), the highest number of filled grains panicle^{-1} (157.56), lowest number of unfilled grains panicle^{-1} (28.08), the highest weight of 1000-grains (25.30 g), higher straw yield (7.56 t ha^{-1}), the highest biological yield (14.38 t ha^{-1}) and harvest index (47.14%) than other tested varieties in this experiment. On the other hand, the variety V_1 (BRRI dhan92) returned with 17.18% lower yield than variety V_3 (Aloron) which was significantly the lowest compared to other varieties under study. Significant differences existed among different water deficit treatments with respect to yield and yield attributing parameters of rice. A yield advantages of 1.81 t ha^{-1} and 3.63 t ha^{-1} was observed from T_1 treatment [Control)] over T_2 [Water deficit at 45–55 days after transplanting (tillering)] and T_3 [Water deficit at 85–95 days after transplanting (flowering)] treated pot, respectively. The higher amount of yield from T_1 treatment was possibly aided by the tallest plant at harvest (91.81 cm), highest number of tillers hill^{-1} at harvest (11.68), highest number of leaves hill^{-1} at harvest (78.73), maximum leaf area index (4.49), highest SPAD value (46.20), higher number of filled grains panicle^{-1} (167.08), lowest number of unfilled grains panicle^{-1} (28.90), highest weight of 1000-grains (28.40 g), the highest straw yield (9.23 t ha^{-1}), biological yield (17.36 t ha^{-1}) and harvest index (46.81%). It was observed that water deficit at flowering stage (85–95 days after transplanting) could be move detrimental to rice plant than water deficit at tillering stage (45–55 days after transplanting) and significantly reduced yield attributes and yield of rice. Among the interaction effects, T_2V_3 was superior and comparable to T_1V_3 in most of the growth and yield attributing parameters along with grain yield. Aloron variety seems promising for combating water deficit in rice field and produces significantly higher yield compared to other varieties.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BBS	Bangladesh Bureau of Statistics
BRRI	Bangladesh Rice Research Institute
CV%	Percentage of Coefficient of Variance
DAT	Days After Transplanting
e g.	As for example
et al.	and others
i e.	that is
LSD	Least Significant Difference
DOASL	Department of Agriculture Government of Sri Lanka
IRRI	International Rice Research Institute
SAU	Sher-e-Bangla Agricultural University

UNIT

%	Percent
@	At the rate of
^{0}C	Degree Celsius
Cm	Centimeter
g	Gram
kg	Kilogram
ha	Hectare
kg ha^{-1}	kg per hectare
t ha^{-1}	Ton per hectare
m	Meter

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa L.*) is an important cereal crop that requires a relatively higher amount of water for its normal growth in comparison to other crops (Sarkar *et al*., 2019). Therefore, water deficit is a major factor limiting rice production that causes a great threat to rice cultivation (Henry *et al*., 2016). Bangladesh is an agro-based and densely populated country in Asia. The population of Bangladesh will reach over 200 million in 2050, which is around 30% higher than the present population (Islam *et al*., 2017). Rice which is the driving force of Bangladesh agriculture occupies about two-thirds of the cultivated land area and constitutes 90% of the food grain production in Bangladesh (BBS, 2020). As a staple food, rice production will need to be increased to about 50 million tons from 35 million today.

Bangladesh is one of the most natural hazard-prone countries in the world because of its high climatic variability, low flat topography, hydro-geological setting, and diverse complex geomorphology. Every five years Bangladesh is affected by the major country-wide droughts (Islam *et al*., 2017). A definition of drought generally accepted by plant breeders is “a shortfall of water availability sufficient to cause reduction in yield” or “a period of no rainfall or irrigation that affects crop growth”. Drought stress is multidimensional stress that affects plants at different growth stages. The impact of drought stress on the total green plant surface and plant response to drought stress are very intricate because it reflects a combination of stress impacts and plant response in all essential levels of the plant over time and space (Fatima *et al*., 2018). However local droughts occur regularly and affected crop production. Northwestern regions of Bangladesh are particularly exposed to droughts. The average crop production reduced about 25-30% because of the effect of droughts in these regions of Bangladesh (Habiba, 2013). A strong drought can cause greater than 40% damage to broadcast Aus and, it also causes significant destruction to the T. Amon crop in approximately 2.32 million hectares every year. In the Boro season, about 1.2 million hectares of rice cropped face droughts of different magnitudes in Bangladesh (Abdullah, 2015). So, drought stress is one of the major constraints for rice production in Bangladesh. Besides climate change is likely to shift the patterns of drought and possibly increase the frequency and intensity of drought events in the foreseeable future (Shahid, 2011). Rice is more susceptible to drought than any other crops (Usman *et al*., 2018). Under water stress condition, the rice plant shows several morphological changes at different growth stages such as panicle initiation, anthesis and grain filing. These involve reduced plant height, leaf rolling, leaf senescence, stomatal closure, decreased leaf elongation and lower dry matter production (Bhupinder Singh *et al*., 2017). Besides drought stress results in various physiological changes in plants that may include, reduction in PAR, photosynthetic rate, relative water content, proline accumulation, estimation of leaf chlorophyll, pigment degradation resulting in decreased water use efficiency and growth reduction prior to plant senescence (Akram *et al*., 2013). In rice water stress at vegetative growth especially booting stage, flowering and reproductive period can interrupt floret initiation causing spikelet sterility, reduced number of panicles per unit area and grain filling resulting in lower grain weight and ultimately poor paddy yield (Moonmoon *et al*., 2017). However, the impact of drought stress on various morpho-physiological changes significantly differ among rice cultivars. Drought stress is affecting about 50% of rice production in the world.

In Bangladesh, population is increasing at an alarming rate but the cultivable land is reducing due to urbanization and industrialization. To meet the present population demand among the high yielding rice varieties hybrid rice is the first-generation crop and cultivated during Boro season. Boro (January - May) is the single largest crop grown in Bangladesh which accounts more than 50% of total rice production (BBS, 2020). Boro rice is generally cultivated under irrigated condition when rainfall is very scanty. Irrigated rice cultivation is the most productive and plays a vital role in fulfilling global food demand. But one estimate shows that 2000–5000 L of water is required to produce 1 kg of rice (Caine *et al.* 2019). The Boro cultivation area is increasing with a rate of 3.57% per year during 1984–85 to 2019–20. An inbred rice variety is a pureline, which have the same genetic makeup. It is the result of a cross between two or more different varieties through several cycles of self-pollination or inbreeding. Whereas hybrid rice is a type of rice that has been bred from two very different parents. It can significantly outyield other rice varieties. Today, hybrid rice closing yield gaps evident in many areas. It also raises yield potential and farmers earn higher incomes and rice becomes available and affordable to more consumers. So high yielding variety adoption rate has increased over the period and in recent years it has found 72% for Aus, 73.5% for Aman, and 98.4% for Boro season. As a result, the yield of the Aus, Aman, and Boro seasons has been found increasing growth for most of the regions (Al Mamun *et al*., 2021). Hybrid rice has higher seedling dry matter content, thicker leaves, larger leaf area and long root system. Hybrid rice can give yield advantage through vigorous growth, extensive root system, efficient and greater sink size, greater carbohydrate translocation from vegetative parts to spikelet and larger leaf area index during grain filling stage. Hybrid rice has more dry matter accumulation in the early and middle growth stages. Hybrid rice has 15-30% or more yield advantages. Hybrid rice varieties have been introduced in our country fifteen years ago importing from China, Philippines, India, Vietnam, etc. by different seed companies and got positive experience. These seed companies claims that hybrid rice varieties are disease, pests and climatic stress tolerant. But research findings are very limited in favor of their claims. Very recently hybrid rice varieties are developed by BRRI and most of them are exceptionally high yielding. In Bangladesh, research works on the responses of hybrid rice varieties to climatic stresses especially on drought are scanty. So, it is needed to screen out the water deficit tolerant hybrid and inbred rice varieties and information regarding water deficit tolerance capability of them is to be searched out. It will help to horizontal expansion of hybrid and inbred rice cultivation in our country avoiding water deficit condition. Considering these on the above situation the present research work has been designed with the following specific objectives:

i. To study the effect of water deficit on morphology and yield attributes of various hybrid and inbred rice varieties.

ii. To investigate the varietal differences of hybrid and inbred rice varieties in response to water deficit at tillering and reproductive stages.

iii. To asses the yield condition of hybrid and inbred rice varieties under water deficit and screen out the water deficit tolerant varieties.

CHAPTER II

REVIEW OF LITERATURE

Environmental elements like air, day length or photoperiod, temperature, variety, and agronomic practices like transplanting time, spacing, number of seedlings, depth of planting, fertilizer management, etc. as well as abiotic stresses like salinity, drought, flood, contamination by heavy metals, etc. have a significant impact on the growth and yield of rice plants. Different levels of drought stress have a significant impact on rice yield and yield-contributing traits. There is a wealth of pertinent review material on rice drought stress both globally and in the context of Bangladesh. Under the following headings, some current information on rice drought stress have been reviewed:

2.1 Scenario of water deficit in Bangladesh

The northwestern part of Bangladesh, the Barind Tract area, receives a low annual rainfall than that of the other regions of the country (Ali *et al*., 2007). Crop production in such areas depends on natural rainfall. In addition, changing pattern of rainfall (frequency, amount and its distribution) imposes drought in crop growing period. Research results showed that increase in temperature can increase crop water demand. Rice is the main staple food grain in Bangladesh. During 2016-17, total rice production (Boro, Aus and Aman) of the country is about 3,3804,000 Metric ton (BBS, 2017). Due to continuous increase in population, increased amount of rice should be produced and hence, there is a great need for sustainable rice production. In this context, a solution lies between development of drought tolerant rice variety and sustainable irrigation supply system. In Bangladesh, rice grows in main three seasons: Boro (Jan.- May), Aus (April – July), and Aman (Aug.-Nov.). In Boro season, production of rice depends on irrigation (from surface or groundwater). In Aus and Aman season, the water demand is mostly meet by natural rainfall. Supplemental irrigation is needed for uneven or little rainfall, or during a long dry-spell. Drought sensitive cultivar can suffer from soil moisture in such a period. Drought tolerant cultivars can mitigate the impact of drought. Another possibility is to capture rain water in the rice plot by maintaining sufficient height of levee, which can facilitate plants to maintain turgor during long dry-spell or drought. Both *In Vitro* and *In situ* screening of rice cultivars have been practiced (Sabesan and Saravanan, 2016; Kumar *et al*., 2015). Different indices to screen rice for drought resistance have been used by different researchers. These include drought resistance as estimated from grain yield, visual scoring, canopy-temperature based indices, uprooting force (Zou *et al*., 2007; Ingram *et al*., 1990; Kumar *et al*., 2015). From a detail review, Ingram *et al*., (1990) concluded that visual scoring was the best method. In case, controlled water deficit cannot be imposed, drought resistance may be estimated by measuring both uprooting force and grain yield. Gomathinayagam *et al*., (1998) noted that drought SES scores of susceptible and resistant checks from pot screening were significantly correlated with average scores from field drought tolerance trial results in the IRRI data bank. Zou *et al*., (2007) concluded that drought resistance can be identified by measuring yield potential, delay in flowering, or drought response index under drought stress and normal irrigated condition.

2.2 Effect of water deficit stress

Numerous researchers have investigated and recorded the impact of water stress (or drought) on plant growth mechanisms and adaptation techniques (Arnon, 1975; Clark and Hiller, 1973; Turner, 1986; Andersen and Aremu, 1991; Neumann *et al*., 1994; Yang *et al*., 2001; Ali 2010b; Sikuku *et al*., 2010). But grain yield is the true indicator of water stress. Sikuku *et al*. (2010) examined in the field and greenhouse the impact of water deficit on the physiology and morphology of three types of NERICA rainfed rice. Treatments included daily irrigation (control), irrigation every two days, irrigation every four days, and irrigation every six days. They discovered that a lack of water inhibits plant development and biomass accumulation. In terms of plant development, NERICA 2 was the most tolerant of the three kinds. Yang (2007) scheduled irrigation for rice using the soil-water potential value. Other researchers have also used soil moisture content to plan irrigation (Ali and Talukder, 2001).

Boonjung *et al*., (1996) stated that Rice's future growth and grain yield were only slightly impacted by drought stress during the vegetative phase. Due to fewer panicles in one trial and fewer spikelet in another, the grain production was reduced by up to 30% in both trials.

The number of spikelet per panicle fell by up to 60% compared to controls, and water stress during the panicle growth stage lowered grain yield due to delayed anthesis filled grains decreased up to zero. The decrease in grain yield is associated with low dry matter production during the drought period as well as during the recovery period following the drought (Halder and Burrage, 2003). Drought stress at an early seedling stage may cause wilting, rolling, and drying of leaves (Murty and Ramakrishnayya,1982). The effects may occur even after stress has been eliminated (Jana and Ghildyal, 1972; O' Toole and Cruz, 1979). Cruz *et al.*, (1986) found that mild water stress during vegetative growth decreased tiller and panicle number, leaf area, shoot and total dry matter mass. Castillo *et al*., (1987); BRRI (1991) reported that when water stress occurs during the vegetative phase, total dry matter production is decreased at harvest due to slow growth and the production of a smaller number of tillers. leaf area, shoot area, and entire amount of dry materials. Castillo *et al*., (1987); BRRI (1991) revealed that total dry matter output is decreased at harvest as a result of delayed growth and the formation of fewer tillers when water stress occurs during the vegetative phase

Sharma *et al*., (1987) stated that, almost every component of rice growth and development is impacted by drought stress throughout the reproductive cycle. Early water deficit causes leaf rolling, drying, reduced photosynthetic activity, decreased leaf water potential, decreased dry matter yield, decreased spikelet fertility, decreased grain yield, delayed onset of the reproductive growth period, and delayed flowering and maturity, depending on the severity and duration (Yang *et al*., 1994; Tuong *et al*., 2002). When a drought hit during grain filling, the proportion of filled grains decreased to 40% and the mass of each grain decreased by 20% (Boonjung and Fukai, 1996). Water stress in rice plant decreases the rate of photosynthesis that affects the number of tillers, leaf area, dry matter accumulation, filled grain per panicle, 1000 grain weight and grain yield (Halder and Burrage 2004; Zumber *et al.,* 2007; Sabetfar *et. al*., 2013).

According to Sokoto and Muhammad's (2014) dry season pot experiment findings, water stress had no appreciable ($P<0.05$) impact on plant height three weeks after planting (WAP). But at 6, 9, 12, and 15 WAP, tillering caused a significant ($P<0.05$) decrease in plant height. Control (unstress) and water stress at flowering and grain filling were statistically comparable ($P<0.05$). Water stress applied during the tillering stage was the cause of the decrease in plant height. This was due to the fact that applying water stress caused low leaf water potentials and a decrease in photosynthesis. Stomatal opening is also lowered and chloroplast activity is inhibited, which results in a drop in internode length at the jointing stage, which comes after tillering stage. The jointing stage had already occurred and the plants had grown to their full height when water stress was applied during blooming and grain filling, hence the effect of the stress was useless.

Severe water stress may stop photosynthesis, disrupt metabolism, and ultimately cause plant death (Jaleel, *et al*., 2008a). It inhibits a number of physiological and biochemical activities, including photosynthesis, respiration, translocation, ion uptake, carbohydrate and nutrient metabolism, and growth stimulants, which all contribute to decreased plant growth.

Reduced leaf water potential, turgor pressure, decreased stomata activity, and decreased cell expansion and proliferation are all signs of drought stress. Almost all plants can withstand drought stress, but the degree of their tolerance varies from species to species and even within the same species. In order to secure the survival of agricultural crops and sustained food production, there are global concerns with water shortage and salt pressures (Jaleel, *et al*., 2007). Due to their time-consuming nature and dependence on current genetic variability, conventional plant breeding methods have switched to using physiological selection criteria (Zhu, 2002).

Drought stress is considered to be a loss of water, which leads to stomatal closure and limitation of gas exchange. Drought stress in rice affects the crop in different ways. According to Tao *et al*., (2006) rice is the most unproductive crop in terms of water loss. On average, about 2,500 liters of water need to be supplied (by rainfall and/or irrigation) to a rice field to produce 1 kg of rough rice. These 2,500 liters account for all the outflows of water through evapotranspiration, seepage, and percolation (Bouman and Toung, 2001).

According to Anjum *et al*., (2011), drought stress has a negative impact on plant physiological performance by reducing gas exchange, particularly stomatal conductance, photosynthetic pigments, and crop water relations in general. Regardless of variety, dryness at the vegetative, blooming, and grain-filling stages also affects chlorophyll concentration, photochemical efficiency and leaf relative water content (leaf RWC).

According to Kumar *et al*., (2014), under drought stress conditions, stem and leaf contribution to dry matter partitioning rose dramatically compared to well-watered conditions, consequently impacting grain output.

Rice reacts to water stress quite delicately (Tuong and Bouman, 2016). Plant productivity is severely hampered by water scarcity in the environment. Given that both the intensity and duration of the stress are crucial, losses from drought-induced crop output reduction may outweigh losses from all other sources (Farooq *et al*., 2008). Stress is described as "any environmental condition capable of causing a potentially harmful strain in plants" by (DOASL, 2006). Water is an important component of tissue, a chemical reaction's catalyst, a solvent and a route of transport for metabolites and minerals inside plants, and it's crucial for cell growth by raising turgor pressure. Many physiological processes involved in growth are impacted by the occurrence of water deficits, particularly in cases of severe deficits, death of plants may occur.

According to Clark *et al*., (2008), root branching is similarly hampered by drought stress. Reduced leaf size and pubescence, as well as a change in form and leaf yellowing, are all signs of a limited water supply. Additionally, during a drought, the growth of new leaves, tillers, and stems is slow. A severe drought results in dried-out leaves and eventually plant death. Additionally, a decline in biomass output occurs in conjunction with drought. All these changes to the normal state of the various tissues and organs have an adverse effect on the rate of photosynthetic activity and other biochemical processes. The stomatal closure that restricts CO2 diffusion causes a decrease in the activity of photosynthetic enzymes, which in turn causes a loss or diminishing of photosynthetic pigments like chlorophyll a and b and carotenoids due to a defect in their synthesis or post-synthesis degradation. The loss of the chloroplast membrane may also contribute to a decrease in photosynthetic rate.

According to Liu *et al*., (2006), severe drought at panicle initiation, flowering, and grain filling caused losses of up to 70%, 88 percent, and 52 percent respectively. Mild drought stress during grain filling caused yield declines of 11.6 percent to 14.7 percent. When drought stress was administered 7 days before heading and 10 days after heading, reductions of 22 percent for the number of spikelet per panicle and 15 percent for the weight of 1000 grains were noted. Additionally, they claimed that plants' physiological, morphological, and biochemical processes are impacted by a drop in water availability, and that if a drought happens during a crucial stage of plant growth, it may reduce crop production or even result in crop failure.

2.3 Effect of water deficit on rice varieties

Depending on the type, severity, and length of water stress as well as the stage of growth of the rice crop, different effects of water stress may occur. Reduced plant height, tiller number, and leaf area occur during the vegetative stage as a result of water stress. The impact at this stage, however, varies according on the crop's age and the level of stress. Long vegetative periods could aid the plant in recovering when water stress is eased, causing long duration types to suffer less yield loss than short duration varieties.

The types were treated to Water deficit stress by Pramanik and Grupta (1989) at various growth stages, particularly during the sowing stage. They discovered several interesting lines with water stress tolerance. Singh & Singh (1988) noted cultivar-specific variations in Water deficit stress.

According to Saragih *et al*., (2013), rice grain yield is significantly impacted by drought stress during the early stages of reproduction. The fluctuation in water availability at various growth stages is linked to variation in the rice yield component.

According to Haq *et al*., (2010), the germination and seedling growth phase is of utmost significance in the plant life cycle since it influences the crop's eventual output and the success of its establishment.

According to Shao *et al.*, (2008), the effects of drought stress on growth include both elongation and expansion, with cell enlargement being more inhibited than cell division. It hinders rice seedling germination and lowers the number of tillers and plant height. According to Reynolds and Tuberosa (2008), the majority of the popular high yielding rice cultivars with great yield potential and good grain quality have a low ability to adjust to drought stress, which results in significant output losses during years of drought. The three factors that were thought to influence grain yield were water uptake (WU), water usage efficiency (WUE), and harvest index (HI).

According to Centritto *et al*., (2009), a drought has numerous effects on rice physiology, including changes in net photosynthesis, transpiration rate, stomatal conductance, water use effectiveness, intercellular CO2, photosystem II (PSII) activity, relative water content, and membrane stability index. Under a drought, all these characteristics in rice decrease.

2.3.1 Morphological effect

According to Rahman *et al*., (2002), stress reduced plant height.

When water stress was applied at the tillering stage, Bahattacharjee *et al*., (1973) and De Datta *et al*., (1973) discovered significant decreases in plant height and grain output.

According to Biswas and Choudhuri (1984), the reproductive phase's sensitivity to water stress may be the cause of the decline in plant height.

According to Pirdasthi *et al*., (2003), plant height grew during the vegetative stage under aerobic conditions as opposed to flooded conditions, but during the flowering stage, it reduced under water deficiency conditions as opposed to flooded conditions. Additionally, they noticed that as the amount of drought stress increased, rice genotypes' seedling growth shrank.

According to Kamoshita *et al*., (2004), drought stress during rice cultivation's vegetative growth, blooming, and terminal periods might, respectively, prevent floret initiation (which results in spikelet sterility) and grain filling. On the other hand, it has been suggested that grain filling and the whole-plant senescence process are tightly related.

At the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, from July to December 2006, Zubaer *et al*., (2007) conducted a pot experiment with three transplanted aman rice genotypes (Basmoti, Binadhan 4, and RD 2585), putting them at three different soil water levels (100 percent, 70 percent, and 40 percent FC), to evaluate the performance of the genotypes under varying drought stress. Results showed that among all rice genotypes, the tallest plant at maturity stage was observed at 100% FC (139.2 cm), followed by 70% FC, and the shortest plant at 40% FC (117.1 cm). The findings show that plant height reduced as soil Water deficit stress increased.

According to Tuong *et al*., (2005), drought reduced plant height, tillers per plant, total biomass, and grain output.

In an experiment conducted by Mahmod *et al*., (2014) to examine the growth characteristics of various rice varieties, considerably higher values for tiller number were achieved in an aerobic ecosystem.

According to Rahman *et al*., (2002), stress led to a drop in the number of tillers.

A pot experiment was conducted by Zubaer *et al*., (2007) to assess how well the genotypes performed under various drought stress conditions. The findings demonstrated that during all growth stages (booting, blooming, and maturity), 100% FC produced the most tillers per hill while 40% FC produced the fewest tillers. Different genotypes result in varying numbers of tillers per hill. The maximum number of tillers per hill were created by

Binadhan 4; the middle and lowest numbers were produced by Basmoti and RD 2585, respectively. With a reduction in soil moisture, there were fewer tillers per hill. Lower soil moisture levels may result in decreased tiller production because plants under water stress were unable to create enough assimilates to support reduced photosynthesis. Inhibition of meristematic tissue cell division and decreased water intake could both contribute to a decrease in the number of tillers (Murty, 1987; Castilo *et al.*, 1987; Cruz *et al*., 1986; IRRI, 1974; Islam *et al*., 1994a).

The most noticeable morphological change associated with the onset of drought stress, according to Begg and Turner (1976), is a decrease in leaf area, either by a decrease in leaf size or by the shedding or death of leaves, and a decrease in evapotranspiration.

According to Sikuku *et al*., (2010), rice varieties' tiller number, panicle length, and field grain percentage decrease as a result of water deficiency, affecting the days to maturity and grain production.

Overexposure to radiation can result in midday wilting in rice plants because of the high rate of transpiration that is characteristic of rice leaves in general (Jongdee *et al*., 1998). found in FC that is 100%. With increasing soil Water deficit stress, the number rapidly reduced, and in all growth phases, 40 % FC generated the fewest leaves per hill. Water stress may prevent photosynthesis and result in fewer assimilates, which would reduce the number of leaves (Hossain, 2001).

A pot experiment's findings according to Zubaer *et al*., (2007), 100 percent FC had the most leaves during the booting (106.8), blooming (85) and maturity (58.11) stages. With increasing soil Water deficit stress, the number rapidly reduced, and in all growth phases, 40 percent FC generated the fewest leaves per hill.

Hossain (2001) stated that water stress may prevent photosynthesis and result in fewer assimilates, which would reduce the number of leaves.

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.

According to Rahman *et al*., (2002).'s research, drought stress reduced plant height, tiller number, panicle number, length, number of filled grains per panicle, 1000-grain weight, harvest index (HI), total dry matter (TDM), and yield.

According to Sikuku *et al*., (2010), panicle length was influenced by water deficit because NERICA 4 saw the greatest drop in length at the greatest water deficit when compared to control. Additionally, they noted that rice genotypes with disrupted protein synthesis systems under drought stress saw a drop in protein content. Additionally, they discovered that rice types' tiller number, panicle length, and field grain percentage all decreased under drought stress, which has an impact on the days to maturity and grain production.

2.3.2 Physiological effect

Jha and Singh (1997) investigated the reactions of eight different rice genotypes to simulated drought stress. With increased drought stress, it was seen that seedling growth declined. Additionally, they noticed that as the amount of drought stress grew, the contents of eight rice genotypes increased in starch and phenol while total sugar, reducing and nonreducing sugar dropped.

Watanabe *et al*., (2000) observed that drought stress generally accelerates senescence and reduces photosynthesis in susceptible varieties while water balance 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.

Acording to Samonte *et al*., (2001), the incidence of soil drought stress impacts various physiological processes, including photosynthesis and transpiration, which leads to slower growth and less effective grain filling.

Lafitte *et al*., (2003) noted that when rice has a drought deficit prior to flowering, a delay in the flowering date typically occurs.

In growing rice seedlings' roots and shoots, Sharma and Dubey (2005) noticed a concurrent drop in the concentration of total soluble protein and an increasing degree of water deficit.

Under drought stress, Mostajeran and Eichi (2009) noticed a drop in total, decreasing, and non-reducing sugar in rice seedlings. In comparison to the tolerant variety, the decline was substantially greater in susceptible kinds.

According to Majeed *et al*., (2011), drought stress caused a considerable decrease in the endogenous level of sugar in leaves at the soft dough stage, whereas it caused sugar levels in grains to fall in both cultivars.

In response to drought stress, Cheng and Kato (2010) discovered that rice's protein content and yield decreased, and that PEG (6000) treatment also caused protein degradation and chlorophyll loss in detached rice leaves. The endogenous level of protein contents in leaves at the soft dough stage significantly decreased as a result of drought.

In response to drought stress, Wang *et al*., (2007) investigated a dynamic accumulation of ABA in rice. Inducing a notable increase in antioxidant enzymes, as well as enhancing protein transport, carbon metabolism, and the production of resistance proteins, ABA confers drought stress tolerance. With enhanced expression of numerous drought responsive genes, exogenous ABA treatment in rice improves the recovery of the net photosynthetic rate, stomata conductance, and transpiration rate under drought.

According to Jaleel *et al*., (2008), extreme drought stress can cause the halt of photosynthesis, metabolic disturbances, and ultimately plant death. It inhibits a number of physiological and biochemical activities, including photosynthesis, respiration, translocation, ion uptake, carbohydrate and nutrient metabolism, and growth stimulants, which all contribute to decreased plant growth.

According to Tabaeizadeh (1998), typical physiological and biochemical responses to drought stress include a decrease in photosynthetic activity, an accumulation of organic acids and osmolytes, and alterations in glucose metabolism.

According to Tripathy *et al*., (2000), rice plant growth and development are slowed down by drought stress. Cell development is significantly hampered by stress because turgor pressure decreases.

According to Bota *et al*., (2004), the Calvin cycle enzyme Rubisco activity decreases under extreme drought stress conditions, which limits photosynthesis. However, as a defense mechanism, Rubisco activate production increases under drought stress. Rubisco activate protects Rubisco sites from dead end inhibition by encouraging ATP-dependent conformational modifications. Increased expression of this enzyme may lessen the harm that drought stress causes to Rubisco.

According to Hansen and Jones (2006), drought stress also increases the production of reactive oxygen species (ROS), which has detrimental effects on metabolism overall by causing denaturation of proteins, oxidation of lipids, and damage to nucleic acids.

Drought stress during panicle emergence prevents peduncle elongation, obstructing exertion of spikelet and causing sterility. Relative water content decreases and abscisic acid (ABA) content increases during drought, which also results in down-regulation of gibberellic acid (GA) biosynthesis genes. The ABA-GA antagonism is supposed to play a role in the failure of panicle exertions during drought (Muthurajan *et al.,* 2011).

Silicon minimizes the effect of drought by enhancing the basal quantum yield, maximum quantum efficiency of PSII photochemistry, photosynthetic rate and transpiration rate of rice plants subjected to drought stress. The result is an enhanced dry matter accumulation, improved root system, leaf water content and chlorophyll content, while mineral content of leaves which increases under drought is brought down to the level of well-watered plants (Chen *et al.,* 2011).

2.3.3 Yield attributing effect

When water stress was applied at the tillering stage, Bahattacharjee *et al*., (1973) and De Datta (1973) discovered significant decreases in panicles numbers as well as grain output.

According to Rahman *et al*., (2002), stress reduced panicle length, panicle quantity and yield.

According to Pantuwan *et al*., (2002), stress yields and plant water status indicators were inversely correlated with the delay in heading under stress. The delay in heading is a sign that the plant is sensitive to stress because it shows growth retardation both throughout the drying period and after recovery.

According to Plaut *et al*., (2004), drought stress during the grain filling process causes early senescence and shortens the grain filling period but increases the remobilization of assimilates from the straw to the grains (10–40% of the final grain weight are reserved in the stems and sheaths of rice).

Ji *et al*., (2012) examined the drought-responsive mechanisms at the physiological and molecular levels in two rice genotypes with differing susceptibility to drought stress at reproductive stage in order to understand rice strategies in response to drought situation in the field. In the drought susceptible rice cultivar Zhenshan97B and the drought tolerant rice cultivar IRAT109, respectively, the osmotic potential of leaves decreased after 20 days of drought treatment by 78% and 8%, respectively. In drought-stressed Zhenshan97B and IRAT109, the panicle lengths showed no discernible alterations, indicating that the assimilate transfer from panicle leaf to vegetative development is less affected by drought stress.

The effects of drought stress on final product, that is yield, and the frequency of supplemental irrigation requirement under rainfed rice depends on the soil type, cultivar (maturity period, drought resistance capacity), ET demand, and rainfall availability at the field site (Ali, 2010b, Ali *et al*., 2014). Thus, it is not appropriate to make definite recommendation regarding the number and amount of irrigation to be applied for all cultivars.

Oka and Saito (1999) discovered connections between panicle length, grains panicle-1, and panicle emergence date and parental values.

According to Sarvestani *et al*., (2008), dryness at the flowering stage reduced grain yields more than drought at other stages. The decline in fertile panicle and filled grain percentage were the main causes of the decreased grain yield. When compared to control, the mean grain yield was reduced by 21, 50, and 21% on average, respectively, throughout the vegetative, blooming, and grain filling stages. Under drought stress, the yield advantage of two semi-dwarf cultivars, Fajr and Nemat, was not sustained.

Results of a pot experiment conducted by Zubaer *et al*., (2007) revealed that, across all genotypes, the largest number of filled grains per panicle was discovered at 100% FC, followed by 70% FC, and the lowest number was recorded at 40% FC. The most filled grains per panicle were produced by Binadhan 4 with 100% FC, and the fewest by the treatment combination of RD2585 X 40% FC. Additionally, the findings demonstrated that when soil moisture levels were lower, the quantity of filled grains per panicle reduced. According to Hossain (2001; O'Toole and Moya, 1981), Water deficit stress inhibited the assimilate ability to move from the soil to the grains, which resulted in fewer filled grains per panicle under reduced soil moisture levels.

An investigation on the variability and connection of several morphological and biometric plant characteristics with grain yield was carried out by Shrirame and Mulley (2003). Number of filled grain panicles and grain yield were significantly associated.

Rahman *et al*., (2002) reported that number of filled grains per panicle and yield were decreased with stress.

The findings of a pot experiment conducted by Zubaer *et al*., (2007) demonstrated that lower soil moisture levels increased the number of unfilled grains in all rice varieties. However, the magnitude of the increase varied between genotypes. Under conditions of water stress, Binadhan 4 produced substantially more unfilled grain (33.13 percent for 70% FC and 77.21 percent for 40% FC) than Basmoti and RD 2585. Inactive pollen grains for dryness, incomplete pollen tube formation, and insufficient assimilates generation and distribution to grains could all contribute to more empty grains per panicle under conditions of low soil moisture (Hossain, 2001; Yambao and Ingram, 1988; Begum, 1990; Islam *et al*., 1994a).

Mahmod *et al*., (2014) carried out an experiment to investigate the growth performances of different rice varieties. Significantly higher values were obtained for grain weight density in aerobic ecosystem.

Grain yield, according to Hassan *et al*., (2003), depends on the interaction of several yield factors, including the number of productive tillers plants, the number of spikelet panicles, and the weight per 1000 grains.

Guan *et al*., (2010) found that stress during the vegetative stage has a greater impact on biomass output (plant height and number of tillers per plant), whereas stress during the reproductive stage has a far greater impact on sink size (spikelet fertility, 1000-grain weight, and seed yield).

Summers *et al*., (2003) conducted trials with eight popular California rice cultivars over a number of locations for the 1999 and 2000 seasons, and they discovered straw quantity and quality variability that could have a significant impact on the biomass industry. The most accurate predictor of straw yield was the length of the pre-heading phase. Cutting height has a significant impact on harvested straw output as well. Due to a non-linear distribution, approximately half of the straw biomass is found in the lower third of the plant.

Jiang *et al*., (1995) assessed the yield components of 10 cultivars. Higher harvest index contributed significantly to the yield increase of dwarf varieties over tall types, whereas higher biomass production contributed significantly to the yield increase of hybrid rice over the dwarf kinds.

Rahman *et al*., (2002) reported that harvest index (HI) and yield were decreased with stress.

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.

The harvest index of all rice genotypes decreased with lower moisture level, according to the findings of a pot experiment by Zubaer *et al*., (2007). It could be because the translocation toward the grain was impacted by water stress, which was also shown owing to variety. The HI value at lower moisture levels varied between genotypes. In comparison to Basmoti (13.15 to 36.84%) and RD2585 (12.5 to 28.12%), it was higher in (11.11 to 20.0 percent).

According to Singh (2006), inconsistent rainfall and drought stress during the flowering stage are the main causes of the low production (0.8 to 1.2 t/ha) in rain-fed uplands.

CHAPTER III

MATERIALS AND METHODS

The pot experiment carried during November 2019 to May 2020 was consisted of collection of seed, raising of seedlings, growing and experimentation, data collection, compilation, etc. to study the impact of water deficit on morphology and yield attributes of hybrid and inbred rice varieties. This chapter deals with the brief study of soil, climate, materials and methods used for conducting the experiment have been presented below.

3.1 Experimental site

The experiment was conducted in the Research Farm of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh. The location of the pot experiment at $24^0$75' N latitude and $90^0$50' E longitude at the elevation of above 18m of sea level and it was under the Agro-Ecological Zone-28, namely Madhupur Tract. For better understanding the experimental location, the Map of AEZ of Bangladesh has been added in Appendix I.

3.2 Soil characteristics used in pot

The soils used in pot were collected from the experimental field of Department of Agricultural Botany, SAU, Dhaka. The pot experiment was conducted by using typical rice growing silty loam soil having noncalcareous properties. The soil was Deep Red Brown Terrace Soil under Tejgaon Series belonging to the Agro-Ecological Zone of Madhupur Tract. The soil for the pot was collected from 0-15 cm depth. The collected soil was pulverized followed by the removal of weeds, stubble, brick pieces, insects, etc. The soil was then sun dried, crushed, and passed through a 2mm sieve. After that the soils were mixed up properly and 400 g soil was taken for initial physical and chemical analysis. The morphological properties of this soil have presented in Appendix II and the physio-chemical properties in Appendix III.

3.3 Climate

The study site was characterized by a subtropical monsoon climatic zone. Moderately low temperature along with moderate rainfall prevailed during November to January with the mean temperature 22.67^{0}C. Temperature during February to April was moderately hot but highly humid along with moderate to high rainfall in Appendix IV.

3.4 Planting materials

In this research work, four samples of hybrid rice varieties were used as planting materials. The rice varieties were used in the experiment were BRRI dhan92, Heera 4, Aloron and BRRI hybrid dhan5. The seeds were collected from Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur.

3.5 Treatments

The pot experiment consisted of two factors viz, variety and water deficit in different growth stages given below:

Factor A: Variety

V1= BRRI dhan92

V2= Heera 4

V3= Aloron

V4= BRRI hybrid dhan5

Factor B: Water deficit

T1= control

T2= Water deficit at 45-55 days after transplanting (tillering)

T3= Water deficit at 85-95 days after transplanting (flowering)

Water deficit was applied for a period of 10 days. First day of imposing Water deficit was shifted depending on the tillering and days to flowering of the crop.

3.6 Experimental design and layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) as two factorial arrangements with three replications. The experimental pots were divided into three equal blocks. Each contain 12 pots where 12 treatment combinations were allotted randomly. There was total 36 (12x3) pots in the experiment. The layout of the experiment has been shown in Appendix V.

3.7 Pot preparation

Plastic pots were used in this experiment. The size of the pot was 28cm x 25cm x 35cm. The collected soil was sun dried, crushed and passed through a sieve to remove weeds, stubble, brick pieces, insects, etc. Each pot was filled up with 4:1 mixture of dry soil and farm yard manure. Each pot was filled up with 12 kg soil on 21 December, 2019 and all experimental pots received recommended doses of N, P, and K fertilizers. After that the pots were pre-labeled for each treatment combination and placed at the research field of the Department of Agricultural Botany.

3.8 Manure and fertilizer application

The pots were fertilized with cow dung 40g/pot, Urea 1.72g/pot, TSP 1.44g/pot, MP 0.8g/pot corresponding to 15 ton/ha cow-dung, 215 kg Urea/ha, 180kg TSP/ha and 100kg MP/ha. All TSP, MP and 1/3 of the total Urea were applied as basal dose. The remaining 2/3 of the Urea was applied in two equal splits in each pot at 30 and 50 days after transplanting (DAT).

3.9 Seedbed preparation

Wet seedbed was prepared by December 19, 2019 and sprouted seeds were sown on December 20, 2019.

3.10 Seedling raising

A very common procedure was followed in raising of seedlings i.e., the seeds were soaked for 48 hours and then washed properly in fresh water and after that incubated for sprouting. The sprouted seeds were sown in the wet seedbed on December 20, 2019.

3.11 Uprooting and transplanting

One uniform and healthy seedlings of thirty days old were uprooted carefully from the seedbed and were transplanted in each pot on January 30, 2020. Seedlings in some hills, if die off, then these will be replaced by new one within one week of transplanting with seedlings from the respective source. The seedbed was watered before uprooting the seedlings from the seedbed to minimize the root damage.

3.12 Intercultural operations

After transplanting of seedlings, different intercultural operations like weeding, irrigation, plant protection measures etc. were accomplished for better growth and development of the seedlings.

3.12.1 Weeding and irrigation

The hand weeding was done as when necessary to keep the experimental pots free from small weeds. During soil Water deficit stress period, plants were protected from rain water with the help of polythene shade over the treatment sets. Pots were divided into three sets. The first set was normally irrigated (control), second and third was subjected to water deficit stress at 45-55 days after transplanting (tillering) and at 85-95 days after transplanting (flowering), respectively. Water deficit stress was withholding water supply for a period of 10 days.

3.12.2 Plant protection measures

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 @ 10ml/10-liter 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.

3.13 Harvesting

The crops were harvested at maturity when 80-90% were turned into straw colored on May 2020. The crop was cut at the ground level and pot wise crop was bundled separately, tagged and brought to the threshing floor. The grains were then sun dried to a moisture content of 12% and straw was also sun dried properly. The grain and straw yields and different plant physiological parameters were recorded after harvesting.

3.14 Data collection

The data on the following parameters were collected from each treatment.

3.14.1 Plant height

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

3.14.2 Tillers hill^{-1}

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

3.14.3 Number of leaves hill^{-1}

The number of leaves hill^{-1} was recorded at grain filling stage by counting total leaves as the average of same 10 hills pre-selected plant at random from the inner rows of each pot.

3.14.4 Leaf area index

Leaf area index (LAI) was estimated manually at the time of grain filling stage. Data were collected as the average of 10 plants selected from middle of each pot.

LAI = Leaf area/ ground area

3.14.5 SPAD Value

Leaf greenness was measured by using a hand-held SPAD meter (SPAD 502, Konica Minolta, Japan) at grain filling stage. At each evaluation the greenness was measured three times from randomly selected leaves at different positions plant^{-1} and the average was used for analysis.

3.14.6 Filled grains panicle^{-1}

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

3.14.7 Unfilled grains panicle^{-1}

The unfilled grains panicle^{-1} were counted from each pot during harvest. Lack of any food materials inside the spikelet were denoted as unfilled grains.

3.14.8 Weight of 1000 grain

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

3.14.9 Grain yield

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

3.14.10 Straw yield

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

3.14.11 Biological yield

Grain yield and straw yield were all together regarded as biological yield. Biological yield was calculated with the following formula: Biological yield (t/ha) = Grain yield (t/ha) + Straw yield (t/ha)

3.14.12 Harvest Index (HI)

It is the ratio of economic yield to biological yield. Harvest index (HI) was computed as HI (%) = (Grain yield/ Biological yield) x 100

3.15 Relative performance

The relative performance was calculated as Asana and Williams (1965) by the following formula-

Relative performance =Variable measured under stress condition /Variable measured under normal condition

3.16 Statistical Analysis

The recorded data of different parameters were statistically analyzed to get the level of significance using the MSTAT-C computer package program. Analysis of variance was calculated following two factors randomized complete block design. The mean differences among the treatment were compared by Least Significant Different (LSD) at 5% levels of significance.

CHAPTER IV

RESULTS AND DISCUSSION

A study was undertaken to evaluate the impact of water deficit on morphology and yield attributes of hybrid and inbred rice varieties. The results of the study have been presented with possible interpretations under the following headings:

4.1 Plant height

Effect of water deficit stress

Different levels of water deficit showed significant difference on the plant height of rice varieties at 30, 60, 90 DAT and at harvest (Figure 1). The result revealed that at 30, 60, 90 DAT and at harvest, the tallest plant (30.57 cm, 50.34 cm, 70.04 cm and 91.81 cm, respectively) were recorded from the treatment T_1 and the shortest plant (29.53 cm, 42.09 cm, 61.90 cm and 78.94 cm, respectively) were recorded from the treatment T_3. Halder *et al.*, (2018) reported that drought stress at vegetative and reproductive phase decreased plant height.

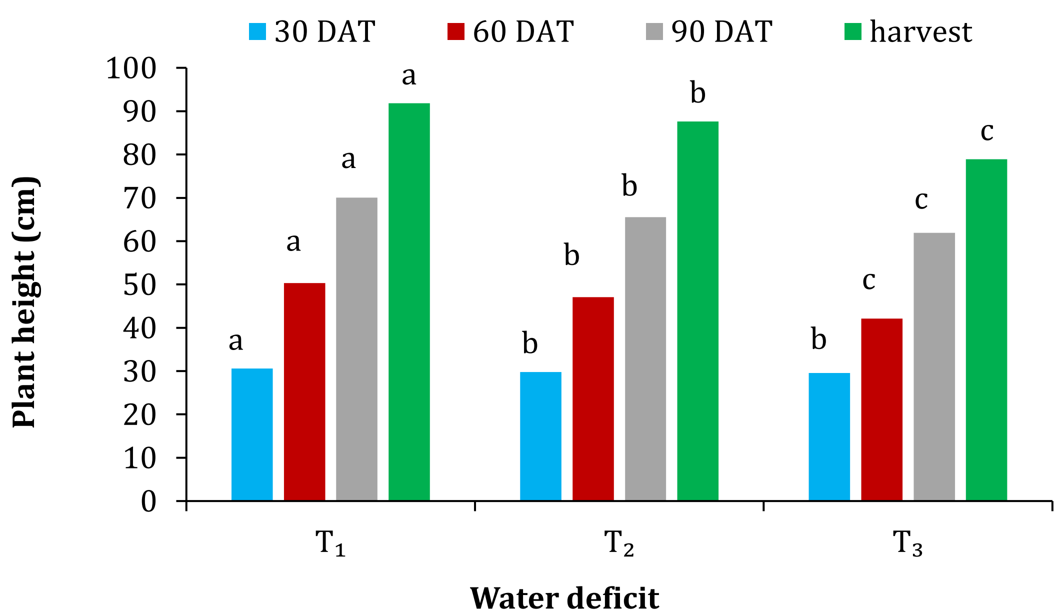

Figure 1. Effect of water deficit on plant height of hybrid and inbred rice

(LSD value = 0.77, 2.23, 3.13 and 3.63 at 30, 60, 90 DAT and at harvest, respectively T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The plant height (cm) of rice was significantly influenced by varieties at 30, 60, 90 DAT and at harvest (Figure 2). The results revealed that at 30, 60 and 90 DAT, V_2 produced the tallest plant (30.66 cm, 47.16 cm and 66.42 cm, respectively) while at harvest V_3 showed the tallest plant (91.60 cm). On the other hand, at 30, 60, 90 DAT and at harvest, V_1 produced the shortest plant (28.75 cm, 45.71 cm, 65.12 cm and 82.99 cm, respectively). Murshida *et al.*, (2017) observed that, the variation in plant height among the different varieties might be due to genetic makeup of different varieties.

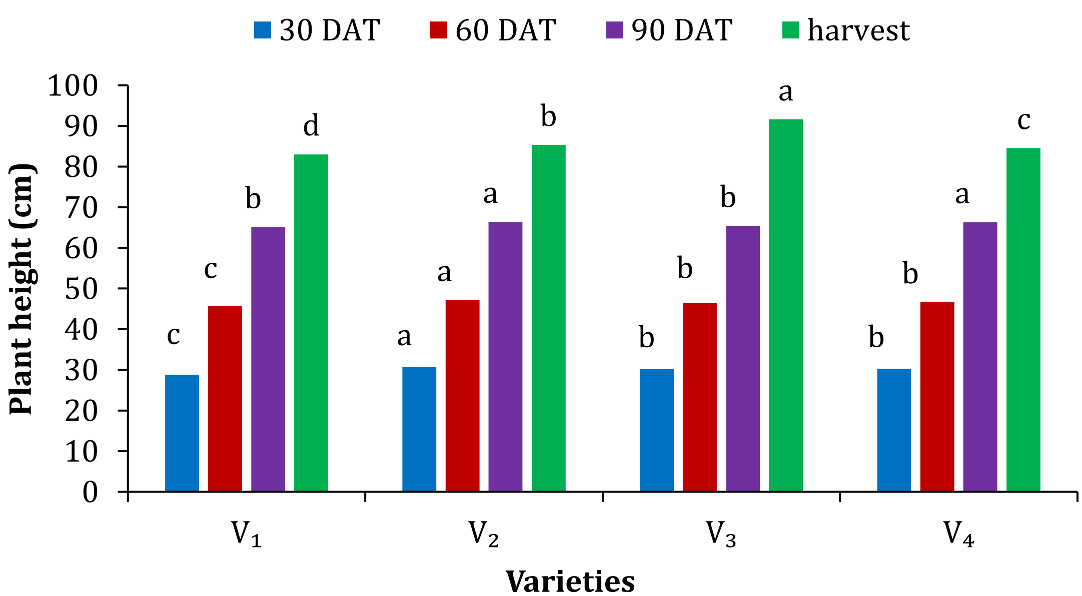

Figure 2. Effect of varieties on plant height of hybrid and inbred rice

(LSD value = 0.40, 0.53, 0.81 and 0.79 at 30, 60, 90 DAT and at harvest, respectively)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on plant height at 30, 60, 90 DAT and at harvest (Table 1). At 30 DAT, the tallest plant (31.75 cm) was observed from the T_1V_2 treatment and the shortest plant (27.95 cm) was observed from T_3V_1 treatment. At 60 DAT, the maximum height of rice plant (50.71 cm) was observed from the T_1V_2 whereas; the minimum height of rice plant (41.07 cm) was observed from the treatment T_3V_1. At 90 DAT, the tallest plant (70.71 cm) was observed from the T_1V_2 treatment and the shortest plant (61.33 cm) was observed from T_3V_1 treatment which was statistically similar with T_3V_3 (61.63 cm). At harvest, the maximum height of rice plant (97.11 cm) was observed from the T_1V_3 whereas; the minimum height of rice plant (75.75 cm) was observed from the treatment T_3V_1. It is cleared that plant height reduced in water deficit condition. This statement was also supported by Chowdhury *et al*., (2004) stated that plant height decreased with the decrease in soil moisture levels and elucidated inhibition of cell division and cell enlargement due to water stress as the possible reason.

Table 1. Interaction effect of water deficit and different varieties on plant height of hybrid and inbred rice

Treatments	**Plant height at**			
	30 DAT	**60 DAT**	**90 DAT**	**harvest**
T_1V_1	29.33 d	50.33 b	70.11 b	89.91 d
T_1V_2	31.75 a	50.71 a	70.71 a	90.33 c
T_1V_3	30.53 b	50.31 b	69.11 c	97.11 a
T_1V_4	30.66 b	49.99 c	70.23 b	89.87 d
T_2V_1	28.97 e	45.19 f	63.63 f	83.31 h
T_2V_2	30.11 c	48.03 d	66.33 d	87.23 e
T_2V_3	30.06 c	48.11 d	65.77 e	93.71 b
T_2V_4	30.01 c	46.93 e	66.39 d	86.23 f
T_3V_1	27.95 f	41.07 j	61.33 h	75.75 k
T_3V_2	30.13 c	43.45 g	62.23 g	78.47 i
T_3V_3	29.98 c	41.61 i	61.63 h	83.97 g
T_3V_4	30.07 c	42.21 h	62.39 g	77.55 j
LSD (0.05)	**0.58**	**0.39**	**0.47**	**0.31**
CV (%)	**6.01**	**3.90**	**2.80**	**2.10**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.
T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85-95 days after transplanting (flowering)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

4.2 Number of tillers hill^{-1}

Effect of water deficit

Different levels of water deficit showed significant difference on the number of tillers hill^{-1} of rice varieties at 30, 60, 90 DAT and at harvest (Figure 3). The result revealed that at 30, 60, 90 DAT and at harvest, the maximum number of tillers hill^{-1} (6.69, 11.08, 13.61 and 14.08, respectively) were recorded from the treatment T_1 and the minimum number of tillers hill^{-1} (5.78, 6.66, 8.84 and 9.58, respectively) were recorded from the treatment T_3. These results are in conformity with IRRI, 1976; Lee *et al.*, (1994) who reported that water stress at the tillering stage reduces plant height, tiller number and leaf area. As a result water deficit induces leaf rolling, drying and premature leaf death.

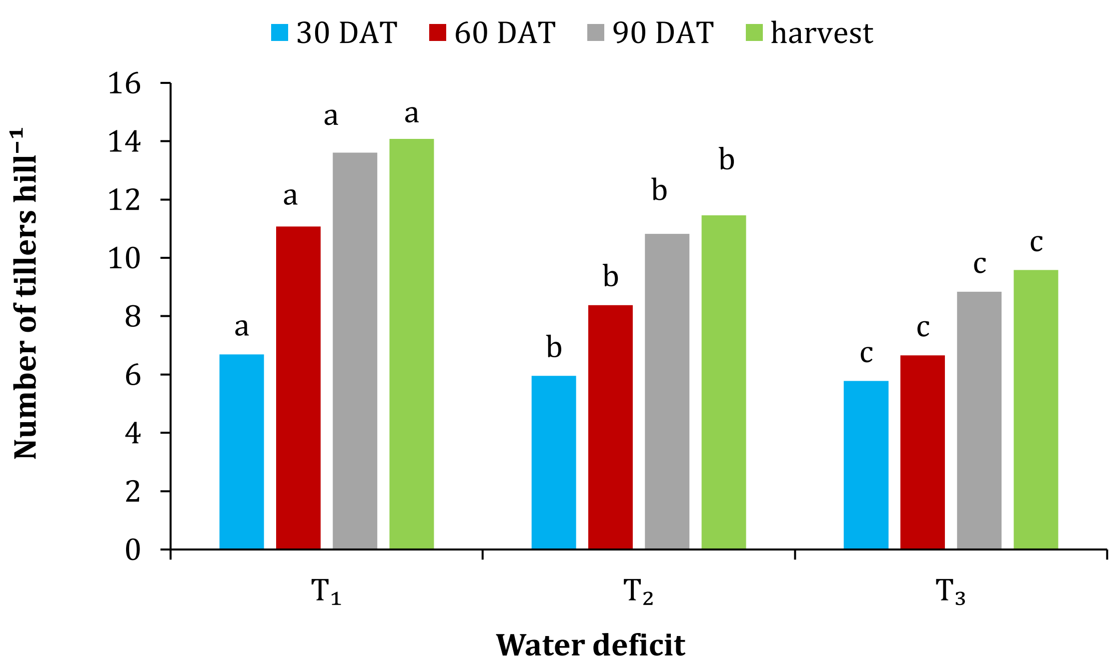

Figure 3. Effect of water deficit on number of tillers hill^{-1} of hybrid and inbred rice

(LSD value = 0.31, 0.80, 1.01 and 0.71 at 30, 60, 90 DAT and at harvest, respectively) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The number of tillers hill^{-1} of rice was significantly influenced by varieties at 30, 60, 90 DAT and at harvest (Figure 4). The results revealed that at 30, 60 and 90 DAT, V_2 produced the highest number of tillers hill^{-1} (6.58, 9.47, 11.80 and 12.94, respectively). On the other hand, at 30 DAT, V_4 produced the lowest number of tillers hill^{-1} (5.92). At 60, 90 DAT and at harvest, V_3 produced the lowest number of tillers hill^{-1} (8.05, 10.62 and 10.12, respectively). In accordance Fatima *et al.*, (2018) under the water deficit as well as in control condition showed wide range of variation in different rice genotypes.

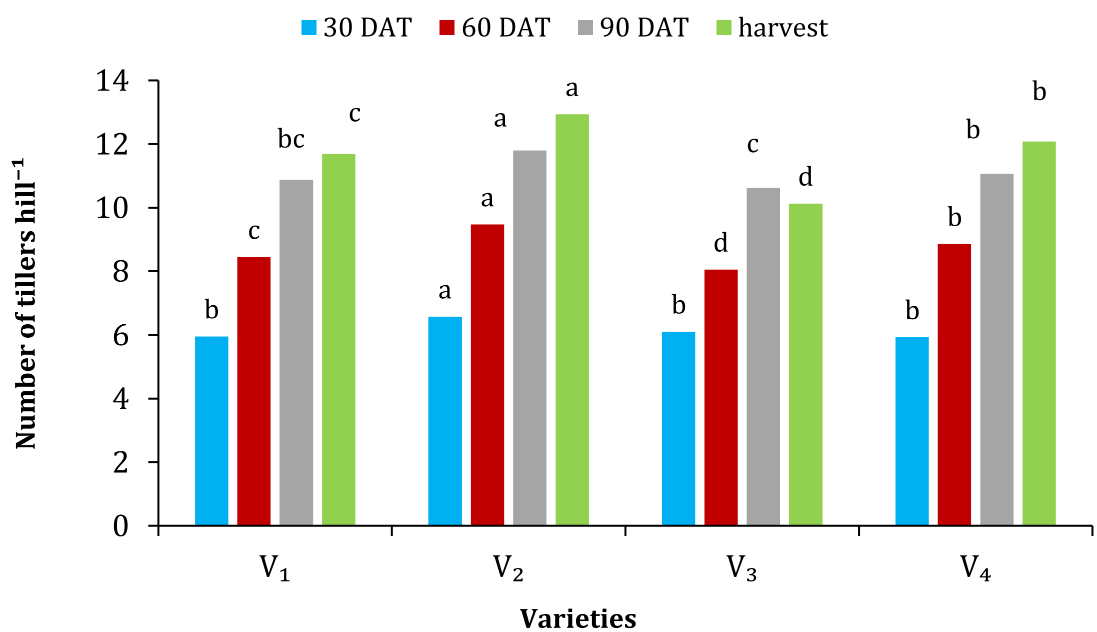

Figure 4. Effect of varieties on number of tillers hill^{-1} of hybrid and inbred rice

(LSD value = 0.47, 0.51, 0.73 and 0.31 at 30, 60, 90 DAT and at harvest, respectively) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on number of tillers hill^{-1} at 30, 60, 90 DAT and at harvest (Table 2). At 30 DAT, the maximum (7.37) number of tillers hill^{-1} was observed from the T_1V_2 treatment and the minimum (5.13) number of tillers hill^{-1} was observed from T_3V_4 treatment. At 60 DAT, the maximum (11.95) number of tillers hill^{-1} was observed from the T_1V_2 whereas; the minimum (6.13) number of tillers hill^{-1} was observed from the treatment T_3V_3 which was statistically similar with T_3V_1 (6.23). At 90 DAT, the maximum (14.63) number of tillers hill^{-1} was observed from the T_1V_2 treatment and the minimum (8.23) number of tillers hill^{-1} was observed from T_3V_3 treatment. At harvest, the maximum (16.33) number of tillers hill^{-1} was observed from the T_1V_3 whereas; the minimum (9.11) number of tillers hill^{-1} was observed from the treatment T_3V_1 which was statistically similar with T_3V_3 (9.33). when water deficit occurs during the vegetative phase, total dry matter production is decreased at harvest due to slow growth and the production of a smaller number of tillers.

Table 2. Interaction effect of water deficit and different varieties on Number of tillers hill^{-1} of hybrid and inbred rice

Treatments	**Number of tillers hill^{-1} at**			
	30 DAT	**60 DAT**	**90 DAT**	**harvest**
T_1V_1	6.23 cd	11.13 b	13.13 b	14.23 c
T_1V_2	7.37 a	11.95 a	14.63 a	16.33 a
T_1V_3	6.53 bc	10.11 c	13.33 b	10.81 f
T_1V_4	6.63 b	11.11 b	13.33 b	14.95 b
T_2V_1	5.59 f	7.98 e	10.91 c	11.71 e
T_2V_2	6.13 d	9.51 d	11.13 c	12.36 d
T_2V_3	6.07 d	7.91 e	10.31 d	10.23 g
T_2V_4	6.01 de	8.13 e	10.95 c	11.55 e
T_3V_1	6.03 d	6.23 h	8.57 g	9.11 i
T_3V_2	6.23 cd	6.95 g	9.63 e	10.13 g
T_3V_3	5.71 ef	6.13 h	8.23 h	9.33 i
T_3V_4	5.13 g	7.33 f	8.91 f	9.75 h
LSD (0.05)	**0.31**	**0.80**	**1.01**	**0.71**
CV (%)	**2.97**	**2.10**	**1.65**	**1.56**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.
T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dha

4.3 Number of leaves hill^{-1}

Effect of water deficit

Different levels of water deficit showed significant difference on the number of leaves hill^{-1} of rice varieties at harvest (Figure 5). The result revealed that at harvest, the maximum number of leaves hill^{-1} (78.73) was recorded from the treatment T_1 and the minimum number of leaves hill^{-1} (42.84) was recorded from the treatment T_3. 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.

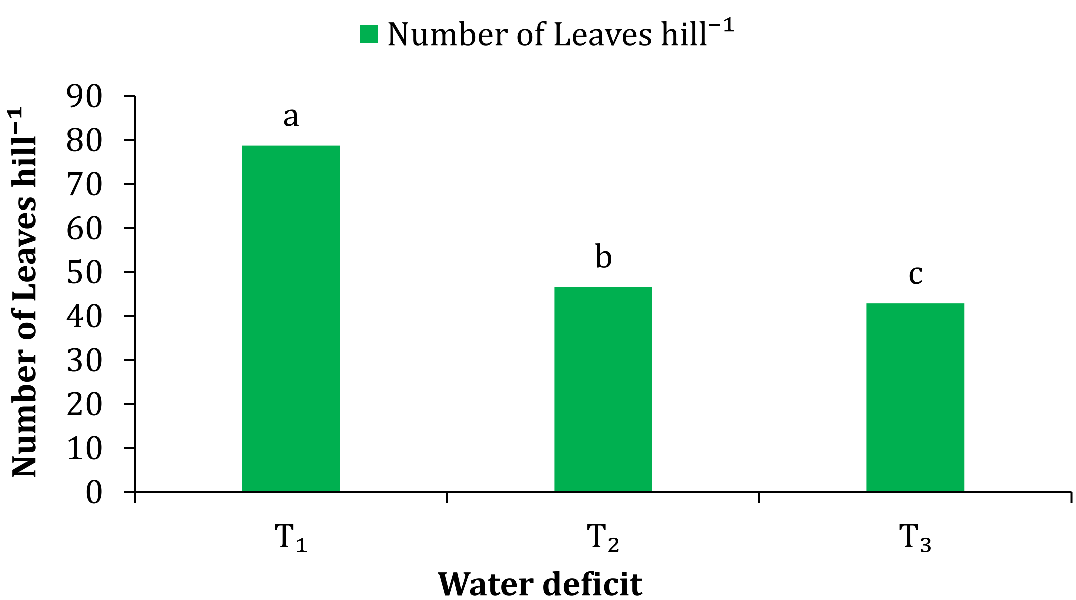

Figure 5. Effect of water deficit on number of leaves hill^{-1} of hybrid and inbred rice (LSD value = 1.11) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The number of leaves hill^{-1} of rice plant was significantly influenced by different varieties at harvest (Figure 6). The results revealed that at harvest, the highest number of leaves hill^{-1} (61.77) was recorded from V_2 whereas; the lowest number of leaves hill^{-1} (50.03) was recorded from V_3. Thus, leaf characters comprising of a number of leaves, leaf area, leaf angle and plasticity in leaf rolling and unrolling can be used as selection criteria in selecting drought-resistant rice varieties.

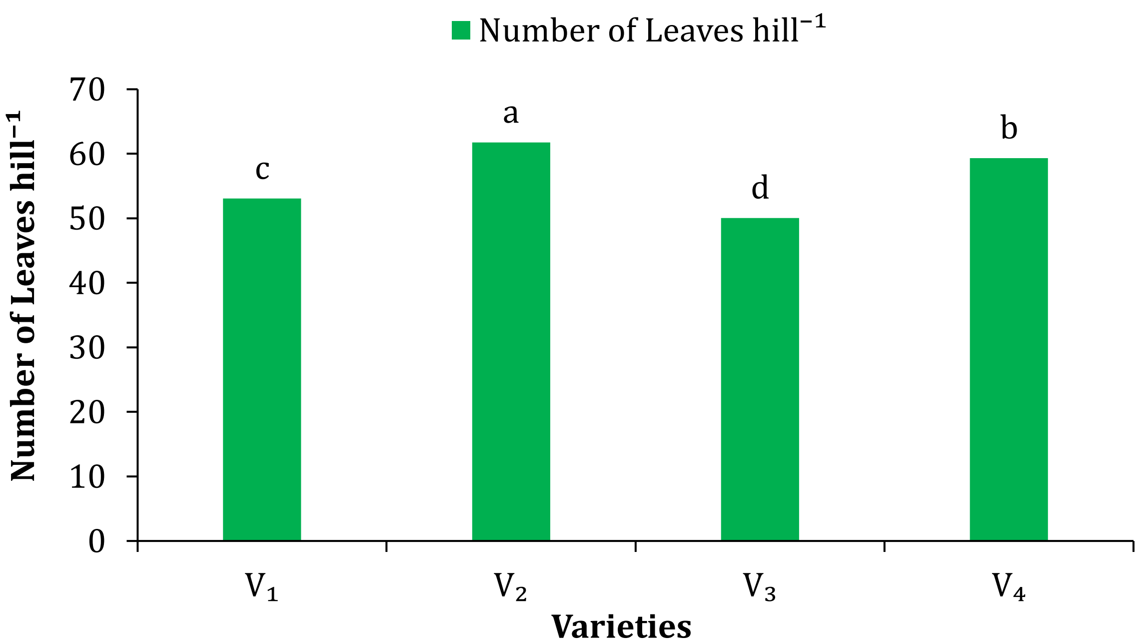

Figure 6. Effect of varieties on number of leaves hill^{-1}of hybrid and inbred rice (LSD value = 1.01) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on number of leaves hill^{-1} at harvest (Table 3). The result showed that the highest number of leaves hill^{-1} at harvest (88.75) was observed from the T_1V_2 treatment combination and the lowest number of leaves hill^{-1} at harvest (39.13) was observed from T_3V_3 treatment combination.

Table 3. Interaction effect of water deficit and different varieties on leaf characteristics of hybrid and inbred rice

Treatments	Number of Leaves hill^{-1}	Leaf area index	SPAD value
T_1V_1	71.55 c	4.47 ab	44.23 d
T_1V_2	88.75 a	4.69 a	48.63 a
T_1V_3	68.73 d	4.13 cd	45.23 c
T_1V_4	85.89 b	4.67 a	46.71 b
T_2V_1	45.51 g	3.91 de	38.67 f
T_2V_2	51.33 e	4.23 bc	37.63 g
T_2V_3	42.23 i	3.33 f	39.71 e
T_2V_4	47.23 f	3.93 cde	39.53 e
T_3V_1	42.13 i	3.45 f	32.93 j
T_3V_2	45.23 g	3.63 ef	31.13 k
T_3V_3	39.13 j	3.01 g	35.13 h
T_3V_4	44.88 h	3.45 f	33.45 i
LSD (0.05)	**1.11**	**0.41**	**1.61**
CV (%)	**3.30**	**4.67**	**4.60**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.
T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

4.4 Leaf area index
Effect of water deficit

Different levels of water deficit showed significant difference on the leaf area index of rice varieties at harvest (Figure 7). The result revealed that at harvest, the maximum value of leaf area index (4.49) was recorded from the treatment T_1 and the minimum value of leaf area index (3.39) was reported from the treatment T_3. Water deficit at the tillering stage reduces plant height, tiller number and leaf area index. It induces leaf rolling, drying and premature leaf death and prolongs the vegetative stage.

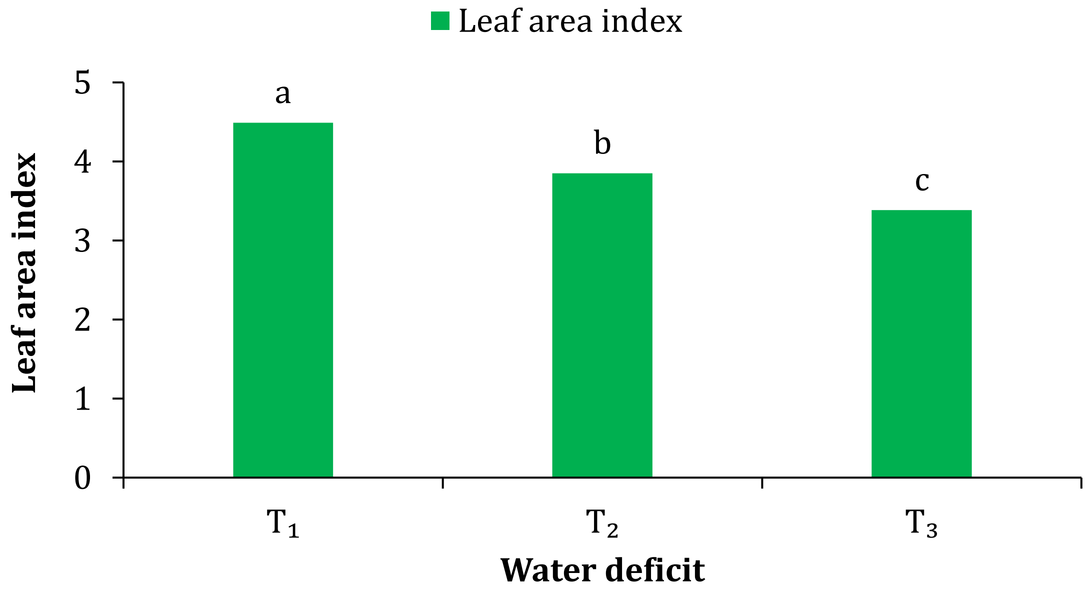

Figure 7. Effect of water deficit on leaf area index of hybrid and inbred rice

(LSD value = 0.41) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The leaf area index value of rice plant was significantly influenced by different varieties at harvest (Figure 8). The results revealed that at harvest, the highest value leaf area index (4.18) was recorded from V_2 whereas; the lowest value of leaf area index (3.49) was recorded from V_3.

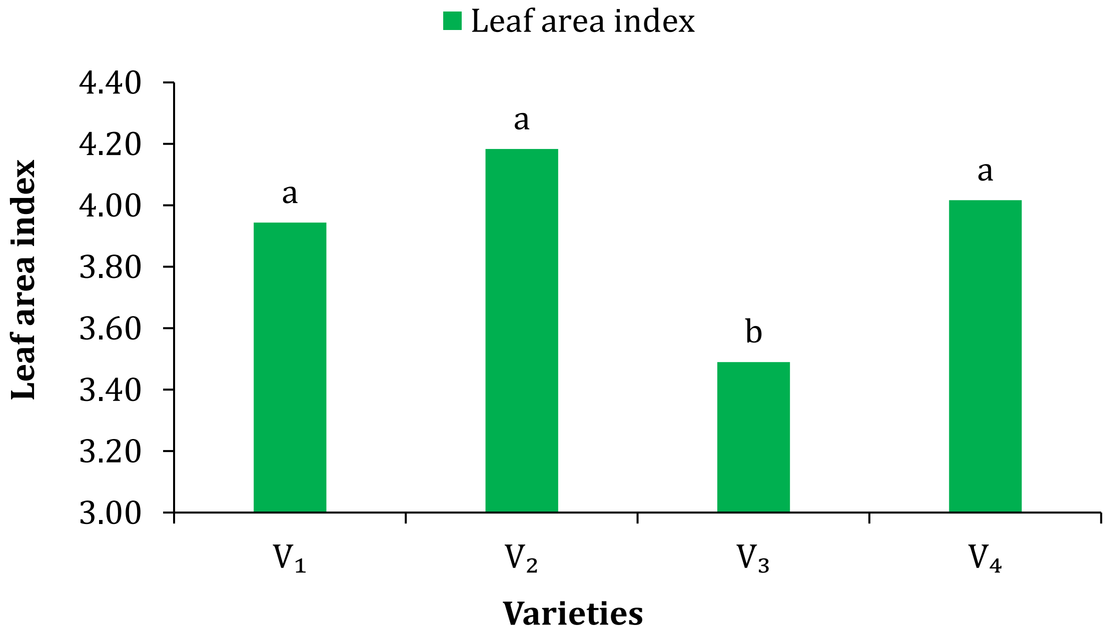

Figure 8. Effect of varieties on leaf area index of hybrid and inbred rice

(LSD value = 0.31) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on leaf area index at harvest (Table 3). The result showed that the highest value of leaf area index at harvest (4.69) was observed from the T_1V_2 treatment combination which was statistically similar with T_1V_4 (4.67) treatment combination. On the other hand, the lowest value of leaf area index at harvest (3.01) was observed from T_3V_3 treatment combination.

4.5 SPAD value

Effect of water deficit

Different levels of water deficit showed significant difference on the SPAD value content of rice varieties at harvest (Figure 9). The result revealed that at harvest, the maximum value of SPAD value (46.20) was recorded from the treatment T_1 and the minimum value of SPAD value (33.16) was reported from the treatment T_3.

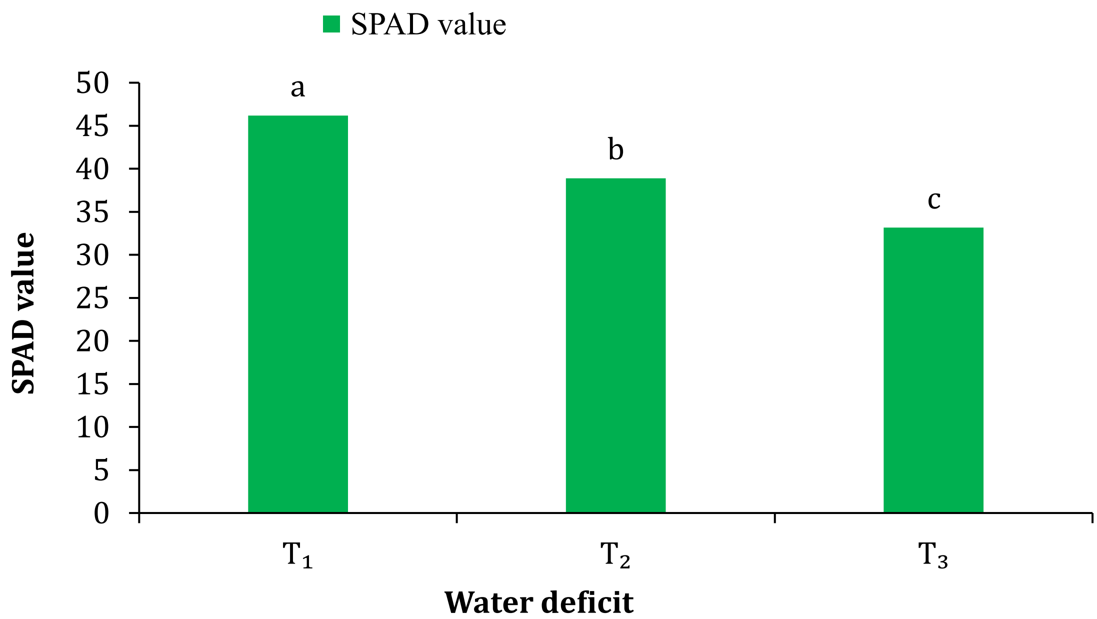

Figure 9. Effect of water deficit on SPAD value of hybrid and inbred rice

(LSD value = 1.61) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The SPAD value of rice plant was significantly influenced by different varieties at harvest (Figure 10). The results revealed that at harvest, the highest SPAD value (40.02) was recorded from V_3 whereas; the lowest SPAD value (38.61) was observed from V_1.

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on SPAD value at harvest (Table 3). The result showed that the highest SPAD value at harvest (48.63) was observed from the T_1V_2 treatment combination. On the other hand, the lowest SPAD value at harvest (31.13) was observed from T_3V_2 treatment combination. SPAD value describes the greenness of leaf. Under water deficit condition SPAD value is reduced due to sufficient water supply as a result plant cannot produce sufficient food themselves with the help of photosynthesis and ultimately give lower yield.

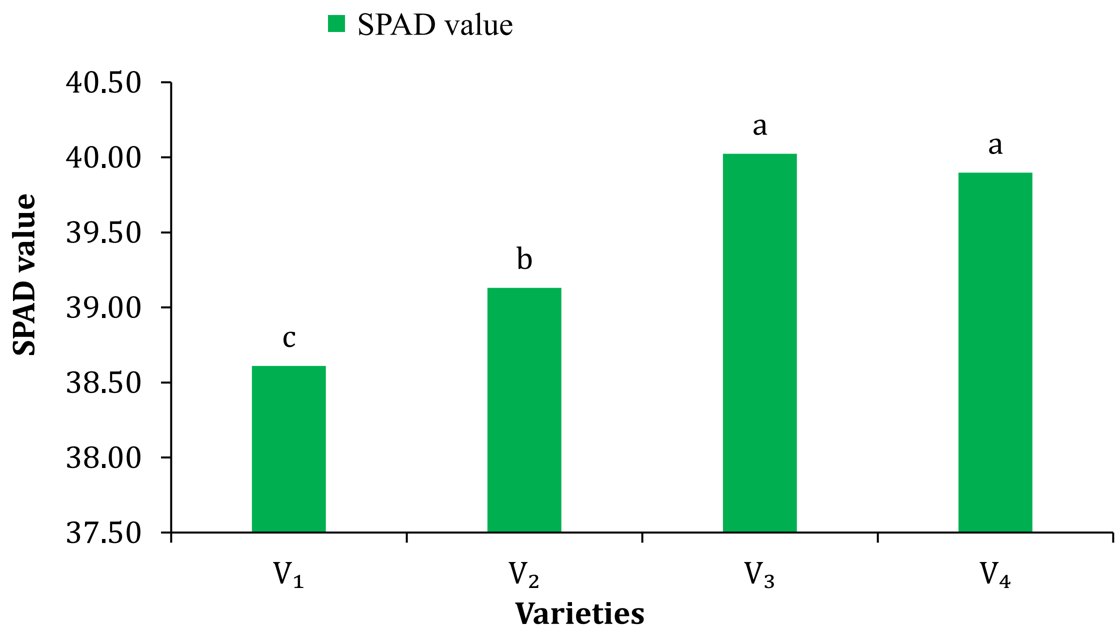

Figure 10. Effect of varieties on SPAD value of hybrid and inbred rice

(LSD value = 0.61) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

4.6 Filled grains panicle^{-1}

Effect of water deficit

Different levels of water deficit showed significant difference on the number of filled grains panicle^{-1} of rice varieties at harvest (Figure 11). The result revealed that at harvest, the maximum number of filled grains panicle^{-1} (167.08) was recorded from the treatment T_1 and the minimum number of filled grains panicle^{-1} (135.96) was recorded from the treatment T_3. In rice plants, water stress reduces the rate of photosynthesis, which has an impact on the number of tillers, leaf area, accumulation of dry matter, filled grain per panicle, 1000 grain weight, and grain yield (Sabetfar *et.al*., 2013).

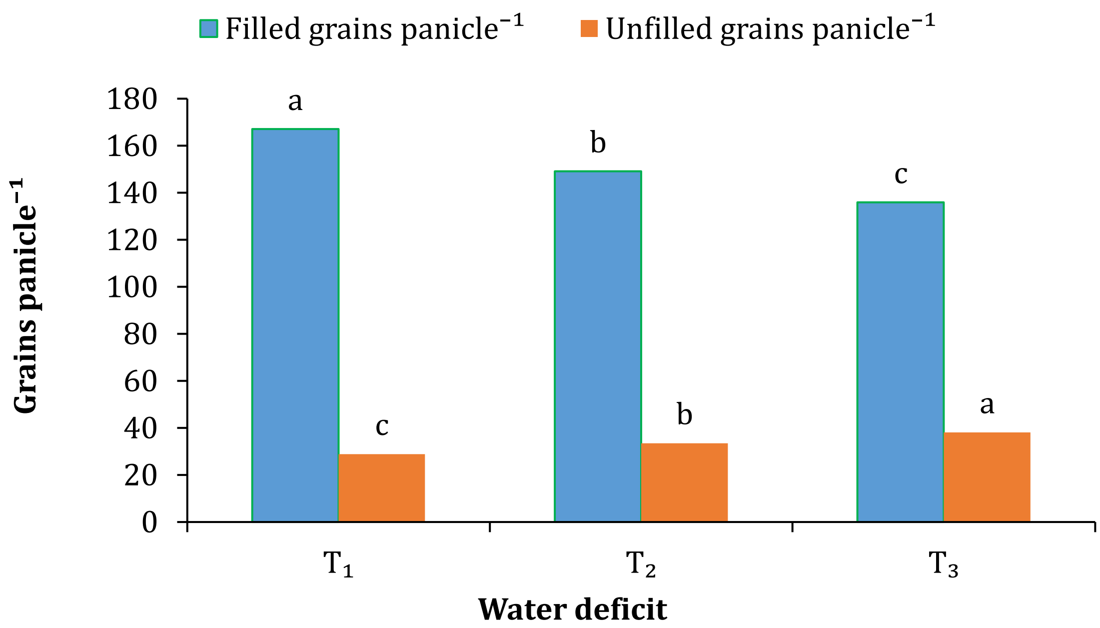

Figure 11. Effect of water deficit on number of filled and unfilled grains panicle^{-1} of hybrid and inbred rice

(LSD value = 1.31 and 0.57, respectively) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The number of filled grains panicle^{-1} of rice plant was significantly influenced by different varieties at harvest (Figure 12). The results revealed that at harvest, the highest number of filled grains panicle^{-1} (157.56) was recorded from V_3 whereas; the lowest number of filled grains panicle^{-1} (140.47) was recorded from V_2.

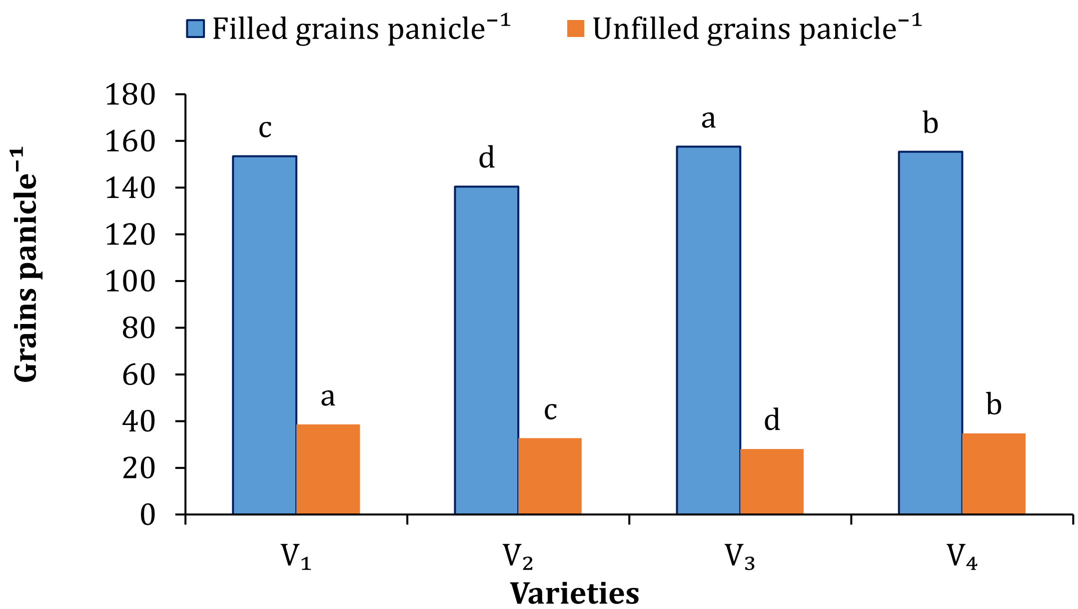

Figure 12. Effect of varieties on number of filled and unfilled grains panicle^{-1} of hybrid and inbred rice

(LSD value = 2.01 and 0.56, respectively) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on number of filled grains panicle^{-1} at harvest (Table 4). The result showed that the highest number of filled grains panicle^{-1} at harvest (173.33) was observed from the T_1V_2 treatment combination and the lowest number of filled grains panicle^{-1} at harvest (115.13) was observed from T_3V_3 treatment combination.

4.7 Unfilled grains panicle^{-1}
Effect of water deficit

Different levels of water deficit showed significant difference on the number of unfilled grains panicle^{-1} of rice varieties at harvest (Figure 11). The result revealed that at harvest, the maximum number of unfilled grains panicle^{-1} (38.15) was recorded from the treatment T_3 and the minimum number of unfilled grains panicle^{-1} (28.90) was recorded from the treatment T_1.

Effect of variety

The number of unfilled grains panicle^{-1} of rice plant was significantly influenced by different varieties at harvest (Figure 12). The results revealed that at harvest, the highest number of unfilled grains panicle^{-1} (38.54) was recorded from V_1 whereas; the lowest number of unfilled grains panicle^{-1} (28.08) was recorded from V_3.

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on number of unfilled grains panicle^{-1} at harvest (Table 4). The result showed that the highest number of unfilled grains panicle^{-1} at harvest (42.23) was observed from the T_3V_1 treatment combination and the lowest number of unfilled grains panicle^{-1} at harvest (23.23) was observed from T_1V_3 treatment combination.

Table 4. Interaction effect of water deficit and different varieties on filled and unfilled grains of hybrid and inbred rice

Treatments	Filled grains panicle^{-1}	Unfilled grains panicle^{-1}
T_1V_1	166.66 c	33.63 d
T_1V_2	173.33 a	27.23 h
T_1V_3	158.71 d	23.23 i
T_1V_4	169.63 b	31.51 f
T_2V_1	151.51 g	39.75 b
T_2V_2	155.71 e	33.13 e
T_2V_3	135.55 k	27.98 g
T_2V_4	153.63 f	33.21 e
T_3V_1	142.31 j	42.23 a
T_3V_2	143.63 h	37.63 c
T_3V_3	115.13 l	33.03 e
T_3V_4	142.75 i	39.71 b
LSD (0.05)	**1.31**	**0.57**
CV (%)	**1.20**	**5.40**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

4.8 Weight of 1000-grains

Effect of water deficit

Different levels of water deficit showed significant difference on the weight of 1000-grains of rice varieties at harvest (Figure 13). The result revealed that at harvest, the maximum weight of 1000-grains (28.40 g) was recorded from the treatment T_1 and the minimum weight of 1000-grains (20.07 g) was recorded from the treatment T_3. The identical outcome was reported by Zubaer *et al*., (2007).They found that as water stress levels increased, plant height, tiller per hill, the number of filled grains per panicle, total dry matter per hill, grain yield, and harvest index all declined.

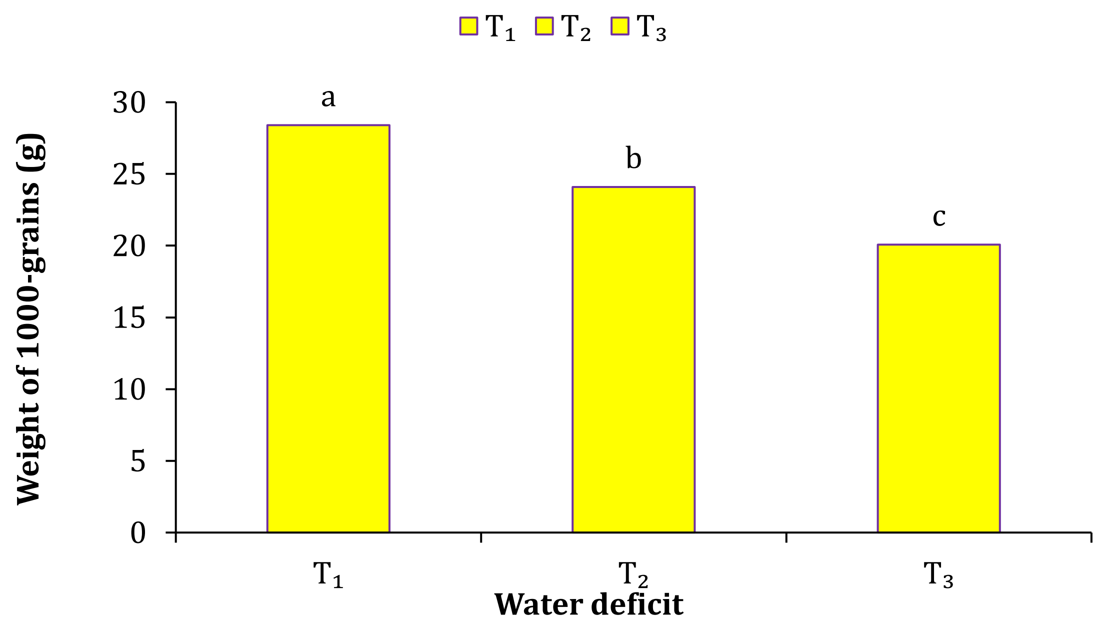

Figure 13. Effect of water deficit on weight of 1000-grains (g) of hybrid and inbred rice

(LSD value = 1.51) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The weight of 1000-grains of rice plant were significantly influenced by different varieties at harvest (Figure 14). The results revealed that at harvest, the highest weight of 1000-grains (25.30 g) were recorded from V_3 whereas; the lowest weight of 1000-grains (23.54 g) were recorded from V_1. The findings concur with Rahman *et al*., (2002) and Zubaer *et al*., (2007), who found that water stress decreased grain weight in many rice varieties.

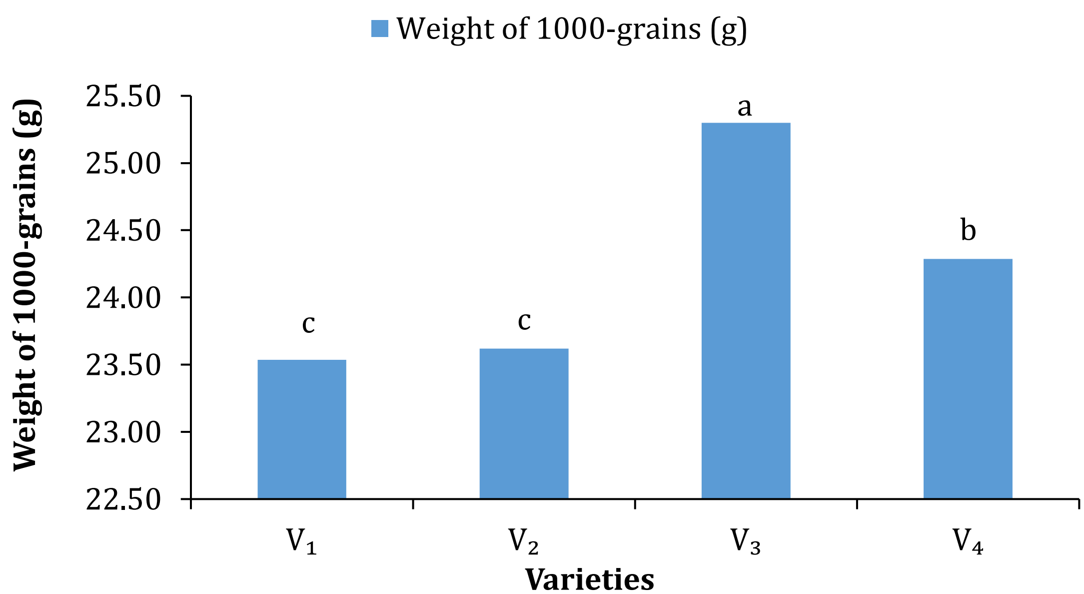

Figure 14. Effect of varieties on weight of 1000-grains (g) of hybrid and inbred rice (LSD value = 0.74) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on weight of 1000-grains at harvest (Table 5). The result showed that the highest weight of 1000-grains at harvest (31.13 g) was observed from the T_1V_2 treatment combination and the lowest weight of 1000-grains at harvest (19.75 g) was observed from T_3V_1 treatment combination which was statistically similar with T_3V_4 treatment combination (19.94 g). 1000 grain weight depend on filled grain per panicle, SPAD value, photosynthesis etc. If filled grain per panicle is higher 1000 grain weight also be higher as we found in control condition. Other-wise 1000 grain weight is lower in water deficit condition.

Table 5. Interaction effect of water deficit and different varieties on weight of 1000-grains of hybrid and inbred rice

Treatments	Weight of 1000-grains (g)	
	Actual weight	Relative %
T_1V_1	27.63 c	—
T_1V_2	31.13 a	—
T_1V_3	25.51 d	—
T_1V_4	29.33 b	—
T_2V_1	23.23 g	84.08
T_2V_2	24.31 e	78.09
T_2V_3	25.23 d	98.90
T_2V_4	23.59 f	80.43
T_3V_1	19.75 j	71.48
T_3V_2	20.47 h	65.76
T_3V_3	20.13 i	78.91
T_3V_4	19.94 j	67.98
LSD (0.05)	**1.51**	
CV (%)	**7.50**	

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.
T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

4.9 Grain yield
Effect of water deficit

Different levels of water deficit showed significant difference on the grain yield of rice varieties (Figure 15). The result revealed that the maximum (8.13 t ha^{-1}) grain yield was recorded from the treatment T_1 and the minimum (4.50 t ha^{-1}) grain yield was recorded from the treatment T_3. All the yield and yield contributing characters achieved maximum value under control condition. Water deficit at reproductive stages caused about 14% yield reduction compared to control condition. Mannan *et al.*, (2012) reported lower number of filled grains per panicle and grain weight due to water stress at reproductive stage. Inactivation of pollen grain due to dryness, hampered pollen tube development and disturbed assimilates production and distribution might be the causes (Fofana *et al.*, 2010) of lower grain yield. Water deficit obstructs photosynthesis and limits the supply of photosynthates to developing grains which eventually reduces grain yield.

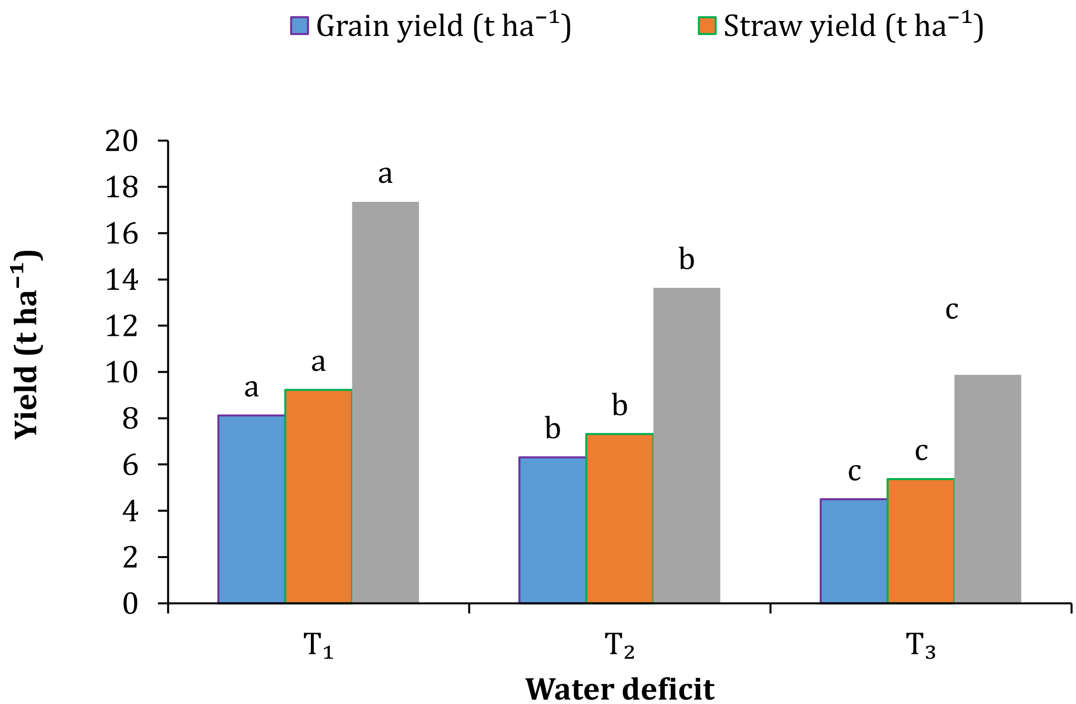

Figure 15. Effect of water deficit on grain, straw and biological yield of hybrid and inbred rice

(LSD value = 0.30, 0.31 and 0.60, respectively) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The grain yield of rice was significantly influenced by different varieties (Figure 16). The results revealed that the highest grain yield (6.82 t ha^{-1}) was recorded from V_3 whereas; the lowest grain yield (5.82 t ha^{-1}) was recorded from V_1 which was statistically similar with V_4 (6.12 t ha^{-1}). As a result of changes in the genetic make-up of varieties, Mannan *et al.*, (2012) also discovered significant variances in case of yield and yield contributing qualities.

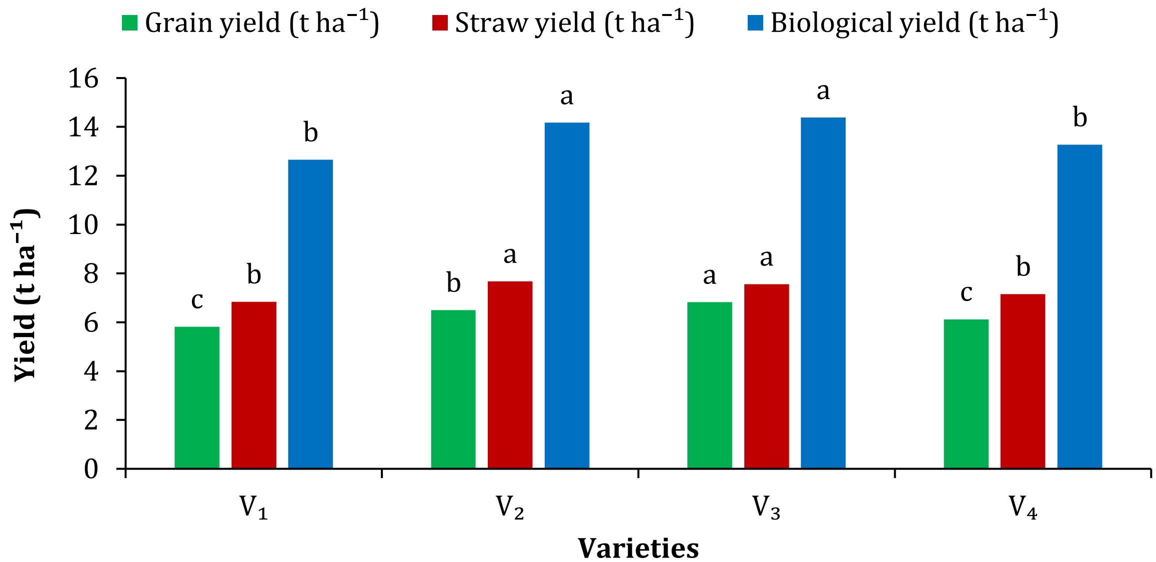

Figure 16. Effect of varieties on grain, straw and biological yield of hybrid and inbred rice

(LSD value = 0.31, 0.30 and 0.61, respectively) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on grain yield of rice (Table 6). The result showed that the highest grain yield (8.54 t ha^{-1}) was observed from the T_1V_3 treatment combination which was statistically similar with T_1V_2 treatment combination (8.50 t ha^{-1}). On the other hand, lowest grain yield (4.31 t ha^{-1}) was observed from T_3V_1 treatment combination which was statistically similar with T_3V_4 treatment combination (4.43 t ha^{-1}) and T_3V_2 treatment combination (4.53 t ha^{-1}). In water deficit condition the highest (46.71 %) yield reduction observed from T_3V_2 treatment combination and lowest (15.57 %) yield reduction from T_2V_3 treatment combination. This outcome also confirmed with Mostajeran and Rahimi- Eichi's (2009). They discovered that the effects of drought stress on vegetative phase growth and grain output were rather minor. However, they found that water stress during the panicle growth stage lowered grain yield because it delayed anthesis, and that the number of spikelet per panicle decreased by up to 60% in comparison to the control, as well as the proportion of full grains.

Table 6. Interaction effect of water deficit and different varieties on grain yield of hybrid and inbred rice

Treatments	Grain yield (t ha^{-1})	
	Actual	Relative % (% Reduction)
T_1V_1	7.51 c	—
T_1V_2	8.50 a	—
T_1V_3	8.54 a	—
T_1V_4	7.95 b	—
T_2V_1	5.63 f	74.97 (25.03)
T_2V_2	6.45 d	75.88 (24.11)
T_2V_3	7.21 c	84.43 (15.57)
T_2V_4	5.98 e	75.22 (24.78)
T_3V_1	4.31 h	57.39 (42.61)
T_3V_2	4.53 gh	53.29 (46.71)
T_3V_3	4.71 g	55.15 (44.85)
T_3V_4	4.43 gh	55.72 (44.28)
LSD (0.05)	**0.30**	
CV (%)	**2.89**	

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.
T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

4.10 Straw yield

Effect of water deficit

Different levels of water deficit showed significant difference on the straw yield of rice varieties (Figure 15). The result revealed that the maximum straw yield (9.23 t ha^{-1}) was recorded from the treatment T_1 and the minimum straw yield (5.38 t ha^{-1}) was recorded from the treatment T_3.

Effect of variety

The straw yield of rice was significantly influenced by different varieties (Figure 16). The results revealed that the highest straw yield (7.68 t ha^{-1}) was recorded from V_2 which is statistically similar with V_3 (7.56 t ha^{-1}) whereas; the lowest straw yield (6.84 t ha^{-1}) was recorded from V_1 which was statistically similar with V_4 (7.15 t ha^{-1}).

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on straw yield of rice (Table 7). The result showed that the highest straw yield (9.91 t ha^{-1}) was observed from the T_1V_2 treatment combination. On the other hand, lowest straw yield (5.13 t ha^{-1}) was observed from T_3V_1 treatment combination which was statistically similar with T_3V_4 treatment combination (5.23 t ha^{-1}).

4.11 Biological yield

Effect of water deficit

Different levels of water deficit showed significant difference on the biological yield of rice varieties (Figure 15). The result revealed that the maximum biological yield (17.36 t ha^{-1}) was recorded from the treatment T_1 and the minimum biological yield (9.87 t ha^{-1}) was recorded from the treatment T_3.

Effect of variety

The biological yield of rice was significantly influenced by different varieties (Figure 16). The results revealed that the highest biological yield (14.38 t ha^{-1}) was recorded from V_3 which is statistically similar with V_2 (14.17 t ha^{-1}) whereas; the lowest biological yield

(12.65 t ha^{-1}) was recorded from V_1 which is statistically similar with V_4 (13.27 t ha^{-1}). The differences in biological yield may be attributed to the genetic make-up of the varieties.

Table 7. Interaction effect of water deficit and different varieties on yields attributes and harvest index of hybrid and inbred rice

Treatments	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1V_1	8.75 c	16.26 c	46.19 d
T_1V_2	9.91 a	18.41 a	46.17 d
T_1V_3	8.93 c	17.47 b	48.88 a
T_1V_4	9.33 b	17.28 b	46.01 de
T_2V_1	6.63 f	12.26 f	45.92 e
T_2V_2	7.61 e	14.06 e	45.87 e
T_2V_3	8.13 d	15.34 d	47.00 b
T_2V_4	6.89 f	12.87 f	46.46 c
T_3V_1	5.13 i	9.44 h	45.65 fg
T_3V_2	5.51 gh	10.04 gh	45.11 h
T_3V_3	5.63 g	10.34 g	45.55 g
T_3V_4	5.23 hi	9.66 h	45.85 ef
LSD (0.05)	**0.31**	**0.62**	**0.21**
CV (%)	**2.50**	**2.68**	**0.26**

In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.
T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on biological yield of rice (Table 7). The result showed that the highest biological yield (18.41 t ha^{-1}) was observed from the T_1V_2 treatment combination. On the other hand, lowest biological yield (9.44 t ha^{-1}) was observed from T_3V_1 treatment combination which was statistically similar with T_3V_4 treatment combination (9.66 t ha^{-1}) and T_3V_2 treatment combination (10.04 t ha^{-1}). In water deficit condition biological yield is decreased with decreasing grain yield and straw yield.

4.12 Harvest index

Effect of water deficit

Different levels of water deficit showed significant difference on the harvest index of rice varieties (Figure 17). The result revealed that the maximum (46.81%) value of harvest index was recorded from the treatment T_1 and the minimum (45.54%) value of harvest index was recorded from the treatment T_3.

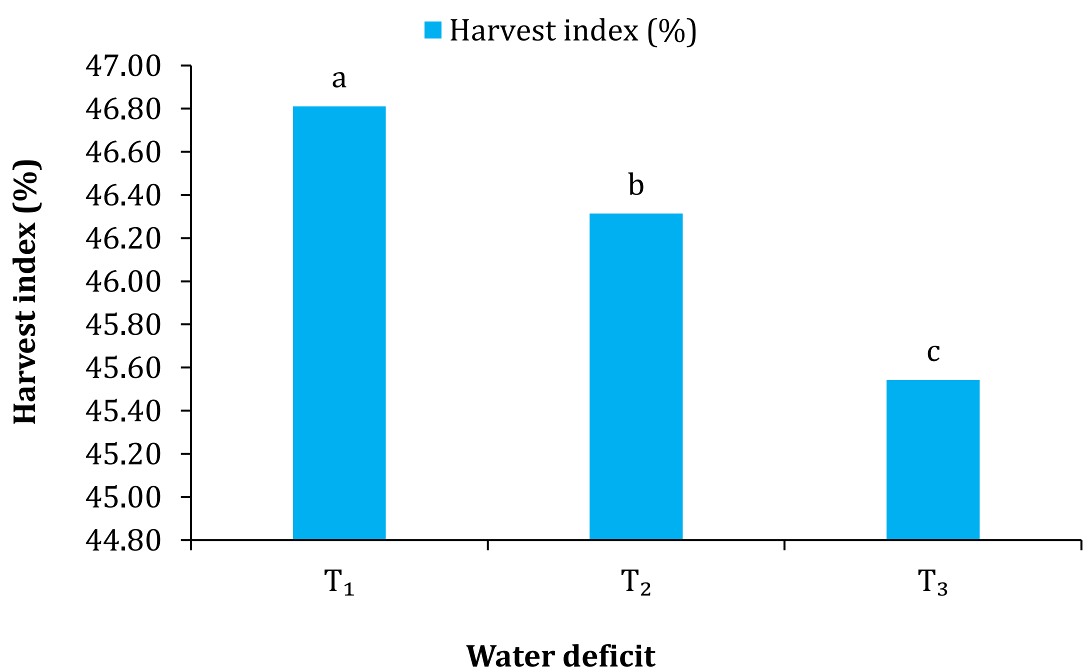

Figure 17. Effect of water deficit on harvest index (%) of hybrid and inbred rice
(LSD value = 0.20) T_1 = Control, T_2 = Water deficit at 45–55 days after transplanting (tillering) and T_3 = Water deficit at 85–95 days after transplanting (flowering)

Effect of variety

The harvest index of rice was significantly influenced by different varieties (Figure 18). The results revealed that the maximum (47.14%) value of harvest index was recorded from V_3 whereas; the minimum (45.72%) value of harvest index was recorded from V_2 which is statistically similar with V_1 (45.92%).These result was also agreed with Zubaer *et al.*, (2007) in a pot experiment he showed that the harvest index of all rice genotypes was reduced with reduced moisture level.

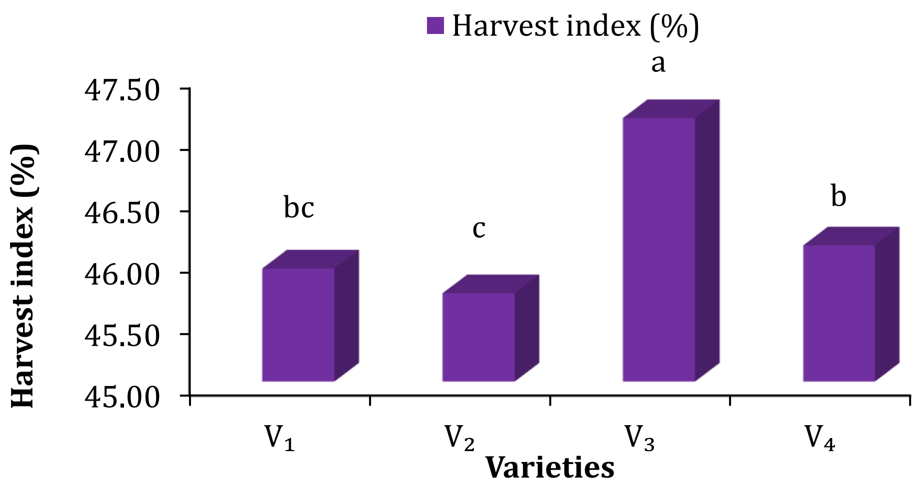

Figure 18. Effect of varieties on harvest index (%) of hybrid and inbred rice

(LSD value = 0.22) V_1 = BRRI dhan92, V_2 = Heera 4, V_3 = Aloron and V_4 = BRRI hybrid dhan5

Interaction effect of water deficit and variety

Interaction of different levels of water deficit and variety showed significant variation on harvest index of rice (Table 7). The result showed that the highest value of harvest index (48.88%) was observed from the T_1V_3 treatment combination. On the other hand, lowest value of harvest index (45.11%) was observed from T_3V_2 treatment combination. Harvest index is related with grain yield and biological yield. If both the yields are increased the harvest index also be increased.

CHAPTER V

SUMMARY AND CONCLUSIONS

The pot experiment was conducted at the Research Farm of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, during the period from November 2019 to May 2020 to study the impact of water deficit on morphology and yield attributes of hybrid and inbred rice varieties. The experiment comprised of two factors viz. Factor A: Variety (4), i) V_1 = BRRI dhan92, ii) V_2 = Heera 4, iii) V_3 = Aloron and iv) V_4 = BRRI hybrid dhan5; factor B: Water deficit (3), i) T_1 = Control, ii) T_2 = Water deficit at 45–55 days after transplanting (tillering) and iii) T_3 = Water deficit at 85–95 days after transplanting (flowering). This experiment was laid out in a randomized complete block design (RCBD) with three replications. Data were collected on different aspects of growth, yield attributes and yield of rice.

The result revealed that V_3 (Aloron) exhibited its superiority to other tested variety Heera 4, BRRI hybrid dhan5 and BRRI dhan92 in terms of seed yield. V_3 (Aloron) out-yielded over V_2 (Heera 4) by 5.08% and V_4 (BRRI hybrid dhan5) by 11.43% higher yield. V_3 (Aloron) also showed the tallest plant at harvest (91.60 cm), highest SPAD value (40.02), the highest number of filled grains panicle^{-1} (157.56), lowest number of unfilled grains panicle^{-1} (28.08), the highest weight of 1000-grains (25.30 g), the highest biological yield (14.38 t ha^{-1}) and harvest index (47.14%) than other tested varieties in this experiment. On the other hand, the variety V_1 (BRRI dhan92) returned with 17.18% lower yield than variety V_3 (Aloron) which was significantly the lowest compare with other varieties under study.

Significant differences existed among different water deficit treatments with respect to yield and yield attributing parameters of rice. A yield advantages of 1.81 t ha^{-1} and 3.63 t ha^{-1} was observed from T_1 treatment [Control] over T_2 [Water deficit at 45–55 days after transplanting (tillering)] and T_3 [Water deficit at 85–95 days after transplanting (flowering)] treated pot, respectively. The higher amount of yield from T_1 treatment was possibly aided by the tallest plant at harvest (91.81 cm), highest number of tillers hill^{-1} at harvest (11.68), highest number of leaves hill^{-1} at harvest (78.73), maximum leaf area index

(4.49), highest SPAD value (46.20), higher number of filled grains panicle^{-1} (167.08), lowest number of unfilled grains panicle^{-1} (28.90), highest weight of 1000-grains (28.40 g), the highest straw yield (9.23 t ha^{-1}), biological yield (17.36 t ha^{-1}) and harvest index (46.81%). On the other hand, treatment T_2 [Water deficit at 45–55 days after transplanting (tillering)] gave significantly better result compared with T_3 treatment in some parameters like-plant height at harvest, number of tillers hill^{-1} at harvest, number of filled grains panicle^{-1}, number of unfilled grains panicle^{-1}, 1000-grains weight, grain and straw yield, biological yield and harvest index. It was observed that water deficit at flowering stage could be detrimental to rice plant than water deficit at tillering stage and significantly reduced rice production by reducing yield attributes and yield of rice.

Interaction results of variety and water deficit indicated that all the studied parameters were influenced significantly. Significantly the highest grain yield (8.54 t ha^{-1}) was found in T_1V_3 [Control × Aloron] interaction due to the tallest plant at harvest (97.11 cm) and significantly the highest value of harvest index (48.88%). It was also observed that T_1V_2 combination [Control × Heera 4] showed the second highest grain yield (8.50 t ha^{-1}) aided by the highest number of tillers hill^{-1} at harvest (16.33), the highest number of leaves hill^{-1} at harvest (88.75), maximum leaf area index (4.69), the maximum SPAD value (48.63), highest number of filled grains panicle^{-1} (173.33), lower number of unfilled grains panicle^{-1} (27.23), the maximum weight of 1000-grains (31.13 g), the highest straw yield (9.91 t ha^{-1}) and biological yield (18.41 t ha^{-1}). In water deficit condition the highest grain yield (7.21 t ha^{-1}) was found in T_2V_3 [Water deficit at 45-55 days after transplanting (tillering)] showed the maximum SPAD value (39.71), the maximum weight of 1000-grains (25.23 g), lower number of unfilled grains panicle^{-1} (27.98), the highest straw yield (8.13 t ha^{-1}) and biological yield (15.34t ha^{-1}), lower yield reduction (15.57%).

CONCLUSION

There was a great effect of water deficit on various hybrid and inbred rice varieties considering there morphology and yield attributes. Water deficit at flowering stage (85–95 days after transplanting) could be detrimental to rice plant than water deficit at tillering stage (45–55 days after transplanting). Among the interactions, T_1V_3 and T_2V_3 were superior in most of the growth and yield attributing parameters along with grain yield.

Among the hybrid rice varieties, the effect of water deficit was comparatively lower in Aloron than the other varieties. The variety Heera 4 was severely affected due to water deficit.

In the present experiment the hybrid rice varieties, Aloron seems promising for combating water deficit compared to other varieties.

CHAPTER VI

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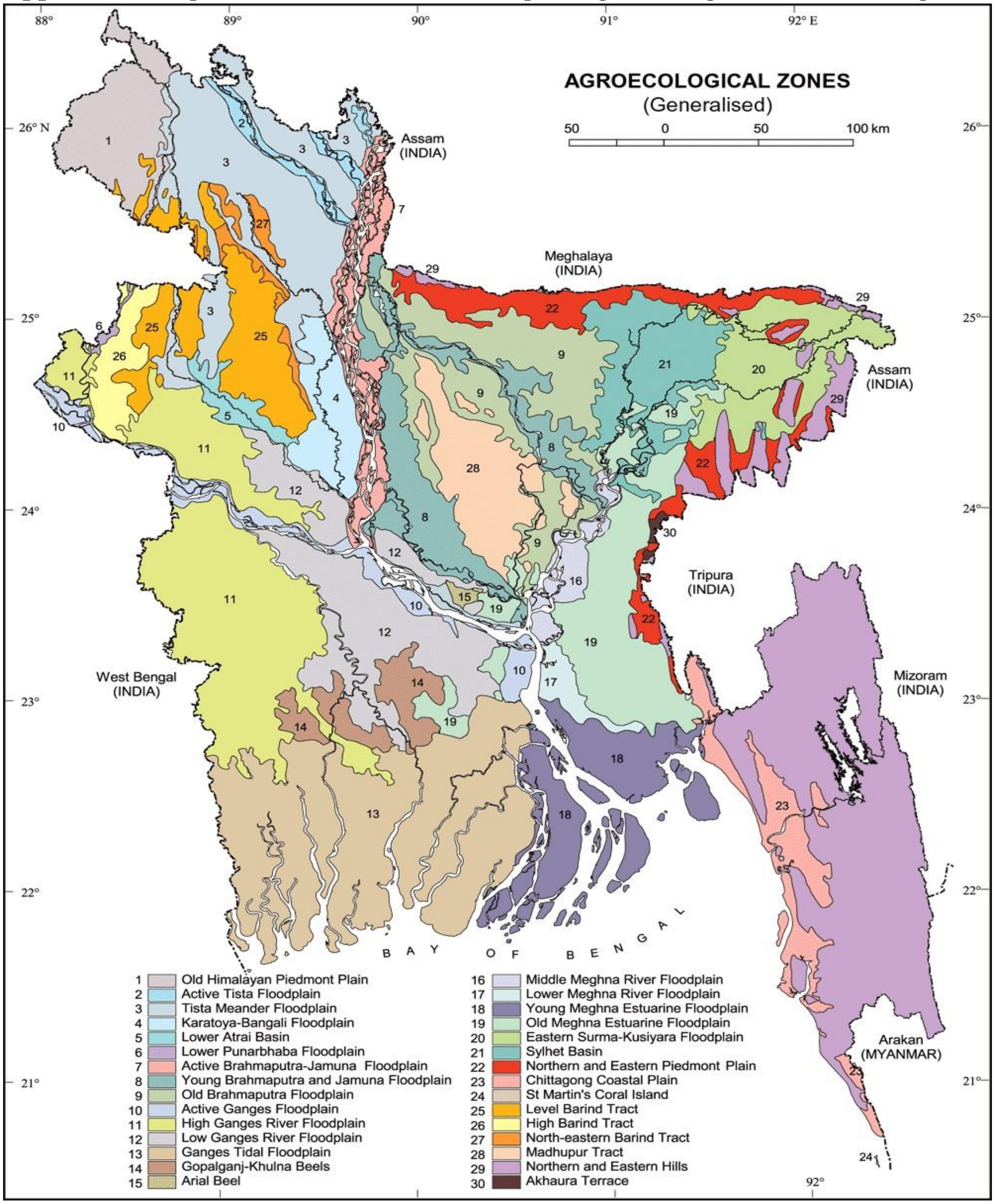
APPENDICES

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)

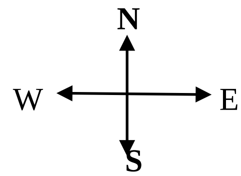
Appendix IV. Monthly records of air temperature, relative humidity and rainfall during the period from November, 2019 to May, 2020

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2019	November	28.60	8.52	18.56	56.75	14.40
2019	December	25.50	6.70	16.10	54.80	0.0
2020	January	23.80	11.70	17.75	46.20	0.0
2020	February	22.75	14.26	18.51	37.90	0.0
2020	March	35.20	21.00	28.10	52.44	20.4
2020	April	34.70	24.60	29.65	65.40	165.0
2020	May	32.64	23.85	28.25	68.30	182.2

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212

Appendix V. Layout of the experimental pots

R_1	R_2	R_3
T_3V_4	T1V2	T2V3
T_3V3	T1V1	T2V4
T3V2	T1V4	T2V1
T3V1	T1V3	T_2V_2
T2V4	T3V2	T1V3
T2V3	T3V1	T1V4
T2V2	T3V4	T1V2
T2V1	T3V3	T1V1
T1V4	T2V2	T3V3
T1V3	T2V1	T3V4
T1V2	T2V4	T3V1
T1V1	T2V3	T3V2



Pot size = 28 cm x 25 cm x 35 cm

T_1= Control

T_2 = Water deficit at 45-55 days after transplanting (tillering)

T_3 = Water deficit at 85-95 days after transplanting (flowering)

V_1 = BRRI dhan92

V_2 = Heera 4

V_3 = Aloron

V_4 = BRRI hybrid dhan5

Appendix VI. Analysis of variance (mean square) of plant height of rice

Source of variation	Degrees of freedom	Mean Square value of			
		Plant height at 30 DAT	Plant height at 60 DAT	Plant height at 90 DAT	Plant height at harvest
Variety	3	6.28*	3.21*	3.87*	128.58*
Water deficit	2	3.49*	207.11*	199.79*	517.16*
Variety × Water deficit	6	0.45*	2.87*	1.64*	2.23*
Error	24	0.03	0.03	0.03	0.03
Total	35	0.84	12.63	12.05	40.98

* Indicates significant at 5% level of probability

Appendix VII. Analysis of variance (mean square) of number of tillers plant^{-1} rice

Source of variation	Degrees of freedom	Mean Square value of			
		Number of tillers plant^{-1} at 30 DAT	Number of tillers plant^{-1} at 60 DAT	Number of tillers plant^{-1} at 90 DAT	Number of tillers plant^{-1} at harvest
Variety	3	0.83*	3.31*	2.30*	12.51*
Water deficit	2	2.83*	59.42*	68.88*	61.29*
Variety × Water deficit	6	0.38*	0.55*	0.29*	3.52*
Error	24	0.03	0.03	0.03	0.03
Total	35	0.32	3.80	4.21	5.20

* Indicates significant at 5% level of probability

Appendix VIII. Analysis of variance (mean square) of leaf characteristics of rice

Source of variation	Degrees of freedom	Mean Square value of		
		Number of Leaves hill^{-1}	Leaf area index	SPAD value
Variety	3	265.98*	0.79*	3.99*
Water deficit	2	4671.58*	3.69*	512.65*
Variety × Water deficit	6	52.22*	0.02*	8.92*
Error	24	0.03	0.03	0.03
Total	35	298.72	0.31	31.19

* indicates significant at 5% level of probability

Appendix IX. Analysis of variance (mean square) of yield attributes of rice

Source of variation	Degrees of freedom	Mean Square value of		
		Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}	Weight of 1000-grains
Variety	3	836.99*	171.48*	5.99*
Water deficit	2	2930.17*	256.69*	208.13*
Variety × Water deficit	6	55.79*	3.98*	6.95*
Error	24	0.03	0.03	0.03
Total	35	248.77	30.07	13.62

* indicates significant at 5% level of probability

Appendix X. Analysis of variance (mean square) of yield and harvest index of rice

Source of variation	Degrees of freedom	Mean Square value of			
		Grain yield	Straw yield	Biological yield	Harvest index
Variety	3	1.72*	1.34*	5.83*	3.62*
Water deficit	2	39.53*	44.58*	168.08*	4.90*
Variety × Water deficit	6	0.24*	0.51*	1.27*	1.63*
Error	24	0.03	0.03	0.13	0.01
Total	35	2.47	2.77	10.41	0.88

* indicates significant at 5% level of probability