RESPONSE OF SOME TOMATO VARIETIES TO WATER STRESS AT DIFFERENT FRUITING STAGES

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This is to certify that thesis entitled, **"Response Of Some Tomato Varieties To Water Stress At Different Fruiting Stages"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **AGRICULTURAL BOTANY,** embodies the result of a piece of Bonafede research work carried out by **Fahim Arshad,** Registration **No.18-09024** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated

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DEDICATED TO
MY
BELOVED PARENTS

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The Author

RESPONSE OF SOME TOMATO VARIETIES TO WATER STRESS AT DIFFERENT FRUITING STAGES

ABSTRACT

An experiment was conducted at the Central Research Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka during October 2018 to March 2019 to study the water stress in different tomato variety. The experiment consisted of two factors: varieties as V_1=Mintoo HYV, V_2=BARI Tomato-4 variety and V_3=BARI Tomato-14 variety, and Different levels of water stress as treatments T_0: Control (no stress), T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage. The two factors experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. For plant height at 30 DAT for the variety V_2 gives the highest plant height (47.58 cm) and lowest for V_1 (31.83 cm). The maximum leaf area was recorded at flowering stage for treatment V_1T_0. At flowering stage of 30, 45 and 60 DAF days after flowering, the highest SPAD values (62.12, 59.83 and 62.7, respectively) was obtained from V_1. At 45 DAF T_2 shows the highest SPAD value (61.87). % Moisture of was drastically reduced due to water stress as V_1T_0 with the control treatment shows highest moisture level of 94.67% and for V_3T_3 with the treatment of late fruiting stage water stress gives the least moisture level of 84%. The highest dry matter content of leaf in plant. V_1T_0 with the control treatment shows highest dry matter content of 4.57% and for V_2T_2 with the treatment of late fruiting stage water stress gives the least dry matter content of 2.60%. Highest number of fruit drops due to early fruiting stage water stress as for V_1T_1 36 fruits drops but its shows less effect for late fruiting stage water stress. The highest weight of individual fruit 67.83 g was found from V_3T_0. The highest yield plant^{-1} (2.15 kg) was recorded from V_3T_0, while the lowest yield (1.16 kg) was found from V_1T_1. The highest fruit yield (89.29 t ha^{-1}) was recorded from V_3T_0, while the lowest fruit yield (16.83 t ha^{-1}) was found from V_1T_1. Based on the findings of the present study, it may be reported that water stress has remarkable influence on morpho-physiology and yield attributes of tomato. Overall performance of BARI Tomato-14 indicates it can be cultivated without application of sufficient irrigation.

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LIST OF ABBREVIATION AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
BBS	=	Bangladesh Bureau of Statistics
FAO	=	Food and Agriculture Organization
N	=	Nitrogen
B	=	Boron
et al.	=	And others
TSP	=	Triple Super Phosphate
MOP	=	Murate of Potash
RCBD	=	Randomized Complete Block Design
DAT	=	Days after Transplanting
ha^{-1}	=	Per hectare
g	=	gram
kg	=	Kilogram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources Development Institute
wt	=	Weight
LSD	=	Least Significant Difference
^{0}C	=	Degree Celsius
NS	=	Not significant
Max	=	Maximum
Min	=	Minimum
%	=	Percent
NPK	=	Nitrogen, Phosphorus and Potassium
CV%	=	Percentage of Coefficient of Variance

CHAPTER I
INTRODUCTION

The tomato (*Lycopersicon esculentum*) belongs to the *solanaceae* (night shade) family. It is native to tropical America where its indigenous name was tomati. From Mexico the tomato was taken to Europe and then to Asia. An important vegetable crop, it is grown in most home gardens and by market gardeners and truck farmers. It is also produced by forcing in green houses. It can be eaten either fresh or processed into many different products. It plays a vital role in maintaining health and vigor. Tomatoes are very helpful in healing wounds because of the antibiotic properties found in the ripe fruit. It is a good source of vitamins A, B and C. It is widely used in salad as well as for culinary purposes. Tomato gain popularity very rapidly and attain the status of widely consumed. Although tomato is a tender perennial crop, which is susceptible to frost as well as high temperature but it is being grown in a variety of climatic conditions (Malik, 1994). At present, tomato ranks first and cabbage to next, in terms of world vegetable production (FAO, 2018). The biggest producer of tomatoes in 2016 was China by far with more than 50 million tons harvested, followed by India, USA, Turkey and Egypt. Italy, Iran, Spain, Brazil and Mexico complete the top 10. Overall tomatoes are harvested in more than 170 countries (FAO, 2019).

In nature, water is usually the most limiting factor for plant growth. If plants do not receive adequate rainfall or irrigation, the resulting water stress can reduce growth more than all other environmental stresses combined. A plant responds to a lack of water by halting growth and reducing photosynthesis and other plant processes in order to reduce water use. As water loss progresses, leaves of some species may appear to change color usually to blue-green. Foliage begins to wilt and, if the plant is not irrigated, leaves will fall off and the plant will eventually die.

Water is by far the most important environmental stress in agriculture and many efforts have been made to improve crop productivity under water – limiting condition. While natural selection has favored mechanisms for adaptation and survival, breeding activity has directed selection towards increasing the economic yield of cultivated species. More than 80 years of breeding activities have led to some yield increase in water environment for many crop plants. Meanwhile, fundamental research has provided significant gains in the understanding of the physiological and molecular responses of plant to water deficit, but there is still a large gap between yield in optimal and stress conditions. Minimizing the 'yield gap' and increasing yield stability under different stress conditions are of strategic importance in guaranteeing food for the future (Ashraf, 1994). It is reported that across plant species water imposes various physiological and biochemical limitations and adverse effects (Chaves and Oliveira, 2004; Wang *et al.*, 2003).

The distribution of xylem hydraulic resistance in fruiting truss of tomato influenced by water stress. In this study xylem hydraulic resistances of peduncles (truss stalk), pedicels (fruit stalk) and the future abscission zone (AZ) halfway along the pedicel of tomato (*Lycopersicon esculentum* L.) plants were directly measured at different stages of fruit development, in plants grown under two levels of water availability in the root environment. They noted that the largest resistances were measured in the AZ where most individual vessels ended. Plants grown at low water availability in the root environment had xylem with higher hydraulic resistances in the peduncle and pedicel segments on both sides of the AZ, while the largest increase in hydraulic resistance was measured in the AZ. During fruit development hydraulic resistances in peduncle and pedicel segments decreased on both sides of the AZ, but tended to increase in the AZ. The overall xylem hydraulic resistance between the shoot and fruit tended to increase with fruit development because of the dominating role of the hydraulic resistance in the AZ (Leperen *et al.*, 2003).

Deficit irrigation is an agricultural water management strategy by which crops are exposed to a level of water stress either during a certain period of time or during the entire growing season (Topcu *et al.*, 2007). Studies of deficit irrigation for tomato have shown mixed results in terms of fruit yield and quality. Pulupol *et al*. (1996) found that water stress resulted in a drastic reduction in dry mass yield, while other studies reported no adverse effects on yield and fruit quality for a field-grown processing cultivar (Nangare *et al.*, 2016). Chen *et al.* (2014) showed that tomato yield was mainly affected by water stress that occurred throughout the course of fruit growth and maturation, but quality was sensitive to water stress during the fruit ripening stage. To the best of our knowledge, to date only a limited number of experiments have studied the effect of deficit irrigation on fruit yield and qualitative characteristics at various stages when tomatoes are grown in high tunnels whereby the growth periods and micro-climates were significantly different from open-field and greenhouse conditions (Shao *et al*., 2015). Therefore, it is essential to understand the effect of water stress for tomato production grown in high tunnels with a limited water supply.

With conceiving the above scheme in mind, the present research work was undertaken in order to fulfilling the following objectives:

1. To study the response of water stress on some tomato varieties at fruiting stages and
2. To determine the most affected fruiting stage of tomato varieties to water stress

CHAPTER II
REVIEW OF LITERATURE

Water is by far the most important environmental stress in agriculture and many efforts have been made to improve crop productivity under water-limiting condition. While natural selection has favored mechanisms for adaptation and survival, breeding activity has directed selection towards increasing the economic yield of cultivated species. Tomato is one of the important vegetable crops in Bangladesh and other countries of the world and it has drawn attention by the researchers for its various way of consumptions and nutritional value. It can be cultivated to a wide range of climates ranging from tropics to within a few degrees of the arctic circle. However, it is susceptible to frost as well as high temperature but being grown in a variety of climatic conditions. Very limited research works have been conducted to adapt tomato crop in the water prone area of Bangladesh. An attempt was made to find out the performance of different tomato varieties at different levels of moisture stress as the water stressed tolerance of tomato plants. To facilitate the research works different literature have been reviewed in this chapter under the following sub headings.

2.1 Effect of water stress

Several studies have compared groups of tomato varieties, landraces or wild species, observing a differential expression on some water-associated traits between varieties, but without having a consistent response in the literature. For instance, the osmolyte L-proline is usually induced by water, but the level of induction is a variety-dependent trait, whereas leaf water content is generally less reduced on tolerant plants (Tapia *et al.,* 2016).

Water stress causes an imbalance between the production and scavenging of ROS in plants. ROS accumulation causes membrane damage and membrane lipid peroxidation (Xu *et al.,* 2006). Several antioxidant enzymes and osmotic substances (including soluble sugars, proteins, free prolyls, and so forth) in plants constitute the antioxidant enzyme systems (Malviya, 2015).

Water movement through a plant is a passive process, where it is driven by water potential differences between the soil, plant and atmosphere and the hydraulic conductivities between each component (Lobet *et al.*, 2014). Water moves from high water potential to a lower potential. Plants absorb water from soil through roots and absorbed water moves to xylem vessels through radial water movement. After entering to xylem vessels, water moves from roots to leaves through the xylem and release to atmosphere as water vapor through stomata.

Stomatal closure is the initial response from a plant to water stress (Osakabe *et al.*, 2014). Stomatal closure stimulated by the turgor pressure change in guard cells due to low water supply. This is induced by the secretion of abscisic acid where it can activate different signaling molecules to trigger stress tolerance through activation of stress responsive genes in the system.

When the plant is under water stress, the root pushes deeper in search of water. It was found that the root length increases with water stress (Turkan et al., 2005; Bahrami *et al.*, 2012). Sharp and LeNoble (2002) observed an increase in the rate of root tip elongation with the increase in water stress in maize. However, the root volume and the dry weight reduced significantly under the water stress (Geetha *et al.*, 2012; Hadi *et al.*, 2014).

Under water stress, stomata close and this affects CO2 flux. Stomatal closure is one of the first responses to water stress (Hommel *et al.*, 2014; Xie *et al.*, 2014). Stomata close when plant water potential reduces or if the leaf turgor reduces. The response limits CO2 exchange in leaves (Chaves *et al.*, 2002). Low CO2 flux causes an increase in ROS. On the other hand, plant tissue water potential is reduced by water. Low tissue water potential reduces the activities of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), phosphoenolpyruvate carboxylase (PEPCase), NADP- malic enzyme (NADP-ME), fructose-1,6-bisphosphatase (FBPase) and pyruvate orthophosphate-dikinase (PPDK) enzymes. Both ROS production and reduced activity of enzymes lower the carboxylation. Further, water causes a down-regulation of non-cyclic electron transport, which negatively affects ATP synthesis. As a result of low carboxylation and low ATP levels, photosynthesis drops under water conditions (Farooq *et al.*, 2009).

Giannakoula and Ilias (2013) conducted an experiment to evaluate the effect of water stress and salinity on growth and physiology of tomato (Lycopersicon esculentum mill.) and they observed that the application of moderate salt stress on tomato plants can enhance lycopene and potentially other antioxidant concentrations in fruits. The increase in lycopene in response to salt stress in the tomato fruits varied from 20% to 80%. Although the specific biological mechanisms involved in increasing fruit lycopene deposition has not been clearly elucidated, evidence suggests that increasing antioxidant concentrations is a primary physiological response of the plant to salt stress. Additionally, water stress during cultivation increased the antioxidant capacity of tomato fruit while maintaining the lycopene concentration. In addition, the effects of silicium were investigated, added to the nutrient solution either at low concentration or at an increased concentration. The present study clearly indicates that an enhanced silicium supply to tomato increases markedly the lycopene contents, irrespective of the salinity status in the tomato fruit.

Water stress also affects shoot length. Under water deficient, shoot length in sesame (*Sesamum indicum* L.) was reduced (Bahrami *et al.*, 2012), but in some cases, it showed reduction at the initial stage and then an increase in shoot length. Further, some plants increased shoot length initially and then reduced (Turkan *et al.*, 2005).

Moisture stress at vegetative growth stage caused a maximum reduction in plant height, when compared to control. The morphological attributes associated with the adaptation under water deficit conditions in tomato. Their data revealed that some, resistant genotype recorded highest plant height compared to some other individuals, whereas susceptible genotype had recorded least plant height. Application of glycinebetaine decreased plant height (Mohammed and Tarpley, 2011).

An experiment with nutrient solution was conducted in the glasshouse of the University of Applied and Life Science, Vienna, Austria to evaluate the effect of water stress on root and shoot development of seven tomato cultivars. The stress levels were 20, 25 and 30 minutes (withholding water) as low, medium and severe stress. The experiment revealed that the cultivars BR-4 and BR-5 showed comparatively tolerance to water as their root length, root dry weight and root/shoot ratio were higher under water stress condition (Nahar, 2011).

Yin *et al.,* (2010) explained that limitation of water supply has an immediate negative impact on the efficient use of water in the plant and it has effects on photosynthesis, plant growth, and production of fruits. Plants respond to water-deficit conditions by disrupting cellular pathways or whole plant functions. Environmental stresses affect both tomato physiology and the synthesis of secondary metabolites such as phenolic acids, avonoids, and terpenoids. Nevertheless, water-deficit may benefit tomato fruit quality due to the increased levels of total soluble solids (sugars, amino acids, and organic acids), which are major compounds which accumulate in the fruit. A rise of soluble solids increases the value of the fresh fruits and improves the quality of the fruits because it affects the flavor, taste, and water content of the fruits. In addition, plants growing under stress conditions react by increasing their antioxidant production from both non-enzymatic systems (e.g., flavonoids, phenolic compounds, vitamins C and E, and carotenoids) and enzymatic systems (e.g., superoxide dismutase, glutathione reductase, catalase, and several peroxidases). The inadequate water uptake caused by water stress leads plants to lose water as a result of metabolic processes depending on subjected stress level. Therefore, plants involve various strategies to conserve cellular water in response to increasing water intensity. The availability of the controlled mechanism is an important factor to define tolerance of different varieties against water. In this context, many studies reported alterations on relative water contents of various crop plants depending on the duration of applied water (Keyvan 2010).

A field experiment was conducted by Birhanu and Tilahun (2010) at Melkassa Agricultural Research Center, Ethiopia to study the effects of moisture stress on the yield and quality of two tomato cultivars. The two tomato cultivars were exposed to four irrigation water deficit levels expressed as percentages of potential evapotranspiration (ETc) as: 0% ETc, 25% ETc, 50% ETc, and 75%ETc deficit. The total plant biomass decreased with stress level while the fruit dry matter increased. As a result, the harvest index (fruit dry matter weight/plant dry matter weight) was increased with stress level. Both the number and size of tomato fruits were found to decrease with moisture stress. The incidence of sun-scald and blossom end rot was higher in the more stressed plants (75% ETc) deficit. The total soluble solids (TSS) content was significantly affected by irrigation treatments. The total soluble solids content was increased with stress level while the fruit water content was decreased.

The experiment was conducted by Aynur and Tari (2010) under ecological conditions typical of the Konya Plain, a semi-arid climate, in 2004 and 2005. Results of the field experiments showed that yield suitable for processing (68.7-72.7 t ha-1) and paste output 5 (12.2-12.9 t ha^{-1}) were obtainable under conditions of II application ($p<0.01$). MFW, FD, PV, and TSS were significantly affected from treatments ($p<0.05$). High stress resulted in the highest soluble solids. The total irrigation water amount and water consumptive use of the mentioned application were determined as 426 and 525mm in 2004. In 2005, the total irrigation water amount and water consumptive use of the same treatment were 587 and 619 mm, respectively.

Water stress during vegetative or early reproductive growth usually reduces yield by reducing the number of seeds, seed size and seed quality. To assess the effect of water stress on seed yield, seed quality and growth of tomato, the experiment was conducted by Pervez *et al.* (2009) in green house in plastic pots at Pen-y-Fridd field station, University of Wales, Bangor, U.K. during 2003-2004. Tomato cv. „Moneymaker‟ was used as a test crop. There were four treatments i.e. early stress (when first truss has set the fruits), middle stress (when fruits in first truss were fully matured and started changing their color), late stress (when fruits on first truss were ripened fully), whereas in control no stress was imposed. Analysis of data regarding various attributes (fruit weight and shoot dry weight per plant, number of seeds per fruit, total number of seeds and seed weight per plant and vigor of seed) showed that water stress had non-significant effect on vigor, quality and yield of tomato seed. Plant height, number of leaves and number of fruits per plant showed significant results toward water stress signifying water effects on growth of tomato.

An experiment was conducted by Nahar and Gretzmacher (2002) to evaluate the effect of water stress on nutrient uptake, yield and quality of tomato (Lycopersicon esculentum Mill.) under subtropical conditions with four tomato varieties (BR-1, Br-2, BR-4 and BR-5) in the net house of the Department of Soil Science, Dhaka University, during the period from November 1998 to March 1999. Results revealed that yield and dry matter production were adversely affected at 100 % and 40 % of the field capacity. The dry matter produced by the plants due to stress was dependent on variety. In dry matter production the highest dry matter was obtained by BR-1, followed by BR-5, BR-2 and BR-4. However, BR-2, BR-4 and BR-5 did not show significant difference among themselves. The results also revealed that 70 % field capacity was the best treatment. However, there was no significant difference between the two treatments, 70 % and 40 %, but the dry matter production was lower at 40 % compared to 70 % field capacity.

An experiment was carried out by Nuruddin *et al.* (2003) at greenhouse in Canada in which two available soil water deficit thresholds, 65 and 80%, at which plants were irrigated to field capacity were factorially combined with five irrigation timing patterns: (l) no water stress; (2) stress throughout the entire growing season; (3) stress during first cluster flowering and fruit set; (4) stress during first clusters fruit growth; and (5) stress during first cluster fruit ripening. They observed that water stress throughout the growing season significantly reduced yield and fruit size, but plants stressed only during flowering showed fewer but bigger fruits than completely non-stressed plants.

Tomato being very sensitive to soil water regime it is necessary to maintain even moisture supply, over watering is harmful, so also insufficient irrigation for tomato. Flower development in tomato cv. Roma was arrested and flower at all stages dropped and fruit growth ceased when water was withheld for a few days (Bose *et al.*, 2000).

Rainfall is the main source of water for plant growth and unpredictable weather patterns and improper water use in agriculture are the main causes for water (Smith, 2000). Water impacts all stages of plant growth. During germination, water stress delays the germination process and at extreme water deficit, germination ceases (Blum, 1996). At the vegetative stage, it reduces plant vigor and growth. In the early reproductive stage, water affects fertilization, leading to reduction in seed set and at a later stage, it affects seed filling and hence, reduced yield (Boutraa and Sanders, 2001). Water stress also reduces the quality and economic value of the crop.

Ubaidullah *et al.* (2002) revealed that different irrigation intervals showed significant effects on all the parameters except the number of days to flowering. Maximum number of fruits per plant and fruit weight per plant, plant height and total yield were recorded in treatments irrigated at 10 days intervals, while maximum number of flower of clusters per plant (13.47) was observed at 15 days intervals of irrigation.

Plants prefer adequate water supply for functioning. However, under water conditions, create high water pressure difference between soil and plant roots initially and it continues towards canopy with the progression of the stress. This is not favorable to its normal functioning. Plants have different mechanisms to overcome water stress and can involve either tolerance or avoidance. Tolerance describes those physiological and biochemical adaptations that allow plants to survive under water stress. Avoidance is concerned with maintaining a favorable water status in the plant by adopting different physiological and biochemical processes (Malinowski and Belesky, 2000).

Besides affecting plant growth and productivity, water stress also causes secondary stresses like oxidative stress, which in turn leads to denaturation of functional and structural proteins (Wang *et al.*, 2003). Some plants like corn tend to produce toxic chemicals, such as nitrates under water deficiency, which are lethal to livestock (Livingston *et al.*, 1995).

Plant vascular bundles have a major role in the transport of water and nutrients in tomatoes. It was found that the rate of flow of xylem fluids was reduced and hydraulic resistance at the pedicel and the peduncle increased with water stress (Van Ieperen *et al.*, 2003). Salleo *et al.* (2000) tested the effects of xylem cavitation on stomatal conductance in Laurel (Laurus nobilis L.). Cavitation was measured using ultrasound acoustic emissions (UAE) and when water potential was reduced, UAE level increased. Increased UAE level indicates, that the high loss of hydraulic conductance due to reduced rate of xylem fluid flow.

There is a significant reduction in Smit and Singles (2006) studied how canopy development was affected by water stress in sugarcane. Poor canopy development reduces light interception, and their photosynthesis. Furthermore, they showed that the water stress increased leaf senescence and led to yield reduction. Bosabalidis and Kofidis (2002) proved that water stress results in a decrease in size of both mesophyll and epidermal cells in olive, however, the cell density increased.

Different parts of a plant respond differently to water deficit. Leaves have different strategies when they are under water stress. Leaf rolling, leaf shedding or low stomatal conductance is the main responses of the leaf to water stress (Hu *et al*, 2006). Stomatal closure helps to minimize transpiration. Root growth increase with water stress. Accumulation and translocation of assimilates, maintaining cell wall elasticity and osmotic adjustment are some of the other water stress tolerance mechanisms exhibited by plants (Malinowski and Belesky, 2000).Plant growth under water stress. Initially, turgor pressure is reduced and this results in reduction of cell elongation (Farooq *et al.*, 2009). Also, water stress causes damage in mitosis which results in limited cell division. Both reduced cell elongation and limited cell division negatively impacts plant growth (Farooq *et al.*, 2009).

Plant water potential influences physiological functions of plants, including photosynthesis, transpiration, respiration, photorespiration, stomatal conductance (Chaves *et al.*, 2002; Blanke and Cooke, 2004; Flexas *et al.*, 2004). Rizhsky *et al.* (2002) observed that respiration was reduced with water stress. Bell *et al.* (1971) noted that the mitochondrial oxygen uptake declined with an increase in water stress in maize. Furthermore, Burton *et al.* (1998) observed limited root respiration with water in sugar maple. Ribas-Carbo *et al.* (2005) found that respiration rate was diminished with a rise in water stress in soybean leaves. However, photorespiration was greater in water stressed soybean than in non-stressed plants (Haupt-Herting *et al.*, 2001).

As water stress progresses, it reduces the leaf water potential and stomatal conductance (Smit and Singles, 2006). Blanke and Cooke (2004) found that the leaf water potential reduced under severe water stress, but Miyashita *et al.* (2005) discovered that the leaf water potential stayed constant for a period after the onset of water and then reduced rapidly. Furthermore, the recovery after re-watering declined gradually when the water stress progressed. Reduction of leaf water potential with stress also affected leaf relative water content. Leaf relative water content was reduced with water (Turkan *et al.*, 2005; Valentovic *et al.*, 2006).

When a plant is subjected to water, there is an increase in ABA biosynthesis, leading to elevated ABA levels in the tissues (Plant *et al.*, 1991). The increase in the ABA concentration in leaves results in stomatal closure and minimal water loss from the plant. However, the stomatal closure reduces photosynthesis (Zegzouti *et al.*, 1997). High ABA concentration in root tips was observed in plants subjected to water stress (-1.6 MPa) (Sharp and LeNoble, 2002). Bray (1988) studied the role of ABA in water, using an ABA deficient tomato. In optimal growth conditions, ABA concentration in this mutant was 50% of the wild type plant. When both the wild type and mutant were exposed to water stress, there was a significant increase in the synthesis of ABA in the wild type but reduced in the mutant. It was recorded that the ABA concentration of the mutant under water stress was 6% of its ABA concentration grown under optimal conditions.

Rahman *et al.* (1999) found that water stress decreased yield, flower number, fruit set percentage and dry matter production in all varieties tested. Photosynthetic rate (Pr), transpiration rate (T), leaf water potential (ψ) WUE were reduced and leaf temperature (T) and stomatal resistance (r) were increased by water stress in all cultivars.

A field experiment was conducted by Kirda and Kanver (1998). They stated that Crop quality may be increased with proper deficit irrigation practice. It has been observed that protein content and baking quality of wheat (Triticum aestivum L.) fiber length and strength of cotton (Gossypium hirsutum L.) and sugar concentration of sugar beet (Beta vulgaris L.) and grape (Vitis vinifera L.) increase under deficit irrigation.

Karim *et al.* (1996) carried out a field experiment to determine the optimum soil moisture regimes and water requirement for achieving the maximum yield potential of tomato on a clayey terrace in Bangladesh. A maximum yield of 37.0 8 t ha-1 was obtained when allowing 30% depletion of soil available water (SAW). The total water use and the WUE were found to be 193.6 mm and 1911 kg ha-1 cm-1, respectively. They also concluded that at soil moisture depletions exceeding 40% of SAW, a severe water stress was placed on growing tomatoes, hence yield was significantly reduced.

Younghah *et al.* (1999) found that total and marketable yields were increased by increasing soil water tension and by varying night temperature (14 ± 1°C to 10 ± 1°C). Fruit cracking decreased with increasing soil water tensions. They also found that total yield was positively correlated to soil water. Soluble solids content, total acidity and citric acid content were higher in cracked fruits than in normal fruits.

Water is a vital substrate in the photosynthetic process. Crop production as well as plant growth is restricted by water scarcity. If deficit irrigation programs are in practice, throughout the growing season or during a particular growth period, plants are exposed to specific levels of water stress. This occurs where evapotranspiration demand or crop water requirements are significantly reduced. Close to optimum yields can be obtained under deficit irrigation, providing a specific amount of yield reduction of a given crop with a certain amount of water-saving. The saved water can be used in irrigating other areas or crops. This innovative concept has been given different name such as deficit irrigation, deficient evapotranspiration (ET) or irrigation and limited irrigation (English *et al.* 1990).

CHAPTER III
MATERIALS AND METHODS

The experiment was conducted during the period from November 2018 to March 2019 to study the effect of water stress in different tomato varieties. The materials and methods that were used for conducting the experiment have been presented in this chapter. It includes a short description of the location of experimental site, soil and climate condition of the experimental area, materials used for the experiment, design of the experiment, data collection and data analysis procedure.

3.1 Location of the experimental site

The experiment was conducted at the Central Research Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka. It was located in 24.09˚N latitude and 90.26˚E longitudes. The altitude of the location was 8 m from the sea level as per the Bangladesh Metrological Department, Agargaon, Dhaka.

3.2 Characteristics of soil that used in plot

Experimental site belongs to the Modhupur Tract (UNDP, 1988) under AEZ No. 28 and the soil of the plot was medium high in nature with adequate irrigation facilities and remained fallow during the previous season. The soil texture of the experiment was sandy loam. The nutrient status of soil under the experimental plot were collected and analyzed in the Soil Resource Development Institute, Dhaka and results have been presented in Appendix II.

3.3 Climatic condition of the experimental site

Experimental area is situated in the sub-tropical climate zone, which is characterized by heavy rainfall during the months of April to September and scanty rainfall during the rest period of the year. Details of the meteorological data during the period of the experiment was collected from the Bangladesh Meteorological Department, Agargoan, Dhaka and presented in Appendix III.

3.4 Planting materials

Seedlings of 30 days of Mintoo HYV, BARI Tomato-4 and BARI Tomato-14 were used as planting material. The seedlings of tomato were grown at the nursery of Central Farm of Sher-e-Bangla Agricultural University. Mintoo HYV, BARI Tomato-4 and BARI Tomato-14 as high yielding varieties of Tomato was developed by the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, Bangladesh.

3.5 Treatment of the experiment

The experiment consisted of two factors:

Factor A: Different varieties

V_1 = Mintoo HYV

V_2 = BARI Tomato-4 variety and

V_3 = BARI Tomato-14 variety

Factor B: Different levels of water stress

T_0: Control (no stress)

T_1: Stress at early fruiting stage,

T_2: Stress at mid fruiting stage and

T_3: Stress at late fruiting stage

There were 12 (3 × 4) treatments combination such as:

V_1T_0, V_1T_1, V_1T_2, V_1T_3, V_2T_0, V_2T_1, V_2T_2, V_2T_3, V_3T_0, V_3T_1, V_3T_2 and V_3T_3

3.6 Design and layout of the experiment

The two factors experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. An area of 35 m x 12 m was divided into 12 equal blocks. Each block consisted of 3 plots where 4 treatments were allotted randomly. There were 36-unit plots altogether in the experiment. The size of each plot was 2 m x 1.8 m. The distance between two blocks and two plots were l m and 0.5 m respectively. Seedlings were transplanted on the plots with 60 cm x 40 cm spacing.

3.7 Raising of seedlings

A common procedure was followed in raising of seedlings in the seedbed. Tomato Seedlings were raised in one seedbed on a relatively high land at Central Farm of Sher-e-Bangla Agricultural University, Dhaka. The size of the seedbed was 3m × 1 m. The soil was well prepared with spade and made into loose friable and dried mass to obtain fine tilth. All weeds and stubbles were removed and 5 kg well rotten cow dung was applied during seedbed preparation. The seeds were sown in the seedbed at 16 November, 2018 to get 30 days old seedlings. Germination was visible 3 days after sowing of seeds. After sowing, seeds were covered with light soil to a depth of about 0.6 cm. Heptachlor 40 WP was applied @ 4 kg ha^{-1} around each seedbed as precautionary measure against ants and worm. Necessary shading by banana leaves was provided over the seedbed to protect the young seedlings from scorching sun. Weeding, mulching and irrigation were done from time to time as and when required and no chemical fertilizer was used in this seedbed.

3.8 Preparation of seedbed

A ratio of 1:3 well rotten cow dung and soil were mixed 15 days before transplanting. Silty Loam soils were used for plot preparation. Weeds and stubbles were completely removed from the soil.

3.9 Uprooting and transplanting of seedlings

Healthy and uniform 30 days old seedlings were uprooted separately from the seedbed and were transplanted in the experimental plots in the afternoon of 16 December, 2018 maintaining two seedlings in each pot. The seedbed was watered before uprooting the seedlings from the seedbed so as to minimize damage to roots with ensuring maximum retention of roots. The seedlings were watered after transplanting. Shading was provided using banana leaf sheath for three days to protect the seedlings from the hot sunlight and removed after seedlings were established.

3.10 Application of manure and fertilizers

The collected soil was measured as a cubic meter by applying length (m) × width (m) × high (m). For field crops, a depth of soil is considered 15 cm (0.15m). So, one decimal land is (40.5m2× 0.15 m) = 6.075 m^3 (approximate) which has considered as a root zone soil. Total volume of collected soil was calculated which has found 14.65 m^3 considering Length 3.5 m × width 3.1 m × height 1.35 m. Recommended fertilizer dose for tomato for very low status soil: organic matter, urea (Total nitrogen: minimum 46%), MP (as Muriate of potash: 60% K_2O), TSP (as Triple Super Phosphate: 48% P_2O_5) and gypsum (as $CaSO_4.2H_2O$

containing 19% S) for one decimal land is 50 kg, 1.6 kg, 0.68 kg, 0.5 kg, and 0.43 kg which has considered for 6.075 m^3 of root zone soil, respectively (FRG 2012). Total soil volume was 14.65 m^3 and one decimal is equal to 6.075 m3. So, a comparison was made to estimate the exact amounts of organic matter, MP, TSP and Gypsum has found organic matter OM = 120.6 kg, MP = 1.64 kg, TSP = 1.20 kg, Gypsum = 1.04 respectively. Finally, the calculated amount of organic matter, half of MP and all required TSP and Gypsum were applied prior filling the pot with soil. One decimal land can be accommodating 60 plants considering spacing row to row and plant to plant 50 cm × 50 cm. Our total plants under experimentation were 108 which needed 1422 g of urea for three time of application. Each time @ 3.30 g urea per plant was applied at 15, 30 and 45 days after transplanting as a ring method. Rest half of MP was applied in two split doses at 30 and 45 days after transplanting at the time of 2nd and 3rd dose of urea application. Each time @ 3.42 g MP was applied per plant.

3.11 Application of the treatments (Water stress)

Common irrigation method was used to find out proper strategy to irrigate tomato plants, growth stage of tomato plant was considered for the different level of stress at early fruiting stage, mid fruiting stage and at late fruiting stage.

3.12 Intercultural operations

3.12.1 Gap filling

Very few seedlings were damaged after transplanting and these were replaced by the new seedlings from the same stock.

3.12.2 Weeding

Weeding was done whenever it was necessary, mostly in vegetative stage.

3.12.3 Staking

When the plants were well established, staking was given to each plant by bamboo sticks for support to keep them erect.

3.12.4 Plant protection measures

Melathion 57 EC was applied @2 ml L^{-1} of water against the insect pests like cutworm, leaf hopper, fruit borer and others. The insecticide application was made fortnightly after transplanting and was stopped before two weeks of first harvest. Furadan 10 G was also applied during pot preparation as soil insecticide. During foggy weather precautionary measure against disease attack of tomato was taken by spraying Diathane M-45 fortnightly @2 g L^{-1} of water at the early vegetative stage. Ridomil gold was also applied @ 2 g L^{-1} of water against blight disease of tomato.

3.13 Harvesting

Fruits were harvested at 3 days interval during early ripe stage when they developed slightly red color. This indeterminate type of fruit harvesting was started from last week of February and was continued up to first week of March, 2019.

3.14 Data collection

Experimental data were recorded from 30 days after transplanting and continued until harvest. The following data were recorded during the experimental period.

A. Morphological characteristics

3.14.1 Plant height (cm)

Plant height was measured from plant of each unit plot from the ground level to the tip of the longest stem and mean value was calculated. Plant height was recorded at 15 days interval starting from 30, 45 days and 60 DAT.

3.14.2 Number of leaves per plant

The total number of leaves per plant was counted from plant of each unit pot. Data was recorded at 15 days interval starting from 30 days to 60 DAT.

3.14.3 Number of branches per plant

The total number of branches per plant was counted from plant of each unit pot. Data was recorded at 15 days interval starting from 30 days to 60 DAT.

3.14.4 Leaf area (cm^2)

Leaf area (LA) was determined from plant samples by using an automatic leaf area meter (Model LI-3100, Li-COR, Lincoln, NE, USA) immediately after removal of leaves from plants to avoid rolling and shrinkage. Leaf area was recorded at flowering stage and 30 days after flowering.

B. Physiological characteristics.

3.14.5 SPAD value

The SPAD meter is a hand-held device that is widely used for the rapid, accurate and non-destructive measurement of leaf chlorophyll concentrations. Chlorophyll content of leaf was determined from plant samples by using an automatic SPAD meter. SPAD was recorded at first flowering stage and 30 days after flowering.

3.14.6 % Moisture in fruit

Wight of fresh fruit of each plant was taken. Fruit was pressed so that some moisture was released and it was kept in hot air oven at 80°C for 48 hours. After 48 hours, dry weight of fruit was measured and percentage of Moisture content was measured by following formula:

$$\text{\% Moisture content} = \frac{\textit{Weight of fresh fruit} - \textit{Weight of Oven dried fruit}}{\textit{Weight of fresh fruit}} \times \mathbf{100}$$

3.14.7 Dry matter of fruits (%)

After harvesting, randomly selected 100 g fruit sample sliced into very thin pieces were put into envelop and placed in oven maintained at 60°C for 72 hours. The sample was then transferred into desiccators and allowed to cool down at room temperature. The final weight of the sample was taken. The dry matter contents of fruit were computed by the following formula:

$$\text{\% Dry matter content of fruit} = \frac{\textit{Dry weight of fruit}\ (g)}{\textit{Fresh weight of fruit}(g)} \times \mathbf{100}$$

C. Yield and yield contributing characteristics

3.14.8 Number of flower cluster plant^{-1}

The number of flower cluster was counted from plant of each unit plot and the numbers of flower clusters produced per plant were recorded.

3.14.9 Number of flowers cluster^{-1}

The number of flowers was counted from plant of each unit plot and number of flowers produced per cluster was recorded on the basis of flower cluster per plant.

3.14.10 Number of fruits plant^{-1}

The number of fruits per plant was counted from plant of each unit plot and the average number of fruits per plant was recorded.

3.14.11 Number of fruits drop due to stress

The number of fruits drop due to stress was counted from plants of each unit plot and average the number of fruits drop due to stress was recorded.

3.14.12 Length of fruit (cm)

The length of fruit was measured with a slide calipers from the neck of the fruit to the bottom of 5 selected fruits from each plot and their average was taken and expressed in cm.

3.14.13 Diameter of fruit (cm)

Diameter of fruit was measured at the middle portion of 5 selected fruit from each plot with a slide calipers and their average was taken and expressed in cm.

3.14.14 Weight of individual fruit (g)

Among the total number of fruits during the period from first to final harvest the fruits, except the first and final harvest, was considered for determining the individual fruit weight by the following formula:

Weight of individual fruit (g) = $\frac{\textit{Total weight of fruit per plant}}{\textit{Total number of fruit per plant}}$

3.14.15 Yield plant^{-1} (kg)

Yield of tomato per plant was recorded as the whole fruit per plant harvested in different time and was expressed in kilogram.

3.14.16 Yield (t/ha^{-1})

Yield per hectare of tomato fruits was calculated by converting the weight of total plant yield into hectare on the basis of total plant population of tomato per hectare and expressed in ton.

Relative performance

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

$$\text{Relative performance} = \frac{\textbf{Variable measured under stress condition}}{\textbf{Variable measured under normal condition}} \times 100$$

3.15 Statistical analysis

The data obtained for different characters were statistically analyzed by using MSTAT-C computer package program to find out the significance of the difference for water stress on yield and yield contributing characters of tomato. The mean values of all the recorded characters were evaluated and analysis of variance was performed by the F (variance ratio) test. The significance of the difference among the treatment combinations of means was estimated by Duncans Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULT AND DISCUSSION

The experiment was conducted to study of water stress at different fruiting stage of some tomato varieties. Data on different growth and yield parameter were recorded. The analyses of variance (ANOVA) of the data on different growth and yield parameters are presented in Appendix IV-XIV. The results have been presented and discusses with the help of table and graphs and possible interpretations given under the following sub headings;

4.1 Plant height (cm)

Plant height is one of the most important growth parameters that indicates vegetative growth trend of plants. The varieties used for this experiment have both semi-determinate and determinate growth habit. So, for easy understanding and comparison of vegetative growth of tomato, plant height was recorded at different days after transplanting (30, 45 and 60 DAT) has been shown in Figure 1.

Analysis of variance also indicated that the effect of tomato varieties on plant height for different levels of water stress at 30, 45 and 60 days after transplanting (DAT)

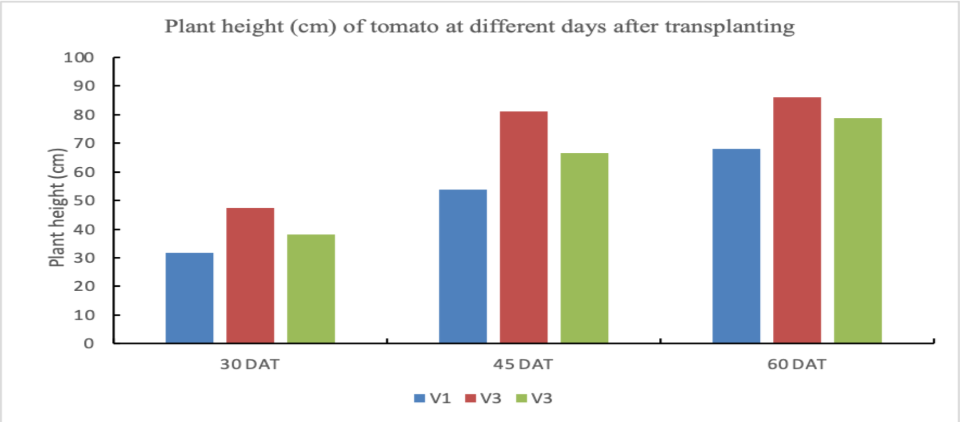

Figure 1. Effect of water stress on plant height (at different days after transplanting, 30 DAT, 45 DAT and 60 DAT, respectively) of different tomato variety

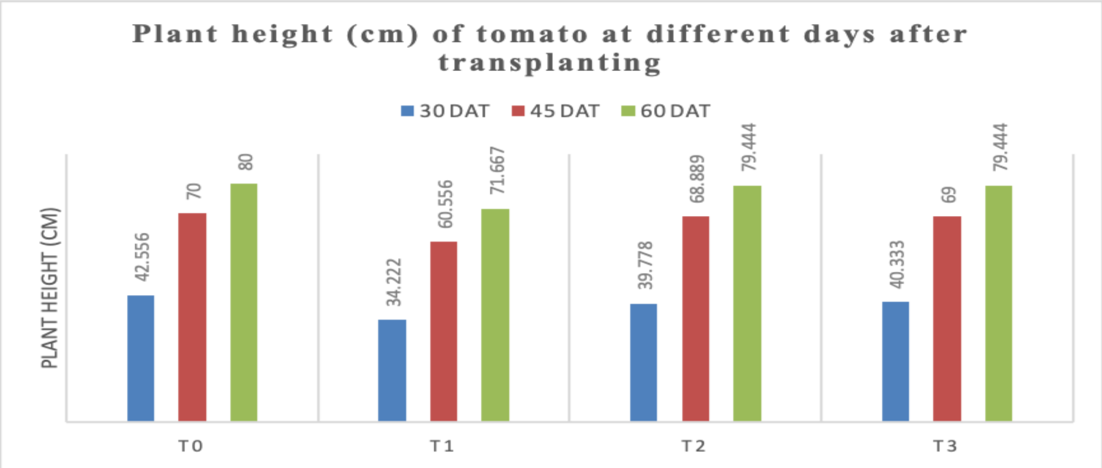

Figure 2. Effect of water stress at 30, 45 and 60 days after transplanting on plant height at different treatment

From the result of plant height at different days after transplanting and final harvest (Fig.1), it can be stated that plants of all varieties possessed a normal growth rate in under water stress. It is clear that variety has significant effect on plant growth rate and they differ from each other. Growth of BARI Tomato-4 was significantly higher in early vegetative to successive days after planting indicating its hybrid vigour over the other varieties. Although growth rate (indicated by plant height) of BARI Tomato-14 is initially a little bit slower than BARI Tomato-4 but final plant height indicated its potential ability to grow over the growth stages up to 60 DAT.

For combination of variety and treatment under controlled condition, plant height increased with time and reaching its maximum near fruiting stage. Considering all the varieties and treatments, the highest plant height was recorded in BARI tomato 4 at 30 DAT for controlled treatment which was similar to control treatment of BARI tomato 4 (Table 1) for 45 and 60 DAT also. Considering the treatment T0 at 30 DAT plant height was recorded (42.55 cm). For combination of variety and treatment V_2T_2 (BARI Tomato-4 and water stress at mid fruiting stage) gives the highest plant length for all 30, 45 and 60 DAT simultaneously. The reduction in irrigation during any fruiting stage decreased soil moisture. Many studies have shown that, in general, deficit irrigation depresses tomato vegetative growth under water stress conditions (Jensen *et al.*, 2010),

Table 1: Effect of different water stress treatment on plant height at different days after transplanting (DAT) of some tomato varieties.

Treatment combination	Plant height (cm)		
	30 DAT	45 DAT	60 DAT
V_1T_O	37.67 cd	62.33 ef	72.00 f
V_1T_1	25.67 f	46.34 h	61.33 g
V_1T_2	30.34 e	51.67 gh	67.00 fg
V_1T_3	33.67 de	54.68 fgh	71.67 f
V_2T_0	48.35 a	77.00 bcd	85.00 abc
V_2T_1	45.67 ab	77.66 abc	81.33 cd
V_2T_2	47.68 a	86.00 a	89.67 a
V_2T_3	48.65 a	83.33 ab	88.33 ab
V_3T_0	41.68 bc	70.67 cde	83.00 bcd
V_3T_1	31.35 e	57.65 fg	72.34 ef
V_3T_2	41.33 bc	69.00 de	81.67 cd
V_3T_3	38.67 c	69.00 de	78.35 de
LSD	4.58	8.36	6.17
CV%	6.87	7.37	4.69

[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]

(Variety: V1: Mintoo variety, V2: BARI Tomato 4 variety and V3: BARI Tomato 14 variety and treatments: T0: Control, T1: Stress at early fruiting stage, T2: Stress at mid fruiting stage and T3: Stress at late fruiting stage)

4.2 Number of leaves plant^{-1}

Statistically significant variation was recorded for number of leaves plant^{-1} of tomato due to different levels of moisture at 30, 45 and 60 DAT under the present trial (Appendix IV).

The number of leaves per plant was different at 30, 45 and 60 DAT. For 30 DAT V_2 (BARI Tomato-4) shows the highest number of leaves per plant as (18.66) where the other two varieties show no significant difference for number of leaves per plant. Figure 3. For treatments no significant was observed for all three varieties. (Figure 4)

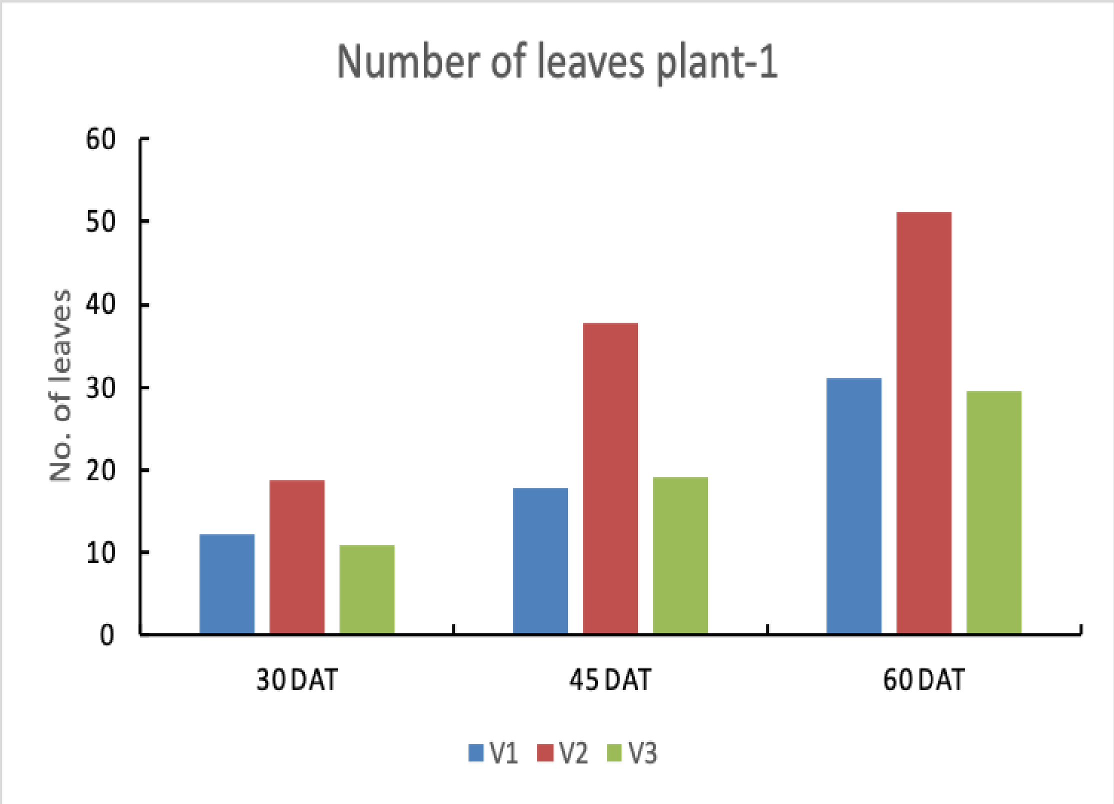

Figure 3: Effect of different levels of stress on the number of leaves plant^{-1} of tomato at different days after transplanting (DAT) on variety

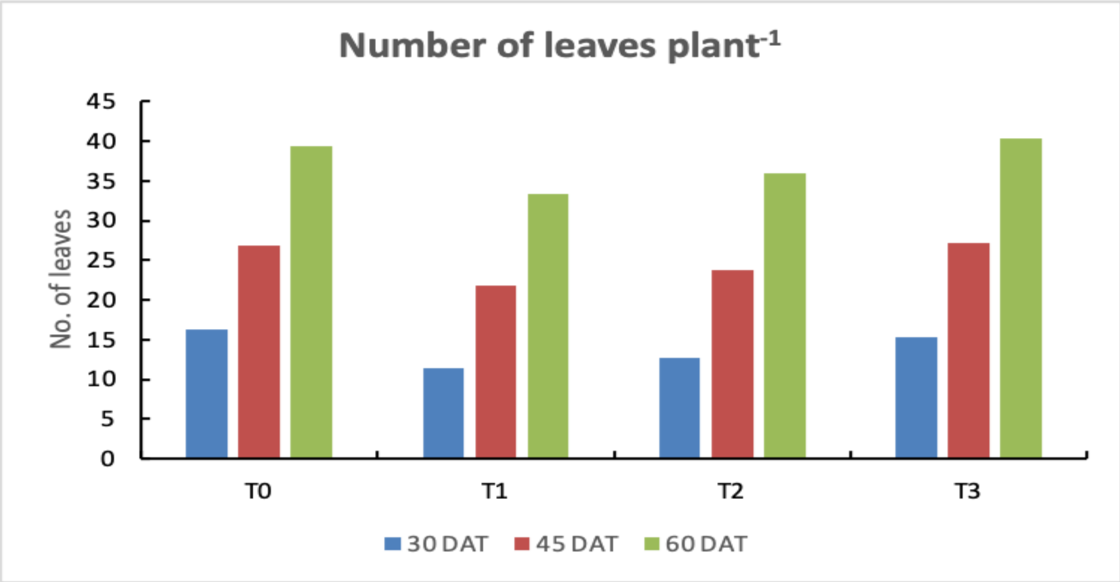

Figure 4: Effect of different levels of water stress on the number of leaves plant^{-1} of tomato at different days after transplanting (DAT) on treatment

Considering the treatment there is no significant difference between the treatments applied as T_0 and T_3 gives the number of leaves 16.33, 15, 33 respectively which is statistically similar at 30 DAT, and similar results can be found for 45 DAT and 60 DAT as well. (Table 2)

In case of treatment combination with variety number of leaves per plant was statistically insignificant and at 30 DAT V_2T_0 (BARI Tomato 4 variety and control stress) gives the highest value (20.67) and for 60 DAT similar trend can be found also. It is clear that neither variety nor treatment has significant effect on number of leaves per plant only weather effects this trait for all tomato varieties. Tomato is considered to be a crop that has a high-water demand but is moderately tolerant to water stress (Karlberg *et al.*, 2007). Irrigation is the most important source of water for tomato in high tunnels, making it one of the key determinants to affect both fruit yield and vegetative growth. The tolerance of tomato to water deficit depends on the variety, the growth stage at which the deficit occurs, and the severity of the water stress (Patanè *et al.*, 2011).

Table 2: Effect of different water stress treatment on number of leaves plant^{-1} at different days after transplanting (DAT) of some tomato varieties.

Treatment	Number of leaves plant^{-1}		
	30 DAT	45 DAT	60 DAT
V_1T_0	14.33 d	41.000 a	31.00 gh
V_1T_1	9.00 f	39.000 b	28.67 i
V_1T_2	11.33 e	36.333 c	29.66 hi
V_1T_3	14.00 d	35.000 c	34.67 e
V_2T_0	20.67 a	21.667 d	55.33 a
V_2T_1	16.66 c	20.667 de	47.00 d
V_2T_2	17.68 bc	19.667 ef	49.00 c
V_2T_3	19.66 ab	19.667 ef	53.33 b
V_3T_0	14.00 d	18.667 f	31.67 fg
V_3T_1	8.33 f	16.333 g	24.33 j
V_3T_2	9.00 f	16.000 g	29.33 hi
V_3T_3	12.33 de	14.333 h	33.00 ef
LSD	2.28	1.50	1.89
CV%	9.67	3.56	2.99

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.3 Number of branches plant^{-1}

Plants develop strong branch number was found in BARI Tomato-4 which was statistically similar to Mintoo Tomato but varied significantly with BARI Tomato-14 (Table 3). Branch supply water and other mineral salts for ensuring proper growth and development. From the result of statistical analysis of number of branches per plant accumulation (Karlberg *et al.*, 2007), it was found that relative development of branch system of two BARI Tomato varieties varied significantly as influenced by variety. As like the plant height, branch development of BARI Tomato-4 was also better compared to other Tomato varieties which indicating higher branch number. Different levels of water stress varied significantly in terms of number of branch plant^{-1} of tomato for at 30, 45 and 60 days after transplanting (DAT) under the present trial. Treatment combination was considered and for all 30, 45 and 60 DAT V_2T_0 for BARI Tomato-4 and control treatment.

Table 3: Effect of different water stress treatment on number of branches plant^{-1} at different days after transplanting (DAT) some tomato varieties

Treatment	Number of branches plant^{-1}		
	30 DAT	**45 DAT**	**60 DAT**
V_1T_0	9.33 ab	12.667 ab	19.333 cd
V_1T_1	5.34 e	10.667 cd	18.667 d
V_1T_2	5.67 e	12.333 abc	18.667 d
V_1T_3	7.33 d	12.667 ab	19.333 cd
V_2T_0	9.67 a	14.000 a	22.667 a
V_2T_1	8.66 abc	11.000 bcd	20.667 bc
V_2T_2	8.00 cd	12.333 abc	22.667 a
V_2T_3	8.33 bcd	13.333 a	22.000 ab
V_3T_0	6.00 e	11.333 bc	18.000 d
V_3T_1	2.33 f	7.333 f	11.333 f
V_3T_2	3.33 f	8.333 ef	15.000 e
V_3T_3	5.67 e	9.333 de	18.000 d
LSD	1.09	1.86	1.90
CV%	9.78	9.75	5.96

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.4 Leaf area (cm^2)

Statistically significant variation was recorded for leaf area at flowering stage and 40 days after flowering (Appendix VI). The maximum leaf area was recorded at flowering stage for treatment V_1T_0 (Mintoo variety with control treatment). The total leaf area indicates amount of sunlight accumulation and vegetative growth trends to flowering and fruiting. Lowest leaf area resulted from V_3T_3 at first flowering for the variety BARI Tomato 14. (Table 4 and 5).

In case of leaf area relative to control, Leaf area of Mintoo variety got less affected at early fruiting stage while most stressed condition showed at late fruiting stage which is 5.79% reduced relative to control. In term of BARI Tomato 4 variety, Leaf area got less affected at early fruiting stage while most stressed condition observed at late fruiting stage which is 27.08% less which is the highest reduction of leaf area relative to control among all the varieties and BARI Tomato 14 variety got less affected at mid fruiting stage while this variety became most stressed at same stage like both Mintoo and BARI tomato-4 variety presented at table 4 and 5.

Table 4: Effect of different water stress treatment on leaf area (cm^2) of some tomato varieties at first flowering stage

Treatment	Leaf area (cm^2) at first flowering	% Relative to control
V_1T_0	893.00 a	--
V_1T_1	884.00 b	98.99%
V_1T_2	873.67 c	97.84%
V_1T_3	841.33 d	94.21%
V_2T_0	690.67 e	--
V_2T_1	641.00 f	92.81%
V_2T_2	609.33 g	88.22%
V_2T_3	503.67 ij	72.92%
V_3T_0	543.67 h	--
V_3T_1	505.00 i	92.88%
V_3T_2	498.00 j	91.60%
V_3T_3	476.67 k	87.68%
LSD	5.81	--
CV%	0.52	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

Table 5: Effect of different water stress treatment on leaf area (cm^2) at 40 days after flowering (DAF) of some tomato varieties

Treatment	Leaf area (cm^2) at 40 DAF	% Relative to control
V_1T_0	1005.0 a	--
V_1T_1	961.7 b	95.69%
V_1T_2	903.7 d	89.92%
V_1T_3	915.0 c	91.04%
V_2T_0	840.3 e	--
V_2T_1	813.3 f	96.79%
V_2T_2	791.0 g	85.56%
V_2T_3	758.0 h	90.21%
V_3T_0	492.7 i	--
V_3T_1	492.0 i	99.85%
V_3T_2	485.0 j	98.43%
V_3T_3	473.0 k	96%
LSD	4.76	--
CV%	0.38	--

[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]
(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.5 SPAD values

SPAD (Soil Plant Analysis Development) meter reading of leaf was analysed and presented in order to having an idea about relative leaf chlorophyll content per unit leaf area of the tomato varieties. Analysis of variance indicated that the effect of tomato varieties on relative chlorophyll content of leaf (Table 6). Effect of variety on relative chlorophyll content of leaf during winter season, LSD value was varied significantly during the season. Significant variation was observed for SPAD values of tomato 30 days after flowering (Appendix VI). At flowering stage of 30, 45 and 60 DAF days after flowering, the highest SPAD values 62.12, 59.83 and 62.7 (nm) respectively was obtained from V_1 Mintoo variety. At flowering stage of 30, 45 and 60 DAF (days after flowering), considering the treatments no statistically significant data was recorded for 30 and 60 DAF, but at 45 DAF T_2 shows the highest SPAD value (61.87 nm). The higher SPAD value obtained from the Mintoo tomato variety indicated that leaves of this variety contained relatively higher but statistically similar amount of chlorophyll per unit leaf area compare to the later one. (Table 7)

As the SPAD value was measured until 60 DAF, effect of treatment can clearly visible for early fruiting stage water stress % reduction over control was 96.20% comparing to control treatment (100%). Total marketable fruit yields were highest comparing to SPAD value for controlled treatment which only differed significantly from the water stress at early mid and late fruiting stage as treatment. Total, marketable, and weighted yield values in control treatment was higher 89.29 t/ha. In BARI tomato 14, where lowest SPAD value leads the yield reduction 87.05% at early fruiting stage water stress comparing to control treatment (100%). Weighted yield indicates the production cash value as it takes into account the price relationships between each fruit size grade (Fontes, 1997).

For interaction of variety and treatment, highest SPAD value found in V_3T_0 (BARI Tomato 14 and control treatment). This data also reflects the yield performance as the highest yield was obtained from the similar treatment combination V_3T_0 (BARI Tomato 14 and control treatment) (Table 12). Which supports the information SPAD value mirrors crop quality and crop yield by providing an indication of the amount of chlorophyll present in plant leaves, Konikaminolta, (2009).

Table 6: Effect of different water stress treatment on SPAD value of some tomato varieties at flowering stage of 30, 45 and 60 days after flowering (DAF)

Variety	SPAD value of tomato at		
	30 DAF	**45 DAF**	**60 DAF**
V_1	62.13 a	59.833 a	62.7 a
V_2	58.25 b	58.692 a	57.78 b
V_3	57.81 b	59.317 a	59.85 ab
LSD	2.863	2.924	3.963
CV%	5.79	5.92	7.92

[Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety]

Table 7: Effect of different water stress treatment on SPAD value of tomato at flowering stage of 30, 45 and 60 days after flowering (DAF)

Variety	SPAD value of tomato at		
	30 DAF	**45 DAF**	**60 DAF**
T_0	60.622 a	60.4 ab	61.267 a
T_1	58.778 a	57.633 bc	62.211 a
T_2	58.789 a	61.878 a	57.556 a
T_3	59.4 a	57.211 c	59.311 a
LSD	3.8561	2.808	4.769
CV%	6.74	4.92	8.25

[T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage]

Table 8: Effect of different water stress treatment on SPAD value of some tomato varieties at flowering stage of 30, 45 and 60 days after flowering

Treatment	SPAD value of tomato at		
	30 DAF	45 DAF	60 DAF
V_1T_0	65.90 a	59.06 cd	64.10 b
V_1T_1	60.60 bcd	57.07 def	62.33 bc
V_1T_2	59.80 bcd	62.13 ab	60.90 cd
V_1T_3	62.20 b	61.07 bc	63.47 b
V_2T_0	54.23 ef	57.87 de	52.70 f
V_2T_1	62.40 b	56.77 def	67.23 a
V_2T_2	58.70 cd	64.50 a	52.83 f
V_2T_3	57.67 de	55.63 ef	58.07 e
V_3T_0	61.73 bc	64.27 a	67.00 a
V_3T_1	53.33 f	59.06 cd	57.07 e
V_3T_2	57.87 d	59.00 cd	58.93 de
V_3T_3	58.33 cd	54.93 f	56.40 e
LSD	3.47	2.87	2.56
CV%	3.44	2.86	2.52

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.6 Moisture % of fruits

Water stress shows significant effect on moisture % of fruits. Moisture of fruits was drastically reduced due to water stress at late fruiting stage for all varieties as V_1T_0 BARI Tomato 4 with the control treatment shows highest moisture level of 94.67% and for V_3T_3 BARI Tomato 14 with the treatment of late fruiting stage water stress gives the least moisture level of 84%. Moisture content of fruit affects the fruit quality as lower moisture content of fruit loss its commercial acceptance as well as market value. Data shows that water stress at late fruiting stage reduce moisture content of fruits drastically (Table 9). It is likely that deficit irrigation for treatment T_0 did not affect total fruit and marketable yield compared to the water stress at early mid and late fruiting stages as treatment.

In case of moisture content of fruit relative to control, moisture content of Mintoo variety got less affected at early fruiting stage while highest reduction of moister content observed at late fruiting stage which is 10.99% reduction relative to control which is the highest reduction of moister among all the varieties. In term of BARI Tomato 4 variety, moisture content got less affected at early fruiting stage while highest reduction found at late fruiting stage which is 8.6% reduction relative to control and BARI Tomato 14 variety got less affected at same stage like both mintoo and BARI tomato-4 while highest loss of moister observed at late fruiting stage at (9.36%). presented at table 9. As studies have shown that water limitations during the vegetative stage occur too early to affect fruit yield. Fruit moisture content and dry matter % are concerns for both growers and consumers because they impact the storage quality of tomato (Kader, 2008).

Table 9: Effect of different water stress treatment on %moisture content of some tomato varieties.

Treatment	%moisture content of fruit	%moisture content of fruit relative to control
V_1T_0	94.67 a	--
V_1T_1	91.33 b	96.47%
V_1T_2	87.33 cd	92.25%
V_1T_3	84.34 de	89.01%
V_2T_0	93.00 ab	--
V_2T_1	92.67 ab	99.65%
V_2T_2	90.66 b	97.49%
V_2T_3	85.00 de	91.40%
V_3T_0	92.67 ab	--
V_3T_1	92.00 ab	99.27%
V_3T_2	90.33 bc	97.47%
V_3T_3	84.00 e	90.64%
LSD	3.16	--
CV%	2.08	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.7 Dry matter of fruit (%)

Dry matter content of fruit per plant at final harvest due to the varietal effect of tomato was statistically significant during winter season considering selected tomato varieties for different levels of water stress under the present trial (Appendix VII). Starting from the late fruiting stage, fruit setting to fruit development and subsequent maturation cause large part of photosynthate accumulates into the sink of the developing fruits. The highest dry matter content of fruit V_1T_0 for Mintoo tomato with the control treatment shows highest dry matter content of 4.57% and for V_2T_2 BARI Tomato 4 with the treatment of late fruiting stage water stress gives the least dry matter content of 2.60% trends poor crop quality and lessening the market value of tomato even the yield was acceptably higher. Water stress at early fruiting stage shows statistically similar result for all tomato varieties express less or no effect of stress on Dry matter content of fruit per plant (Table 10). Highest reduction of dry matter percentage compare to control showed in Mintoo HYV at late fruiting stage water stress. 10.28% reduction occurs compared to control treatment on similar variety. Other two trial varieties, BARI tomato 4 and BARI tomato 14 showed reduction too at late fruiting stage water stress (9.21% and 3.88% respectively). Water deficit, especially during the fruiting stage, reduced fruit moisture content similar to the findings of Patanè and Cosentino (2010). Smaller fruits tend to be firmer due to an increase in % dry matter content, which was confirmed by the results in our study.

Table 10: Effect of different water stress treatment on %dry matter content of fruits of some tomato varieties.

Treatment	%Dry matter content of fruit	% Relative to control
V_1T_0	4.57 a	--
V_1T_1	4.47 b	97.81%
V_1T_2	4.13 c	90.37%
V_1T_3	4.10 c	89.72%
V_2T_0	2.80 g	--
V_2T_1	2.64 h	94.29%
V_2T_2	2.60 h	92.86%
V_2T_3	2.57 h	91.79%
V_3T_0	3.60 d	--
V_3T_1	3.55 de	98.61%
V_3T_2	3.50 ef	97.22%
V_3T_3	3.46 f	96.11%
LSD	0.08	--
CV%	1.51	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.8 Number of flowers cluster plant^{-1}

Different levels of moisture varied significantly in terms of number of flower cluster plant^{-1} of tomato presented at Table 11.

At 45 DAT, Data revealed that there was significant variation for the characters of number of flower cluster plant^{-1}. The highest number of flower cluster plant^{-1} was observed at V_1T_0 Mintoo tomato variety (31) which was followed by V_1T_1 and V_2T_0 which were statistically similar to each other. The lowest number flower cluster plant^{-1} was observed at V_3T_3 BARI Tomato 14 (8.3) which was statistically similar to all the treatment of BARI Tomato 14 variety.

At 60 DAT, Data revealed that there was significant variation for the characters of number of flower cluster plant^{-1}. The highest number of flower cluster plant^{-1} was observed at V_1T_0 Mintoo tomato variety (38) which was followed by V_1T_0 and V_2T_0 which were statistically similar to each other. The lowest number flower cluster plant^{-1} was observed at V_3T_3 BARI Tomato 14 (13.33) which was statistically similar with V_3T_1 and V_3T_2. This is similar to the findings of Ubaidullah *et al*. (2002) reported both late (high temperature with water) and early (low temperature) stress conditions affect the growth and development of the crops compared to overall performance.

Table 11: Effect of different water stress treatment on number of flower cluster plant^{-1} at 45 and 60 DAT of some tomato varieties.

Treatment	Flowers cluster plant $^{-1}$ (No.)	
	45 DAT	60 DAT
V_1T_0	32.33 a	38.33 a
V_1T_1	28.67 ab	35.00 a
V_1T_2	17.67 cd	29.33 bc
V_1T_3	19.33 c	26.67 c
V_2T_0	31.00 a	35.00 a
V_2T_1	26.33 b	31.00 b
V_2T_2	15.33 cde	21.33 d
V_2T_3	13.33 def	19.00 de
V_3T_0	12.66 efg	17.00 ef
V_3T_1	10.67 fg	16.33 efg
V_3T_2	9.33 fg	14.00 fg
V_3T_3	8.34 g	13.33 g
LSD	4.43	3.56
CV%	13.96	8.52

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.9 Number of flowers cluster^{-1}

Different levels of moisture varied significantly in terms of number of flowers cluster^{-1} of tomato presented at Table 12. The highest number of flowers cluster^{-1} (5.67) was recorded from both V_2T_0 (BARI Tomato 4 variety with control treatment) and V_3T_0 (BARI Tomato 14 variety with control treatment) which was statistically similar with V_2T_1. On the other hand, the lowest number (2.67) was recorded from V_1T_2 (Mintoo tomato with stressed at mid fruiting stage).

In case of number of flowers cluster^{-1} relative to control, number of flowers cluster^{-1} of Mintoo variety got less affected at early fruiting stage while highest reduction of number of flowers cluster^{-1} observed at mid fruiting stage which is 38.34% reduction relative to control. In term of BARI Tomato 4 variety, number of flowers cluster^{-1} got less affected at early fruiting stage while highest reduction found at mid fruiting stage which is 35.28% reduction relative to control but in term of BARI Tomato 14 variety, early fruiting stage got less affected and highest reduction was observed at same stage (41.3%) which is the highest reduction of number of flowers cluster^{-1} among all the varieties. This is similar to the findings of Nuruddin *et al.* (2003) who reported that, water stress only during flowering resulted in better yields and quality than stress at other specific developmental stages (fruiting stage) or at all times, but equal or poorer yields and water use efficiency than nonstresses plants.

Table 12: Effect of different water stress treatment on of flowers per cluster of some tomato varieties.

Treatment	Number of flowers cluster^{-1} (No.)	% Relative to control
V_1T_0	4.33 bc	--
V_1T_1	3.33 cd	76.91%
V_1T_2	2.67 d	61.66%
V_1T_3	3.33 cd	76.91%
V_2T_0	5.67 a	--
V_2T_1	4.67 ab	82.36%
V_2T_2	3.67 bcd	64.72%
V_2T_3	4.33 bc	76.36%
V_3T_0	5.67 a	--
V_3T_1	3.33 cd	58.70%
V_3T_2	4.33 bc	76.37%
V_3T_3	3.67 bcd	64.73%
LSD	1.02	
CV%	14.77	

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.10 Number of fruits plant^{-1}

Number of fruits plant^{-1} of tomato varied significantly for different levels of draught stress under the present study presented at Table 13. All the treatments were statistically similar to V_2T_0 (BARI Tomato 4 variety with control treatment) and number of fruits plant^{-1} at V_2T_0 (BARI Tomato 4 variety with control treatment) was 79.67 which was the highest number of fruits plant^{-1} too. On the other hand, the lowest number of fruits plant^{-1} (43.33) was recorded from V_3T_3

(BARI Tomato 14 variety with stress at late fruiting stage) which is statistically different from the other treatments.

In case of number of fruits plant^{-1} relative to control, number of fruits plant^{-1} of Mintoo variety got less affected at early fruiting stage while highest reduction of number of fruits plant^{-1} observed at late fruiting stage which is 34.54% reduction relative to control. It is the highest reduction of number of fruits plant^{-1} among all the varieties. In term of BARI Tomato 4 variety, number of number of fruits plant^{-1} was less affected at early fruiting stage while highest reduction found at late fruiting stage which is 33.06% reduction relative to control and in term of BARI Tomato 14 variety, early fruiting stage got less affected and highest reduction was observed at late fruiting stage too which is 31.23%. This is similar to the findings of Ubaidullah *et al.* (2002) reported both late (high temperature with water) and early (low temperature) stress conditions affect the growth and development of the crops compared to overall performance.

Table 13: Effect of different water stress treatment on number of fruits plant^{-1} of some tomato varieties

Treatment	Number of fruits plant^{-1} (No.)	% Relative to control
V_1T_0	73.33 b	--
V_1T_1	68.33 cd	93.18%
V_1T_2	58.33 g	79.54%
V_1T_3	48.00 i	65.46%
V_2T_0	79.67 a	--
V_2T_1	69.00 c	86.60%
V_2T_2	64.33 de	80.75%
V_2T_3	53.33 h	66.94%
V_3T_0	63.00 ef	--
V_3T_1	60.00 fg	95.24%
V_3T_2	53.00 h	84.13%
V_3T_3	43.33 j	68.77%
LSD	4.03	--
CV%	3.89	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.11. Number of fruit drop/plot due to stress

Plants faced with water, or simply not quite enough water, may be more likely to drop their fruit prematurely. Due to less irrigation or water stress at fruiting stage photosynthesis was negatively affected which resulted in less energy production and finally low growth and premature fruit drop. Different treatments had significant variation in terms of number of fruit drops is presented in Table 14.

Highest number of fruit drops due to early fruiting stage water stress as for V_1T_1 Mintoo tomato 43 fruits drops which is statistically different from the other treatments and it showed less effect for late fruiting stage water stress as 21 fruit drops for V_3T_3 (BARI Tomato 14 variety with stress at late fruiting stage) treatment combination accept this all treatments were statistically similar.

In case of number of fruit drops relative to control, number of fruit drops of Mintoo variety was 25% less affected at late fruiting stage while highest drop of fruits observed at early fruiting stage which is 19% more drops relative to control. In term of BARI Tomato 4 variety, number of fruit drops was more at every treatment but most was at early fruiting stage which is about 54%. It is the highest drop of fruits among all the varieties and in term of BARI Tomato 14 variety, fruit drop reduced about 25% at late fruiting stage while highest fruit drop was observed at early fruiting stage which is 34.43%.

Table 14: Effect of different water stress treatment on number of fruits drop of some tomato varieties

Treatment	Fruits drop per plot due to stress (No.)	% Relative to control
V_1T_0	36.00 c	--
V_1T_1	43.00 a	119.44%
V_1T_2	32.33 de	89.81%
V_1T_3	27.00 g	75%
V_2T_0	24.00 h	--
V_2T_1	37.00 c	154.16%
V_2T_2	33.00 d	137.50%
V_2T_3	29.33 fg	122.21%
V_3T_0	30.00 ef	--
V_3T_1	40.33 b	134.43%
V_3T_2	27.67 fg	92.23%
V_3T_3	21.00 i	70%
LSD	2.40	--
CV%	4.48	--

[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]
(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.12 Length of fruit (cm)

Water stress treatments affected the vegetative growth of tomato varieties in most of the cases. The treated tomato varieties showed a reduction in biomass production in most of the stress treatments except early fruiting stage stress treatment. This was in association with a reduction of leaf area along with smaller fruit as compared to control, Pervez *et al.* (2009). Length of fruit of tomato varied significantly for different levels of moisture under the present trial (Appendix

VIII). The highest length of fruit (6.38 cm) V_1T_0 Mintoo tomato and lowest 4.09 cm for V_3T_3 BARI Tomato 14 variety with stress at late fruiting stage treatment combination (Table 15). The effect of deficit irrigation on tomato yield and fruit size has been widely studied (Shao et al., 2015). However, in order to achieve optimal tomato production, the impact of water during different fruiting stages overall tomato yield and quality was studied. Studies water deficit sensitivity parameters quantified the responsiveness of tomato yield and quality to water stress during each fruiting stages.

Slightly different results obtained in this study where reduced fruit quality and yield reduction at early fruiting stage might be due the selected varieties (V_1: Mintoo HYV, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety), growth conditions, water management, and the indeterminate nature of the tomato crop. Water stress sensitivity indexes could be improved by considering a compromise between tomato yield, fruit size and water use efficiency as 4.80% fruit length reduced for Mintoo HYV at late fruiting stage water stress compare to control treatment of similar variety.

Table 15: Effect of different water stress treatment on length of fruit (cm) of some tomato varieties.

Treatment	**Length of fruit (cm)**	**% Relative to control**
V_1T_0	6.38 a	--
V_1T_1	6.18 b	96.87%
V_1T_2	5.94 c	93.10%
V_1T_3	5.43 d	85.20%
V_2T_0	4.96 e	--
V_2T_1	4.95 e	99.80%
V_2T_2	4.90 e	98.79%
V_2T_3	4.65 f	93.75%
V_3T_0	4.53 g	--
V_3T_1	4.42 h	97.57%
V_3T_2	4.17 i	92.05%
V_3T_3	4.09 i	90.29%
LSD	0.10	--
CV%	1.24	--

[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]
(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.13 Diameter of fruit (cm)

Acute shortage of irrigation water is adversely affecting the crop production in general and vegetable production in particular. Water stress during vegetative or early reproductive growth usually reduces yield by reducing the diameter of fruit in Tomato, Pervez *et al.* (2009). Different levels of moisture varied significantly for diameter of fruit of tomato presented at Table 15. All the treatments were statistically similar accept V_1T_0 (Mintoo tomato with control) and diameter of fruit at V_1T_0 (Mintoo tomato with control) was 6.85 cm which was the highest diameter of fruit too. On the other hand, the lowest diameter of fruit (3.83 cm) was recorded from V_3T_3 (BARI Tomato 14 variety with stress at late fruiting stage) which is statistically different from the other treatments.

In case of diameter of fruit relative to control, Mintoo variety was 12.60% affected at early fruiting stage while highest diameter of fruit observed at late fruiting stage which is 18.43% more relative to control which is the highest diameter reduction of fruits among all the varieties. In term of BARI Tomato 4 variety, diameter of fruit was reduced most at late fruiting stage which is about 7.14%. In term of BARI Tomato 14 variety, fruit diameter reduced about 11.35% at late fruiting stage.

Table 16: Effect of different water stress treatment on diameter of fruit (cm) of some tomato varieties

Treatment	Diameter of fruit (cm)	%Relative to control
V_1T_0	6.35 a	--
V_1T_1	5.55 b	87.40%
V_1T_2	5.46 b	85.98%
V_1T_3	5.18 c	81.57%
V_2T_0	4.76 d	--
V_2T_1	4.68 de	98.32%
V_2T_2	4.52 ef	94.96%
V_2T_3	4.42 fg	92.86%
V_3T_0	4.32 fg	--
V_3T_1	4.24 gh	98.15%
V_3T_2	4.06 h	93.98%
V_3T_3	3.83 i	88.65%
LSD	0.22	--
CV%	2.77	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.14 Weight of Individual Fruit (g)

Weight of individual fruit of tomato varied significantly due to effects of different levels of water stress under the present trial (Appendix IX). The highest weight of individual fruit 67.83 g was found from V_3T_0 (BARI Tomato 14 with control). On the other hand, the lowest (43.56 g) was observed from V_1T_0 (Mintoo tomato with control).

In case of weight of individual fruit relative to control, weight of Mintoo variety tomato was increased gradually from the early to late fruiting stage. In term of

BARI Tomato 4 and BARI Tomato 14 variety, the result was almost same. Pervez *et al.* (2009) and Ubaidullah *et al*. (2002) also found the similar results and they showed significant results toward water stress signifying water effects on the fruit weight of tomato.

Table17: Effect of different water stress on weight of individual fruit of some tomato varieties.

Treatment	**Weight of individual fruit (g)**	**% Relative to control**
V_1T_0	43.56 f	--
V_1T_1	31.60 h	72.54%
V_1T_2	34.50 gh	79.20%
V_1T_3	37.60 g	86.32%
V_2T_0	61.00 b	--
V_2T_1	51.73 e	84.80%
V_2T_2	52.46 de	86%
V_2T_3	55.86 cd	91.57%
V_3T_0	67.83 a	--
V_3T_1	57.63 bc	84.96%
V_3T_2	60.23 b	88.80%
V_3T_3	61.40 b	90.52%
LSD	4.10	--
CV%	4.72	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.16 Yield plant^{-1} (kg)

Different levels of water stress varied significantly in terms of yield plant^{-1} of tomato under the present trial (Appendix IX). The highest yield plant^{-1} (2.15 kg) was recorded from V_3T_0 (BARI Tomato 14 tomato with control) while the lowest yield (1.16 kg) was found from V_1T_1.

In case of relative to control treatment here we can see that in all three variety under stress condition the early fruiting stage was mostly affected by the water stress and they gradually increase their adaptability towards the water stress and the yield plant^{-1} has increased at the late stage of fruiting.

This is similar to the findings of Pervez *et al*. (2009), Nuruddin *et al.* (2003), Ubaidullah *et al.* (2002) and Karim *et al.* (1996). They observed that water stress throughout the growing season significantly reduced yield and fruit size.

Table 18: Effect of different water stress treatment on yield plant^{-1} (kg/p) of some tomato varieties

Treatment	yield plant^{-1} (kg/plant)	% Relative to control
V_1T_0	1.38 fg	--
V_1T_1	1.16 i	84.06%
V_1T_2	1.21 hi	87.68%
V_1T_3	1.29 gh	93.48%
V_2T_0	1.73 c	--
V_2T_1	1.54 de	89.02%
V_2T_2	1.60 de	92.49%
V_2T_3	1.63 cd	94.21%
V_3T_0	2.15 a	--
V_3T_1	1.41 f	65.58%
V_3T_2	1.52 e	70.70%
V_3T_3	1.86 b	86.51%
LSD	0.09	--
CV%	3.77	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

4.16 Fruit yield (t ha^{-1})

Different levels of moisture varied significantly in terms of fruit yield of tomato under the present trial. The highest fruit yield (89.29 t ha^{-1}) was recorded from V_3T_0, while the lowest fruit yield (16.83 t ha^{-1}) was found from V_1T_1.

Slightly different results obtained in this study where reduced fruit quality and yield reduction at early fruiting stage might be due the selected varieties (V_1: Mintoo HYV, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety), growth conditions, water management, and the indeterminate nature of the tomato crop. In this study, satisfactory fruit yield and quality with smaller water sensitivity were obtained for V_3 BARI Tomato 14 variety. In case of fruit yield relative to control treatment, the yield of Mintoo variety decreases (40.59%) at early fruiting stage and then gradually increases at the late fruiting stage. Same thing happened with all the three varieties but Bari tomato 4 showing average yield and relative to control about 7.48% yield loss due to water stress at late fruiting stage. Bari tomato 14 gave us highest yield but that was far below of this variety's average yield. The impact of water during different fruiting stages overall tomato yield and quality was studied. Water deficit sensitivity parameters quantified the responsiveness of tomato yield and quality to water stress during each fruiting stages (Shao *et al.*, 2015).

Table 19: Effect of different water stress treatment on fruit yield (t/ha.) of some tomato varieties

Treatment	Fruit yield (t/ha)	% Relative to control
V_1T_0	28.33 h	--
V_1T_1	16.83 k	59.41%
V_1T_2	21.14 j	74.62%
V_1T_3	23.25 i	82.05%
V_2T_0	51.73 e	--
V_2T_1	40.67 g	78.62%
V_2T_2	46.27 f	89.45%
V_2T_3	47.86 f	92.52%
V_3T_0	89.29 a	--
V_3T_1	77.73 d	87.05%
V_3T_2	81.50 c	91.28%
V_3T_3	85.10 b	95.31%
LSD	1.64	--
CV%	1.91	--

[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]

(Variety: V_1: Mintoo variety, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety and treatments: T_0: Control, T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage).

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The experiment was conducted at the Central Research Farm of Sher-e-Bangla Agricultural University (SAU), Dhaka during October 2018 to March 2019 to study the water stress in different tomato variety. The experiment consisted of two factors: Factor A: Different varieties V_1 = Mintoo HYV, V_2 = BARI Tomato-4 variety and V_3 = BARI Tomato-14 variety, and factor B: Different levels of water stress T_0: Control (no stress), T_1: Stress at early fruiting stage, T_2: Stress at mid fruiting stage and T_3: Stress at late fruiting stage. The two factors experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Data on different growth and yield parameter were recorded and significant variations were found for different levels of water stress as treatment, variety and their combined effects.

For plant height at 30 DAT for the variety V_2 gives the highest plant height (47.58 cm) and lowest for V_1 (31.83 cm). The trend looks similar for 45 and 60 DAT as well. Statistically significant variation was recorded for number of leaves plant-1 of tomato due to different levels of moisture at 30, 45 and 60 DAT under the present trial. V_2 (BARI Tomato-4) shows the highest number of leaves per plant as (18.66). Considering the treatment there is no significant difference between the treatments applied as T_0 and T_3 gives the number of leaves 16.33, 15, 33 respectively which is statistically similar at 30 DAT, and similar results can be found for 45 DAT and 60 DAT as well. Different levels of moisture varied significantly in terms of number of branches plant-1 of tomato for at 30, 45 and 60 days after transplanting (DAT) under the present trial. Treatment combination was considered and for all 30, 45 and 60 DAT V_2T_0 for BARI Tomato-4 and control treatment. The maximum leaf area was recorded at flowering stage for treatment V_1T_0 (Mintoo variety and control treatment). At flowering stage of 30, 45 and 60 DAF days after flowering, the highest SPAD values (62.12, 59.83 and 62.7, respectively) was obtained from V_1. At flowering stage of 30, 45 and 60

DAF days after flowering, considering the treatment no statistically significant data was recorded for 30 and 60 DAF, but at 45 DAF T_2 shows the highest SPAD value (61.87). As the SPAD value was measured until 60 DAF, effect of treatment can clearly visible for early fruiting stage water stress % reduction over control was 96.20% comparing to control treatment (100%). Total marketable fruit yields were highest comparing to SPAD value for controlled treatment which only differed significantly from the water stress at early mid and late fruiting stage as treatment. Total, marketable, and weighted yield values in control treatment was higher 89.29 t/ha. In BARI tomato 14, where lowest SPAD value leads the yield reduction 87.05% at early fruiting stage water stress comparing to control treatment (100%).

Moisture % of was drastically reduced due to water stress as V_1T_0 with the control treatment shows highest moisture level of 94.67% and for V_3T_3 with the treatment of late fruiting stage water stress gives the least moisture level of 84%. The highest dry matter content of leaf in plant. V_1T_0 with the control treatment shows highest dry matter content of 4.57% and for V_2T_2 with the treatment of late fruiting stage water stress gives the least dry matter content of 2.60%. Highest reduction of dry matter percentage compare to control showed in Mintoo HYV at late fruiting stage water stress. 10.28% reduction occurs compare to control treatment on similar variety. Other two trial varieties, BARI tomato 4 and BARI tomato 14 showed reduction too at late fruiting stage water stress (9.21% and 3.88% respectively). Data revealed that the highest number of flower cluster plant^{-1} (31 and 35) was found from V_1T_0 for 45 and 60 DAT, while the lowest number (8.3 and 13.33) was recorded from V_3T_3 for 45 and 60 DAT. The highest number of flowers cluster^{-1} (5.67) was recorded from V_2T_0. On the other hand, the lowest number (2.67) was recorded from V_1T_2.

The highest number of fruits plant^{-1} (79.67) was recorded from V_2T_0. On the other hand, the lowest number (43.33) was recorded from V_3T_3. Highest number of fruit drops due to early fruiting stage water stress as for V_1T_1 36 fruits drops but its shows less effect for late fruiting stage water stress as 21 fruit drops for V_3T_3 treatment combination. The highest length of fruit (6.38 cm) V_1T_0 and lowest 4.09 cm for V_3T_3 treatment combination. The highest diameter of fruit (6.85 cm) V_1T_0 and lowest 3.83 cm for V_3T_3 treatment combination. Water stress sensitivity indexes could be improved by considering a compromise between tomato yield, fruit size and water use efficiency as 4.80% fruit length reduced for Mintoo HYV at late fruiting stage water stress compare to control treatment of similar variety. The highest weight of individual fruit 67.83 g was found from V_3T_0. On the other hand, the lowest (43.56 g) was observed from V_1T_0. The highest yield plant^{-1} (2.15 kg) was recorded from V_3T_0, while the lowest yield (1.16 kg) was found from V_1T_1. The highest fruit yield (89.29 t ha^{-1}) was recorded from V_3T_0, while the lowest fruit yield (16.83 t ha^{-1}) was found from V_1T_1.

Conclusion

Based on the findings of the present study, it may be concluded that water stress has remarkable influence on morpho-physiology and yield attributes of tomato. The varietal effects suggest that specific variety having tolerance to water stress. In order to prevent fruit dropping, BARI Tomato-4 can be cultivated with application of sufficient irrigation. Overall performance of BARI Tomato-4 indicates that it can be an excellent working material for researchers who are involved in the water stress tolerant varietal development of tomato especially suitable for water stressed condition.

From the results it could also be concluded that-

1. In this study, satisfactory fruit yield with smaller water sensitivity were obtained for V_2: BARI Tomato 4 variety. Other two varieties (Mintoo and BARI Tomato 14) performed alike in the different treatments & gave poor yield than average due to water stress.
2. Reduction of yield occurs mostly at early fruiting stage for all the selected varieties V_1: Mintoo HYV, V_2: BARI Tomato 4 variety and V_3: BARI Tomato 14 variety.

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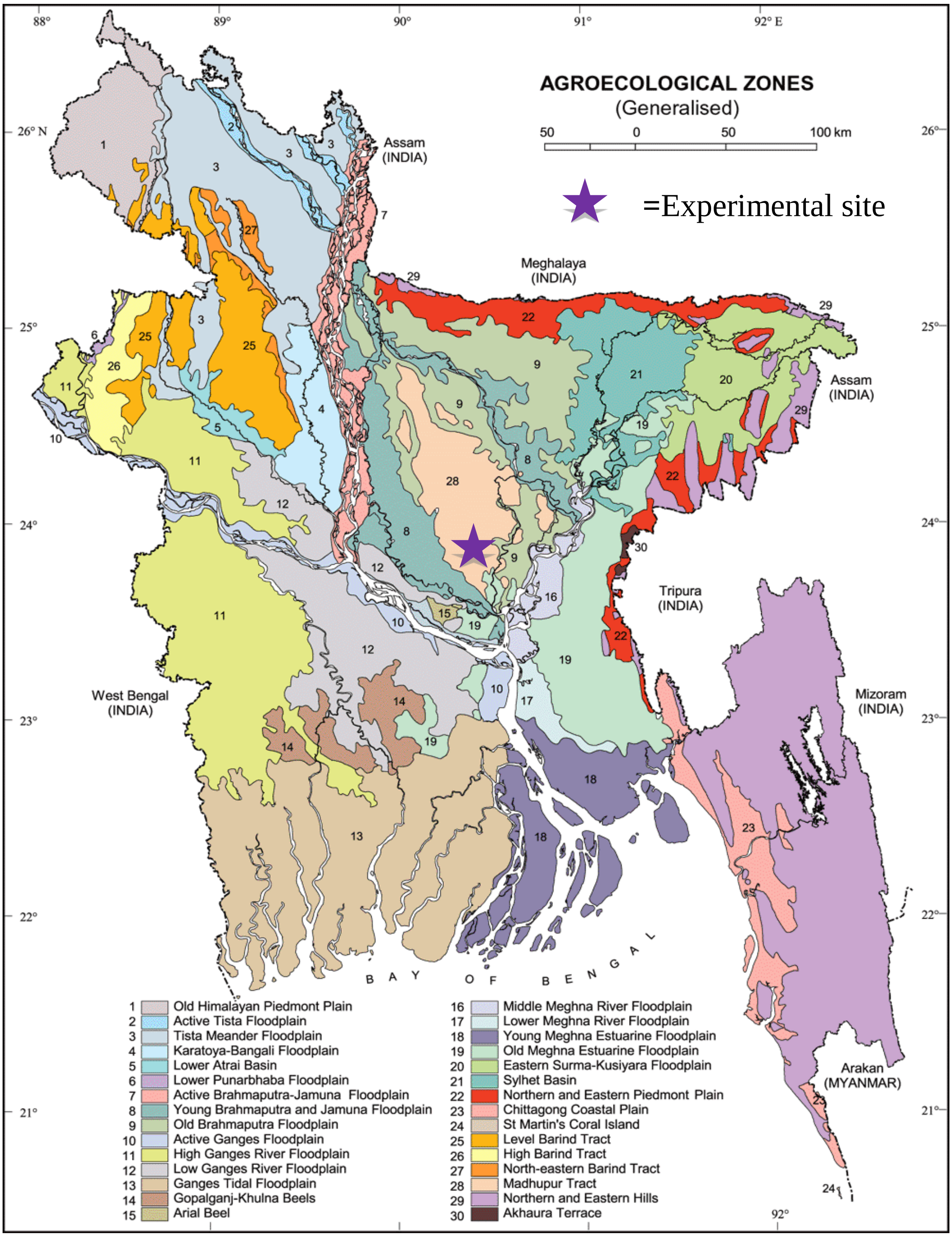
Appendices

Appendix I. Map showing the experimental site under study



Appendix II: Morphological characteristics of the experimental field

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

Appendix III: The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

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

Appendix IV: Monthly meteorological information during the period from November, 2018 to March, 2019

Year	Month	Air temperature (^{0}C)		Relative humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2018	November	28.10	11.83	58.18	47
	December	25.00	9.46	69.53	00
2019	January	25.2	12.8	69	00
	February	27.3	16.9	66	39
	March	31.7	19.2	57	23

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

Appendix V: Analysis of variance of the data of plant height

Source of variation	**Degrees of freedom**	**Mean square of plant height**		
		30 DAT	**45 DAT**	**60 DAT**
Replication	2	13.028	49.69	79.694
Variety	2	752.694	2230.19	993.861
Treatment	3	112.963	174.15	143.287
Variety × Treatment	6	19.657	62.56	20.565
Error	22	13.028	24.45	13.27

Appendix VI: Analysis of variance of the data of No. of branches plant^{-1}

Source of variation	Degrees of freedom	Mean square of No. of branches plant^{-1}		
		30 DAT	45 DAT	60 DAT
Replication	2	2.6944	2.0278	14.778
Variety	2	57.0278	44.3611	123.694
Treatment	3	16.3981	14.5556	18.102
Variety × Treatment	6	2.3981	1.0278	7.546
Error	22	0.4217	1.2096	1.263

Appendix VII: Analysis of variance of the data of No. of leaves plant^{-1}

Source of variation	Degrees of freedom	Mean square of No. of leaves plant^{-1}		
		30 DAT	45 DAT	60 DAT
Replication	2	4.75	2.03	13
Variety	2	207.75	1519.19	1749.08
Treatment	3	48.25	58.25	92.25
Variety × Treatment	6	1.194	2.97	8.08
Error	22	1.811	0.79	1.24

Appendix VIII: Analysis of variance of the data of leaf area

Source of variation	Degrees of freedom	Mean square of leaf area	
		First flowering	40 DAF
Replication	2	7	56
Variety	2	428926	665315
Treatment	3	15927	6739
Variety × Treatment	6	3356	1819
Error	22	12	8

Appendix IX: Analysis of variance of the data of SPAD value

Source of variation	Degrees of freedom	Mean square of SPAD value		
		30 DAS	45 DAS	60 DAS
Replication	2	6.1219	0.6253	0.1669
Variety	2	67.5303	3.9219	75.2519
Treatment	3	6.7632	44.984	38.741
Variety × Treatment	6	42.4166	30.7123	89.2482
Error	22	4.1698	2.8689	2.2906

Appendix X: Analysis of variance of the data of moisture % of fruit, dry matter of fruit

Source of variation	Degrees of freedom	Mean square of leaf area	
		moisture % of fruit	dry matter of fruit
Replication	2	3.25	0.00135
Variety	2	2.583	8.2988
Treatment	3	139.148	0.15151
Variety × Treatment	6	5.176	0.02798
Error	22	3.492	0.00278

Appendix XI: Analysis of variance of the data of No. of flower cluster per plant

Source of variation	Degrees of freedom	Mean square of No. of flower cluster per plant	
		45 DAS	60 DAS
Replication	2	70.333	73.361
Variety	2	677.25	916.194
Treatment	3	301.657	216.102
Variety × Treatment	6	39.657	26.491
Error	22	6.848	4.422

Appendix XII: Analysis of variance of the data of No. of flower per cluster and no. of fruits per plant

Source of variation	Degrees of freedom	Mean square of	
		no. of flower per cluster	no. of fruits per plant
Replication	2	6.7130	0.194
Variety	2	4.33333	420.861
Treatment	3	5.28704	938.991
Variety × Treatment	6	0.7037	12.824
Error	22	0.36364	5.649

Appendix XIII: Analysis of variance of the data of no. of fruit drop due to stress, fruit length and diameter

Source of variation	Degrees of freedom	Mean square of		
		no. of fruit drop due to stress	fruit length	fruit diameter
Replication	2	1.402	0.023	0.402
Variety	2	77.194	3.890	4.809
Treatment	3	327.593	3.550	2.338
Variety × Treatment	6	46.231	0.209	0.133
Error	22	2.02	0.004	0.018

Appendix XIV: Analysis of variance of the data of fruit weight per plant, yield per plant and yield ton/ha.

Source of variation	Degrees of freedom	Mean square of		
		fruit weight per plant	yield per plant	yield ton/ha
Replication	2	1.9001	0.001	4.3
Variety	2	2011.36	0.741	11328
Treatment	3	185.11	0.262	202.9
Variety × Treatment	6	1.79	0.064	1
Error	22	5.87	0.003	0.9

Appendix XV: Experiment layout of the field.

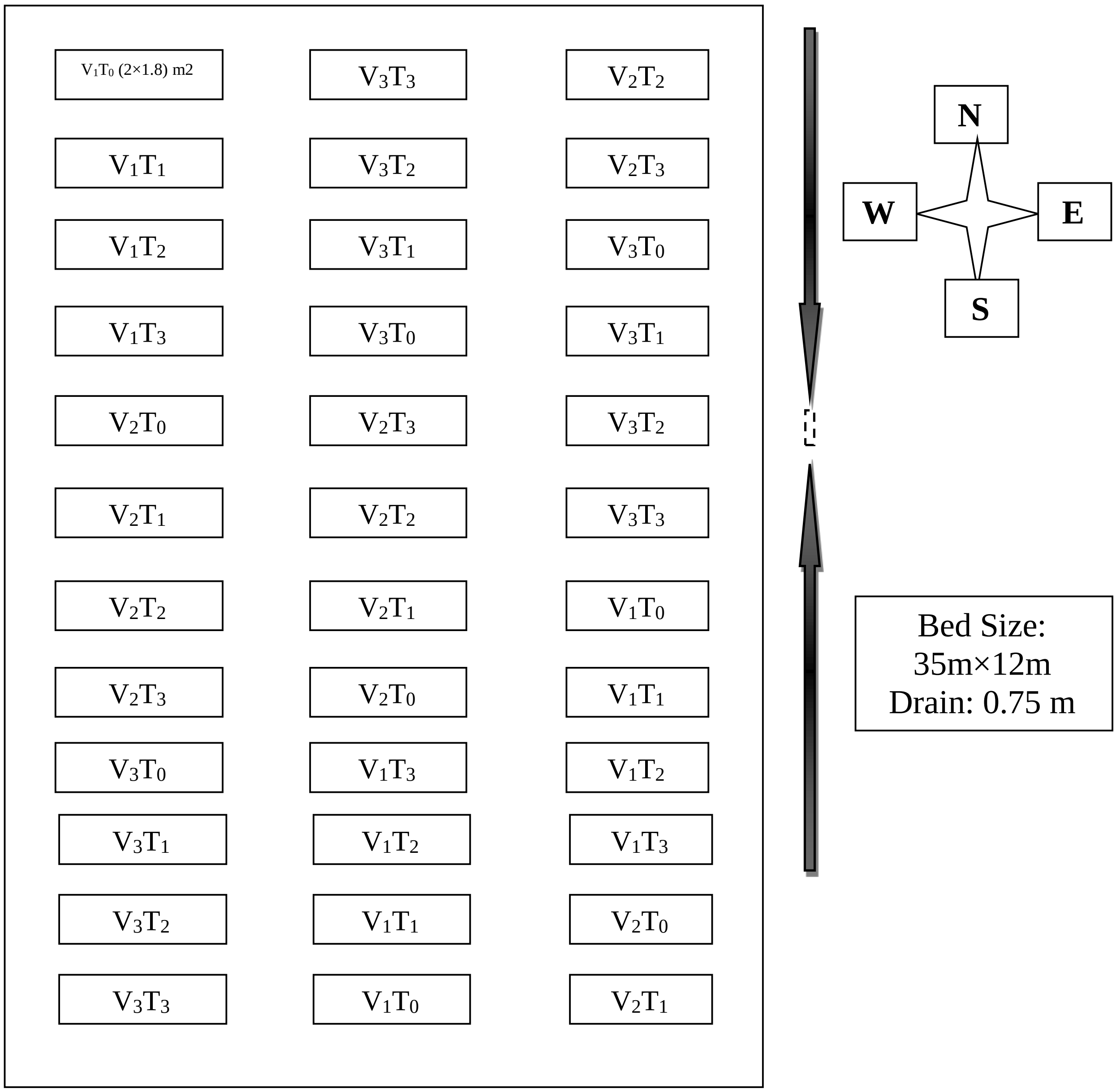


Fig. Layout of the experiment field

Appendix XVI: Pictures during experiment

Plate 1: Crop field after transplanting

Plate 2: Bamboo support to the plant

Plate 3: Measuring plant height

Plate 4: Flowering stage

Plate 5: Taking SPAD value

Plate 6: Netting of crop field

Plate 7: Fruit from experimental field

Plate 8: Harvesting fruits