**DROUGHT INDUCED CHANGES ON GROWTH AND YIELD OF DIFFERENT TOMATO (*Solanum lycopersicum* L.) VARIETIES**

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**BY**

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# *CERTIFICATE*

*This is to certify that thesis entitled, **"Drought induced changes on growth and yield of different tomato (Solanum lycopersicum L.) varieties"** 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 **AGROFORESTRY AND ENVIRRONMENTAL SCIENCE**, embodies the result of a piece of bona fide research work carried out by **S.M. Ashif Mahmud**, Registration No.: **13-05742** 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 been fully acknowledged by him.*

**Dated: June, 2020**
**Place: Dhaka, Bangladesh**

**( Dr. Jubayer-Al-Mahmud)**
**Associate Professor**
**Supervisor**

***DEDICATED***

***TO***

***MY BELOVED***

***FATHER S.M. NAZRUL ISLAM***

***AND***

***MOTHER HOSE-NE ARA BEGUM***

## ABBREVIATIONS

| Full word | Abbreviations | Full word | Abbreviations |
|---|---|---|---|
| Agro-Ecological Zone | AEZ | Milligram(s) | mg |
| Applied | App. | Milliliter | mL |
| Agriculture | Agric. | Millimeter | mm |
| Bangladesh Agricultural Research Institute | BARI | Mean sea level | MSL |
| Bangladesh Bureau of Statistics | BBS | Metric ton | MT |
| Biology | Biol. | North | N |
| Biotechnology | Biotechnol. | Nutrition | Nutr. |
| Botany | Bot. | Pakistan | Pak. |
| Centimeter | Cm | Negative logarithm of hydrogen ion concentration (-log[H+]) | $p^H$ |
| Completely randomized design | CRD | Plant Genetic Resource Centre | PGRC |
| Cultivar | Cv. | Regulation | Regul. |
| Degrees of freedom | DF | Research and Resource | Res. |
| Degree Celsius | °C | Review | Rev. |
| Department | Dept. | Science | Sci. |
| Development | Dev. | Society | Soc. |
| Dry Flowables | DF | Soil plant analysis development | SPAD |
| East | E | Soil Resource Development Institute | SRDI |
| Editors | Eds. | Technology | Technol. |
| Emulsifiable concentrate | EC | Thailand | Thai. |
| Environmment | Environ. | Tropical | Trop. |
| Entomology | Entomol. | Triple super phosphate | TSP |
| And others | *et al.* | United Kingdom | U.K. |
| Food and Agriculture Organization | FAO | University | Univ. |
| Gram | g | United States of America | USA |
| Horticulture | Hort. | Wettable powder | WP |
| International | Intl. | Serial | Sl. |
| Journal | J. | Percentage | % |
| Kilogram | Kg | Microgram | µ |
| Liter | L | Number | No. |
| Milliequivalents | Meqs | Sum of squares | SS |
| Mean sum of squares | MS | Coefficient of variation | CV |

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***- Author***

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## ABSTRACT

Drought is a severe limiting factor for vegetable production. So, a pot experiment was conducted in the field laboratory of the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, from October 2018 to February 2019 to observe the performances of four tomato varieties (BARI Tomato 2, 14, 15 and 16) under three different drought treatments (irrigation interval: 1 day-control, 3 days-mild and 5 days-severe drought) in completely randomized design with three replications. The results showed significant negative influence of drought which decreased plant height, leaf number, stem diameter, SPAD value, growth rate, fresh and dry weight etc. resulting yield loss. Under mild drought, yield plant$^{-1}$ decreased by 32, 8, 14 and 20% where under severe drought, it decreased by 35, 52, 47 and 51% in BARI Tomato 2, 14, 15 and 16, respectively. So, BARI tomato 14 is the best variety under mild and BARI tomato 2 under severe stress condition.

# CHAPTER 1

# INTRODUCTION

Drought is one of the most devastating environmental stresses of the world, which decreases crop growth and productivity. It is the most critical threat for world agriculture as it occurs mostly in combination with high temperature. It was the catalyst of the great famines of the past and now is the great challenge for future food security. Because the world's water supply is limiting, future food demand for rapidly increasing population pressures is likely to further aggravate the effects of drought (Mancosu *et al.*, 2015). Under the climate changing context, drought has been, and is becoming an acute problem most constraining plant growth, terrestrial ecosystem productivity, in many regions all over the world, particularly in arid and semi-arid area (Mavhura *et al.*, 2015; Fischlin *et al.*, 2007). A continuous lacking in precipitation (meteorological drought) combined with higher evapotranspiration demand leads to environmental drought condition (Farooq *et al.*, 2012). Environmental drought is the lack of ample water required for normal plant growth and development to complete the plant life cycle. It severely affects plant growth and development that occurs reductions in crop growth rate and crop productivity.

Tomato is a major vegetable crop of Bangladesh and grown all over the world in outdoor fields, greenhouses and net houses. It is popular for its taste and various types of uses. It is highly used in salad as well as for culinary purposes and provides a variety of processed products, such as, juice, sauces, paste, pickles, puree, soup, ketchup etc. Aside from being tasty, tomatoes are a very good source of vitamins A and C and carotenoids such as lycopene (Perveen *et al.*, 2015; Farooq *et al.*, 2005). It contains 94 mL water, 0.5 g minerals, 0.9 g protein, 0.8g fibre, 0.2 g fat and 3.6 g carbohydrate, 48 mg calcium, 0.4 mg iron, 356 mg carotene, 0.12 mg vitamin $B_1$, 0.06 mg vitamin $B_2$ and 27 mg vitamin C in each 100 g edible ripen tomato (BARI, 2019). It is an important vegetable crop in the world and is grown in most of the countries of the world. The worldwide tomato production is 182,301,395 tons in 2017 **(**FAOSTAT, 2018). The higher tomato producing countries of the world are China, India, United States of America, Turkey, Egypt, Iran, Italy, Brazil, Mexico, Spain, and Russia (FAO, 2018). The total production of tomato in 2017 was 59,626,900 tons in China, 20,708,000 tons in India, 11,900,000 tons in Turkey, and 7,297,108 tons in

Egypt, 6,177,290 tons in Iran 6,015,868 tons in Italy, 4,230,150 tons in Brazil (FAO, 2018). In Bangladesh, the total yield of tomato in the year 2015-2016 was 2,80,871 MT which was cultivated in 65,139 acres of land (BBS, 2017). The top tomato growing areas in Bangladesh are Rajshahi, Dhaka, Dinajpur, Cumilla and Chattogram.

Tomato is sensitive to a number of environmental stresses, especially extreme temperature, drought, salinity and inadequate moisture stresses (Gerszberg *et al.*, 2017). In Bangladesh, lack of irrigation and drought resistant cultivars are the central problems for tomato cultivation. In the dry season with high temperature, flower abortion occurs and fruits drop frequently, which causes very poor yield of tomato. For this reason, farmers are not interested in cultivating tomato, especially in the summer season. Drought also occurs severely in the winter season in the north-west region of Bangladesh due to lack of irrigation facilities and inadequate rain. Water plays an important role in tomato's life cycle. Plant water status controls the physiological processes and conditions which determines the quality and quantity of growth of plants (Negrao *et al.*, 2017). Due to low rainfall and lack of irrigation facilities in winter season, tomato varieties give low yield. Prolonged drought stress condition reduces tomato yield as plant uses energy to be adapted with the stress condition (Leboeuf, 2006). But recently, BARI has released different tomato varieties which can grow both in summer and winter under water stress condition. It is necessary to observe the changes in terms of growth and yield in response to drought to evaluate the performances of different BARI tomato varieties. This may also help to select a better tomato variety which can grow well in drought condition. With considering the above situations in mind, the present research work has been undertaken in order to fulfill the following objectives:

a) To evaluate the changes of growth characters of different tomato varieties under different drought condition; and
b) To evaluate the yield and yield contributing characters of different tomato varieties under different drought condition.

# CHAPTER 2

# REVIEW OF LITERATURE

Tomato is one of the popular and most important vegetable crops of Bangladesh and as well as many countries of the world. It is an important crop for conducting various types of agricultural researches. Various types of resources are accessible now for research on tomato, which can lead to uprising in evaluation of tomato biology (Barone *et al.*, 2008). The researchers gave much attention on various aspects of its production under different adverse condition especially drought. Many studies have done on drought induced changes on growth and yield of tomatoes. The work so far done in Bangladesh is not adequate and advanced. However, some of the important and informative works and research findings so far been done at home and abroad on this topic have been reviewed in this chapter under the followings:

## 2.1 Tomato

Tomato is one of the most popular vegetable crops in the world and has the greatest area under cultivation compared to other vegetables (Nangare *et al.*, 2016). It is an edible and red colored fruit. While it is botanically a fruit, it is considered as a vegetable for culinary purposes. Tomato fruit can be eaten raw or cooked and is used in many dishes. The fruit may also be processed into juice, puree, soup, ketchup, paste or powder. The plant can be erect with short stems or vine-like with long, spreading stems. The stems are covered in coarse hairs and the leaves are arranged spirally. It is a rapidly growing crop with total growing period varying from 90 to 150 days. It is a day-neutral plant. Tomato can be grown in a wide range of soils but a well-drained sandy loam with pH of 5 to7 is preferred. The tomato belongs to Solanaceae family. It contains 24 chromosomes (2n=2x=24). At this moment the accepted scientific name for tomato by most of the scientific community is *Solanum lycopersicum* L. The old scientific name is *Lycopersicon esculentum* Mill. and was widely used from 1768 to 2005. In 2005, Spooner and his associates proposed a change back to the original nomenclature used by Linnaeus in 1753 (Anonymous, 2015). Both names, however, will probably be found in the literature for some time. A member of the deadly nightshade family, tomatoes were erroneously thought to be poisonous (although the leaves are poisonous) by Europeans who were suspicious of their bright, shiny fruit. Native versions were small, like cherry tomatoes, and most likely yellow rather than red (Filippone, 2014). The tomato is native to western South America and Central America (Filippone, 2014). Tomato is a tropical plant and grown in almost every place of the world from tropics to within a few degrees of the Arctic Circle. Mexico has been considered as probable center of domestication of tomato. Italy and Spain are considered secondary centers of diversification (Gentilcore, 2010). Major tomato producing countries are Brazil, USA, Iran, India, Mexico, Spain, Greece, Russia, China, Turkey, Egypt and Italy. Many varieties are now widely grown and popular in Bangladesh (Anonymous, 2016b).

### 2.2 Drought

There are several environmental stresses in our world environment. The most common environmental factor affecting plant growth and productivity/yield is the lack or scarcity of water, a stressful condition known as “drought stress” (Joshi *et al.*, 2016). Drought condition is also referred as water stress in soil. It also can be defined as the scarcity of adequate moisture necessary for a normal plant growth and to complete its life cycle (Zhu, 2004). Water plays a vital role in the production of vegetables and other crops. Scarcity of available water in soil creates drought stress in plants. It is an environmental stress that creates difficulties and problems in completing normal physiological activities by altering the water balance of cells and tissues, by lowering plant water potential and turgor pressure (Conti *et al.*, 2019; Lisar *et al.*, 2012). It has a huge impact on the overall distribution of many species from year to year. Dry lands (5.1 billion ha) cover almost 40% of the world’s land surface and more than 1 billion people live in this region for their livelihood (Roy *et al.*, 2009). According to Bot *et al.* (2000), it has been estimated that up to 45% of the world agricultural lands are subjected to drought. Water is a major constraint in tomato production under drought condition. Drought stress induces elevated osmotic pressure in the root zone and reduces availability of nutrients and water to plant. Water stress condition leads to the abnormality of most of the physiological and biochemical processes and consequently reduces plant growth and yield (Boutraa, 2010). Plants can be affected by drought at any time of their life cycle. Most tomato cultivars are drought sensitive at any stages of plant development. In tomato plants, the effects of drought stress lead to various changes in morphological and physiological characters (Sakya et al 2018). Seed germination, early seedling growth, flowering and fruiting stages are the sensitive stages to drought (Humayun *et al.*, 2010; Delachiave and Pinho, 2003; Nuruddin *et al.*, 2003; Taylor *et al.*, 1982). The characters of seed germination and seedling growth in relation to drought response are extremely important factors in determining overall crop yield (Rauf, 2007). Harmful effects of drought have been reported in not only tomatoes but also in other different crops such as potato, chili, rice, wheat, groundnut, mustard, colt cherry, sugarcane etc. (Ragab *et al.*, 2007).

### 2.3 Effect of drought on plant growth and yield

Drought-induced yield reduction has been reported in many crop species, which depends upon the severity and duration of the stress period. Drought stress is the combination of various types of stress so it shows very complex effect on plant growth and development process (Sakya *et al.,* 2018; Zlatev and Lidon, 2012). Due to drought stress, there is inhibition of cell division and enlargement leading to reduction in vegetative and reproductive growth. Water deficit leads to decrease in the number of flowers and consequently the number of fruit and ultimately to less marketable yield (Buhroy *et al.*, 2017; Losada and Rincaon, 1994; Colla *et al.*, 1999; Rahman *et al.*, 1999; Veit-Kohler *et al.*, 1999). Crop like tomato cultivation is mainly concentrated in semiarid zones, like the Mediterranean, where it needs to be cultivated under irrigation (Rivelli *et al.*, 2013), and where drought events associated with climate change are expected to be more frequent (Nankishore and Farrell, 2016). Thus, water shortage caused by drought periods can have important consequences for tomato production, as it might produce yield reduction of up to a 50 % in the case of an equivalent reduction in irrigation (Cantore *et al.*, 2016). Doorenbos and Kassam (1979) reported that the highest demand for water in tomato plant is during flowering. Ripening is the most sensitive stage and any heterogeneous distribution of irrigation leads to fruit cracking (Losada and Rincaon, 1994). Wahb-Allah *et al.* (2011) conducted an experiment at the Dirab Agricultural Research and Experimental Station of the Faculty of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia (24° 39'N, 46°44'E) to evaluate the effects of drought on tomato production. Four commercial tomato cultivars (Imperial, Pakmore VF, Strain-B and Tnshet Star) were used in this study. He reported that when tomato plants are subjected to different levels of drought stress, it influences plant growth and development. Higher water stress gradually decreases plant height, primary branches, cluster/plant, fruit/cluster, number of fruits and total yield/plant, individual fruit weight, amino acid content in leaves while total sugar and reducing sugar content in leaves increased with the increase of drought stress.

Various works done by various researchers to evaluate the effects of drought or water stress on various growth and yield parameters are stated below separately:

### 2.3.1 Growth attributes

#### 2.3.1.1 Branch number

Salama *et al.* (2017) carried out an experiment to evaluate the effects of tomato growth under water deficit condition and reported that branch number per plant reduced due to the presence of drought condition. Mahapara *et al.* (2018) conducted an experient with tomato through applying drought stress in Department of Plant Breeding & Genetics, Ghazi University and found decreased number of branches per plant under drought condition compared to control. Rao *et al.* (2000) conducted an experiment with 4 tomato cultivars under 3 level of water stress and found that there was a decreased branch number per tomato plants due to increased water stress condition. Again Ban *et al.* (1994) found that drought stress condition reduced total dry matter production in tomato plant due to producing fewer numbers of branches per plant. Same result was also found by Rahman *et al.* (1998a, 1998b) and Weershinghe *et al.* (2003). Taub (2003) conducted a pot experiment with chick pea to know effects of water stress on chick pea production. He used 6 chick pea varieties and 3 water stress level (40, 60, 80% F.C.) in this experiment and he reported that branch number of chick pea plants decreased with increased level of water stress. Same type result was also found by Islam *et al.* (1994) and Gupta *et al.* (1995) in mungbean.

#### 2.3.1.2 Plant height

Khan *et al.* (2020) carried out an experiment to investigate the effect of chitosan on growth and yield of tomato (Cv. Rio Grande) plant under water stress condition at Ornamental Nursery, Department of Horticulture, The University of Agriculture Peshawar, Pakistan, during 2018, using completely randomize design (CRD) with two factors and repeated three times in a control (Glass house) environment. The study revealed that maximum plant height (82.69 cm) was noted in plants with 6 days water stress interval which was statistically similar with plant height (81.18 cm) of plants treated with 3 days water stress interval, while minimum plant height (65.93 cm) was recorded in plants treated with 12 days water stress interval and thus drought condition reduced the tomato plant height. Zhou *et al.* (2017) conducted an experiment to evaluate the effect of drought on the growth characters of tomato plant by using three tomato cultivars ('Arvento', 'LA1994' and 'LA2093') under control, drought, heat and combined stress. The study showed that plant height of all the cultivars significantly decreased under drought stress compared to control. Rahman *et al.* (1998a) conducted an experiment to evaluate the effect of drought on the morphological and physiological characters of tomato plant. He used 3 water stress treatments (control, mild and severe) in this experiment. He found that plant height decreased with increased level of water stress. Same result was also found by Nuruddin *et al.* (2003); Bhattarai and Midmore (2005); Zgallai *et al.* (2005). Singh *et al.* (1995) carried out an experiment with chick pea for 3 years at 2 locations with normal moisture condition (drought less) and drought prone condition. Then he reported that shorter plant height was found in drought prone condition compared to normal moisture condition. Similar type of result also reported by Hossain (2003) in mungbean and Taub (2003) in chick pea.

#### 2.3.1.3 Stem size

Stem size elongation is facilitated by cell division and expansion, and is often a simple and quantitative proxy for a range of drought stress responses (Alem *et al.*, 2015; Hsiao, 1973; Nuruddin *et al.*, 2003). In tomato, reduced stem elongation under drought is associated with shorter internode lengths (Morales *et al.*, 2015). The reduction in stem elongation under drought stress may result from a reduction in cell division, expansion or both (Campbell, 1974; Farooq *et al.*, 2009; Hsiao, 1973). Cell expansion, an increase in cell volume, is very sensitive to drought stress. Reduced cell size is often observed across a range of drought severities (Galmes *et al.*, 2007; Zhao *et al.*, 2011). As a result, reduction of stem length and diameter is observed under drought condition. Conti *et al.* (2019) carried out an experiment to quantify the effects of drought stress on the growth of tomato stem diameter. They investigated how six Italian tomato varieties react to a prolonged period of water depletion and the treatments were $t_0$ (before treatment), $t_1$ (half duration of stress), and $t_2$ (end of stress).

They found that well-irrigated and stressed varieties were still similar while at $t_2$ a slight drop in diameter for all varieties was observed. Sibomana *et al.* (2013) conducted an experiment to quantify the effects of water stress on the growth and yield of tomatoes that was carried out at Egerton University, Horticultural Research and Teaching Field. Tomato cultivar "Money Maker" was subjected to 4 soil moisture threshold levels of 100 % PC, 80 % PC 60 % PC and 40 % PC under randomized complete block design with four replications. He reported that plants that received more than 60 % PC had longer internodes or longer stem (up to 36%) compared to those that received 40% PC. He also found that severe water stress (40% of PC) reduced the plant stem diameter by 18% compared to the control (100% of PC). Pervez *et al.* (2009) conducted an experiment to assess the effect of drought stress on seed yield, seed quality and growth of tomato. The experiment was conducted in green house in plastic pots at Pen-y-Fridd field station, University of Wales, Bangor, U.K. 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. He reported that longer stems were found in control stress compared to water stress conditions. Koti *et al.* (1996) carried out an experiment to evaluate water stress effects on groundnut production. He used 4 types of water moisture level (0, 20,50, 75% F.C.) in this experiment and he reported that plant height as well as stem diameter size reduced with increased level of water stress. Similar result was also found by Gupta *et al.* (1995) in chick pea and Ball *et al.* (1994) in cotton.

#### 2.3.1.4 Shoot weight

Giuliani *et al.* (2018) carried out an experiment to evaluate the combined effect of deficit irrigation (restitution of 100%, 50% and 0% of plant consumption: $WR_{100}$, $WR_{50}$ and $WR_0$, respectively) and strobilurin treatment (no agrochemical added vs azoxystrobin treatment) in two tomato genotypes, IT-22/025, a wild-type plant, and Ikram, a commercial hybrid. In that experiment, both genotypes showed a significant decrease in plant dry matter with the increase in water stress applied. The genotype IT-22/ 025 showed values significantly higher than Ikram both under $WR_{100}$ and $WR_{50}$. The decrease percentage from $WR_{100}$ to $WR_{50}$ was similar for the two genotypes and equal to 38% for IT-22/025 and 35% for Ikram. Zhou *et al.* (2017) conducted an experiment to evaluate the effect of drought on the growth characters of tomato plant by using three tomatoes cultivars (‘Arvento’, ‘LA1994’ and ‘LA2093’) under control, drought, heat and combined stress. The shoot fresh weight of the three cultivars significantly decreased under drought stress compared to control. The shoot dry weight of ‘Arvento’ significantly decreased under stresses. For ‘LA1994’ and ‘LA2093’, the shoot dry weight of plants was significantly smaller under drought stress than control. Pervez *et al.* (2009) conducted an experiment to assess the effect of drought stress on seed yield, seed quality and growth of tomato, the experiment was conducted in green house in plastic pots at Pen-y-Fridd field station, University of Wales, Bangor, U.K. during. 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. He reported that drought stress treatments affected the vegetative growth of plants in most of the cases. The treated plants showed a reduction in biomass production in percentage, as a result lower fresh weight of plant observed in increased water stress level. He also reported that higher shoot dry weight after drying the plant samples was found in control stress compared to water stress conditions. Nahar and Gretzmacher (2002) conducted an experiment with four tomato varieties in the net house of the Department of Soil Science, Dhaka University, during the period from November 1998 to March 1999 to evaluate yield and quality of tomato under water stress. The water stress treatments were 100%, 70% and 40% of F.C. They reported that there was no significant difference between the two treatments, 70% and 40%, but the dry matter production was lower at 40% (severe water stress) compared to 70% F.C. (light stress). Lutfor-Rahman *et al.* (2000) conducted an experiment to evaluate the effect of drought stress on growth, yield and other morphological characters of tomato plants. They used 2 drought sensitive and 2 drought tolerant tomato varieties in this experiment and he reported that shoot and root dry weight decreased significantly with increased water stress condition. Again Ban *et al.* (1994) found that drought stress condition reduced total dry matter production in tomato plant due to producing fewer numbers of branches per plant.

### 2.3.1.5 SPAD value of leaf

Chlorophyll is one of the major chloroplast components for photosynthesis, and relative chlorophyll content has a positive relationship with photosynthetic rate (Guo and Li, 2000). Drought condition gradually decreases plant chlorophyll content and gives a lower SPAD value of leaves compared to normal condition. Sakya *et al.* (2018) conducted an experiment to study physiological characters and tomato yield under drought stress. The study was conducted using 7 lowland tomato cultivars, namely ‘Zamrud’, ‘Permata F1’, ‘Mirah’, ‘Tombatu F1’, ‘Tyrana F1’, ‘Ratna’ and ‘Tymoti F1’. Drought was applied by 8 days interval of watering. He found that total chlorophyll content on tomato in the drought conditions ranged from 1.7 to 2.3 mg/g. Drought stress resulting in a decrease of total chlorophyll content, which ranged between 9-70%. Zhou *et al.* (2017) conducted an experiment to evaluate the effect of drought on the growth characters of tomato plant by using three tomatoes cultivars (‘Arvento’, ‘LA1994’ and ‘LA2093’) under control, drought, heat and combined stress. This study showed that Chlorophyll a/b content of leaves from ‘Arvento’ and ‘LA1994’ significantly decreased under drought stress in comparison with control. The chlorophyll composition was unaffected by the treatments in ‘LA2093’. Khan *et al.* (2020) found in an experiment that maximum chlorophyll content (71.31 SPAD) was noticed in plants with 6 days water stress interval (control) statistically similar with chlorophyll content (67.83 SPAD), while minimum chlorophyll content (51.30 SPAD) was recorded in plants treated with 12 days water stress interval (drought condition). Similar type of result was also found by Salama *et al.* (2017).

### 2.3.1.6 Relative growth rate

Khan *et al.* (2015) conducted an experiment at Institute of Biotechnology and Genetic Engineering during July 2014 by using tomato cv. Bombino to study the effect of drought stress on tomato cv. Bombino. From the experiment, he found that relative growth rate on plant height basis of the tomato variety was lower in drought stress condition compared to stress free condition. Before stress the average plants height was recorded as 23 cm. After withholding water for two weeks the average plants height recorded was 27.5 cm, while in controlled environment the average plants height was 30.5 cm. In control condition, the relative growth rate week$^{-1}$ was 1.14 cm and that in drought condition was 0.43 cm. This indicates how the average plants height has decreased when the plants were subjected to drought conditions.

### 2.3.2 Yield attributes

#### 2.3.2.1 Flowering time

The flowering period of a crop is a critical growth stage. Drought condition brings a significant change in flowering time of all tomato varieties. Reproductive development at the period of flowering of tomato is especially sensitive to drought stress (Samarah *et al.*, 2009c; Zinselmeier *et al.*, 1999, 1995). For this reason, drought condition brings a significant change in flowering time in all tomato varieties. Again, Mohan Ram and Rao (1984) reported that drought stress significantly interferes with flowering period, nectar production, flower opening mode and turgor maintenance of floral organs. Sivakumar and Srividhya (2016) conducted an experiment to determine the effect of drought on flowering and yield of tomato genotypes in the field experiment at Rainout Shelter of Crop Physiology Department, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu during 2012-13. He found that the plants under drought condition initiated flowers earlier (26 days) than plants in control condition (30 days). Drought stress, in general, induces early flowering and flower initiation occurred three days earlier than the control in that experiment. This early flowering under drought might be due to rapid phenological development in order to complete the life cycle under an unfavorable environmental condition. Akter *et al.* (2019) reported that days taken to first flowering was earlier in $T_2$ (30 days withholding of water) (26.69 days) and late in $T_3$ (45 days withholding of water) (27.18 days) and little bit earlier than $T_1$ (control) (26.89 days).

#### 2.3.2.2 Number of cluster per plant

Buhroy *et al.* (2017) conducted an experiment with thirty-two genotypes of tomato through applying drought stress condition and found that number of clusters per plant decreased with increased level of water deficit condition. Akter *et al.* (2019) reported that maximum number of cluster per plant (9.240/plant) was counted in $T_1$ (control) whereas the minimum number of cluster per plant (7.730/plant) in $T_3$ (45 days). Sorial (2001) conducted an experiment with 3 tomato genotypes to evaluate their performance under 3 water stress level (100%, 50% and 25% F.C.). He found that the increased level of water stress decreased the number of flower cluster per plant. Again, Rahman *et al.* (1999) conducted an experiment to compare the performances of drought tolerant and drought sensitive tomato varieties under drought condition. He reported that the number of flower cluster per plant decreased in both drought tolerant and drought sensitive tomato varieties, but this reduction was comparatively higher in drought sensitive varieties than drought tolerant varieties. Similar result was also found in tomato by different researches (Lutfor-Rahman *et al.,* 2000; Nuruddin *et al.,* 2003). Hernandez-Aarmenta (1985) carried out an experiment with bell pepper plant under drought condition. He reported that reduced soil moisture restricts the vegetative and reproductive growth that leads to fewer cluster production per plant.

#### 2.3.2.3 Maturity time

Akter *et al.* (2019) conducted a pot experiment in the net house of the Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka-1207, during November 2013 to March 2014 to observe the performances of 15 tomato genotypes under three different drought treatments and found that days to fruit harvest were significantly affected by drought treatments. Early harvesting was performed in treatment $T_3$ (for 45 days withholding water) treated tomato genotypes and delayed in $T_1$ (control) and thus maturity time decreases with the increasing drought levels in tomato plants. Sibomana *et al.* (2013) conducted an experiment to quantify the effects of water stress on the growth and yield of tomatoes which was carried out at Egerton University, Horticultural Research and Teaching Field between 2009 and 2010. Tomato “Money Maker” was subjected to four soil moisture threshold levels of 100% PC, 80% PC 60% PC and 40% PC under randomized complete block design with four replications. They reported that tomato maturity time decreases with the increasing drought levels in tomato plants.

#### 2.3.2.4 Fruit weight

Most of the studies have revealed that shortage of water due to drought stress interferes with the normal functions of tomato plants through influencing the vigor and productivity at a great extent (Techawongstein *et al.*, 1992). Sakya *et al.,* (2018) conducted an experiment to study physiological characters and tomato yield under drought stress. The study was conducted using 7 lowland tomato cultivars, namely

‘Zamrud’, ‘Permata F1’, ‘Mirah’, ‘Tombatu F1’, ‘Tyrana F1’, ‘Ratna’ and ‘Tymoti F1’. Drought was applied by 8 days interval of watering. The study showed that tomato fruit weight in the drought conditions decreased from 3-148% compared to the normal conditions. Cui *et al.* (2020) conducted an experiment in Nanjing, Jiangsu, China, (31°57’N, 118°50’E, and altitude 144m above MSL), during the tomato-growing season in 2013 and 2016 with four treatments. The plants were irrigated to 100% of F.C. for all growth stages for treatment $T_1$ (control). The experimental treatments were based upon the growth stages as follows: the vegetative stage (stage I) was from transplanting to first fruit set; the flowering and fruit development stage (stage II) from first fruit set to first fruit maturity; and the fruit ripening stage (stage III) from first fruit maturity to final harvest. The three drought treatments received half the amount of irrigation as $T_1$ but at differing stages: treatment $T_2$ during stage I, $T_3$ during stage II, and $T_4$ during stage III. The study showed that comparing with control, total fruit yield was reduced by 11% and 21% for the $T_3$ and $T_4$ treatments, respectively, for the 2013 season; and by 15% and 30% for the 2016 season due to lower fruit weight at drought condition. Giuliani *et al.* (2018) carried out an experiment to evaluate the combined effect of deficit irrigation (restitution of 100%, 50% and 0% of plant consumption: $WR_{100}$, $WR_{50}$ and $WR_0$, respectively) and strobilurin treatment (no agrochemical added vs azoxystrobin treatment) in two tomato genotypes, IT-22/025, a wild-type plant, and Ikram, a commercial hybrid. The experiment showed that total fruit yield, the genotype IT-22/025 showed higher values than Ikram under both WR100 and WR50 regimes, while under WR0, the two genotypes showed similar values. Moreover, the two genotypes showed different yield decreases from the WR100 to the WR50, with a 43% decrease for IT-22/025 and a 51% decrease for Ikram due to fruit size reduction at drought condition. Rahman *et al.* (1998a) reported that increased water stress condition decrease the fruit weight of tomato. Again Weershinghe *et al.* (2003) found that drought stress condition induces tomato yield reduction through reducing fruits per plant. Same type of result also found from Ball *et al.* (1994) during the experiment with cotton. Rahman *et al.* (1999) conducted an experiment with drought tolerant and drought sensitive varieties of tomatoes and he found that fruit weight per plant was decreased in case of both varieties, but higher fruit weight reduction was observed in drought sensitive varieties compared to drought tolerant varieties. The yield reduction occurred due to fewer number of clusters as well as fewer number of fruits and smaller fruit size of tomato. Similar results were also found from other experiments conducted by different persons (Thippeswami and Sreenivasa, 1998; Rao *et al.,* 2000; Lutfor-Rahman *et al.,* 2000; Nuruddin *et al.,* 2003) in tomato.

### 2.3.2.5 Fruit number

Khan *et al.* (2020) carried out an experiment to investigate the effect of chitosan on growth and yield of tomato (Cv. Rio Grande) plant under water stress condition at Ornamental Nursery, Department of Horticulture, The University of Agriculture Peshawar, Pakistan, during 2018, using completely randomize design (CRD) with two factors and repeated three times in a control (Glass house) environment. The study showed that drought condition reduced total fruit number plant$^{-1}$ maximum number of fruit plant$^{-1}$ (24.66) was recorded in plants treated with 6 days water stress interval, while minimum number of fruit plant$^{-1}$ (15.33) was observed in plants treated with 12 days water stress interval. Different studies revealed that drought stress has an impact on fruit number reduction per tomato plant. Akter *et al.* (2019) reported that highest fruits per cluster (3.33/plant) was found in $T_1$ (control) whereas $T_3$ (45 days) provided the lowest number of fruits per cluster (2.66/plant). Nahar and Ullah (2012) conducted a pot experiments in Bangladesh (November to March) to evaluate the effect of water stress on some morphological and physiological parameters of tomato plants, such as growth, yield, flowering and fruiting characters, water consumption, leaf relative water content and transpiration of plants. Two tomato cultivars, namely BARI Tomato-4 and BARI Tomato-5 were used in this study. Three treatments were imposed viz, 100%, 70%, and 40% of the field capacity (F.C.). She found that fruit number per cluster was lower (5.1 fruits/cluster) at 40% F.C. than 70% F.C. (6.8 fruits/cluster) and reported that drought condition reduces significant number of fruits per cluster. Weershinghe *et al.* (2003) conducted an experiment with 45 tomato varieties under normal and drought stress condition in Srilanka and he found that fruit number per tomato plant decreased in drought condition compared to normal condition. Similarly Nuruddin *et al.* (2003) conducted an experiment with tomato grown under two water deficit condition (65% and 80%) and he found that fruit number and size decreased with increased level of water stress. Similar type result was also found by other researchers (Rahman *et al.*, 1998a, Bhattarai and Midmore, 2005, Zgallai *et al.*, 2005). Gupta *et al.* (1995) conducted an experiment with 7 chick pea varieties under drought stress conditions and found that fruit number per plant decreased under water stress condition in all varieties compared to control condition. Similar result was also found by Ball *et al.* (1994) in cotton.

#### 2.3.2.6 Fruit size

Rahman *et al.* (1999) conducted an experiment with drought tolerant and drought sensitive varieties of tomatoes and he found that fruit yield decreased with increased water stress during drought condition due to producing smaller size of fruits. Again, Rao *et al.* (2000) conducted an experiment with 20 tomato cultivars under 4 water stress level comprising of (a) weekly irrigation, (b) water stress during the vegetative stage, (c) water stress during fruiting stage and (d) continuous water stress after seedling establishment and then reported that water stress during fruit development stage induced fruit drop and reduced fruit size. Furthermore, Rao and Padma (1991) conducted an experiment with 5 tomato cultivars to find out the effects of temporary moisture contents on three phenological stages (vegetative, flowering and fruiting) in tomato. They reported that water stress during flowering stage induced fruit drops and lower number of fruit sets; again drought stress during fruiting stage induced highest decrease of fruit size. They also found that average fruit yield was lowest during the stress in fruiting (16.4 ton/ha) followed by that with stress at the vegetative stage (23.1 ton/ha) and stress at flowering stage (23.3 ton/ha) in tomato under water stress. Adams (1990) also observed a reduction in the size of the fruit in his experiment. Klepper *et al.* (1971) reported that the fruit length and diameter changes occur at different level of water stress. He found that well watered plants had an increase in fruit length and diameter compared to the moderate and severe stressed plants. Lapushner *et al.* (1986) observed that the fruit size of tomato was reduced by water stress. Similar result was reported from other researchers (Lutfor-Rahman *et al.* 2000; Nuruddin *et al.* 2003). Hossain (2003) conducted an experiment with 3 mungbean cultivars under 3 level of water stress (30, 50, 70% F.C.) and reported that pod size decreased with increased level of water stress. Similar result was also found by Taub (2003) in chick pea.

# CHAPTER 3

# MATERIALS AND METHODS

This chapter illustrates the concerning methodology used in execution of the experiment to study the drought induced changes on growth and yield of different tomato (*Solanum lycopersicum* L.) varieties. This part comprises a brief description of locations of experimental site, planting materials, climate and soil, seedbed preparation, layout and design of the experiment, pot preparation, fertilizing, transplanting of seedlings, intercultural operations, harvesting, data recording procedure, statistical analysis etc. which are presented as follows:

## 3.1 Experimental site

This experiment was conducted in the Field laboratory of Agroforestry and Environmental Science Department, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period from October 2018 to February 2019. Location of the site is 23°74'N latitude and 90°35'E longitude with an elevation of 8 meter from sea level (Islam, 2014; Laylin, 2014) in Agro-ecological zone of "Madhupur Tract" (AEZ-28) (Anonymous, 1988). The experimental site is shown in the map of AEZ of Bangladesh in [Appendix 1].

## 3.2 Climate and soil

Experimental site was located in the subtropical climatic zone, having with plenty of sunshine and moderately low temperature prevails during October to March (Rabi season), which is highly suitable for tomato growing in Bangladesh. Weather information and physiochemical properties of the soil used in pot experiment are presented in [Appendix 2 and Appendix 3, respectively].

### 3.3 Planting materials

A total of 4 varieties of tomato were collected from PGRC, BARI, Gazipur on September 2018. The list of four selected tomato genotypes is presented in Table 1.

**Table 1.** Name and origin of four tomato varieties used in the study

| Sl. no. | Variety no. | Variety name | Source |
|---|---|---|---|
| 1 | V1 | BARI Tomato 2 | PGRC, BARI |
| 2 | V2 | BARI Tomato 14 | PGRC, BARI |
| 3 | V3 | BARI Tomato 15 | PGRC, BARI |
| 4 | V4 | BARI Tomato 16 | PGRC, BARI |

### 3.4 Treatments of the experiment

The experiment was conducted to evaluate the performance of 4 tomato varieties under different 3 drought treatments. These treatments are (1) D0: 1 days of irrigation interval (control), (2) D1: 3 days of irrigation interval (mild drought stress), and (3) D2: 5 days of irrigation interval (severe drought stress).

### 3.5 Design and layout of the experiment

The experiment was laid out and evaluated during Rabi season 2018-19 in completely randomized design (CRD) using two factors Factor A comprises 4 tomato varieties and Factor B comprises 3 drought treatments. The experiment was conducted in 3 replications and total 36 plastic pots were used. The experimental unit was saved from natural precipitation by temporary polyethylene shed.

### 3.6 Pot preparation

The experimental pot size was 35 cm in height, 30 cm in top diameter and 20 cm in bottom diameter. Pots were filled with fertilizer mixed soils for seed sowing and plant growth on October 24, 2018. Before soil filling, weeds and stubbles were completely removed from soil to ensure smooth plant growth. The soil was treated with Formaldehyde (45%) for 48 hours before filling the plastic pots to keep soil free from pathogen. Each pot was filled with 10 kg soil.

### 3.7 Seed sowing and raising of seedlings

Seed sowing was carried out on October 27, 2018 in the treatment pots. Before sowing, seeds were treated with 70% ethanol for five minutes. Seedlings were raised in the pots using regular nursery practices. Recommended cultural practices were done before and after sowing seeds. When the seedlings become 25 days old on November 22, 2018, only two seedlings were allowed to grow per pot while additional seedlings were uprooting. After a hardening process of 15 days, 1 seedling was uprooted and only one seedling per pot was allowed to grow. Pot preparation, emergence of seedlings, and seedling establishment are shown in Plate 1.

### 3.8 Manure and fertilizers application

Soil was well pulverized and dried in the sun and only well decomposed cow dung was mixed with the soil including other required fertilizers according to the recommendation guide BARI, 2010. The required amount of fertilizer was calculated for each pot considering the dose required for 1 ha land. Overall Total decomposed cow dung was applied before transplanting the seedlings to plastic pots. On an average, each plastic pot was filled with soil containing 100gm decomposed cow dung (10 tons/ha). Fertilizers (urea, TSP, MP) were applied in each pot following recommended dose.

### 3.9 Application of drought treatment

Four varieties of tomatoes were evaluated under different drought treatments such as (1) D0: 1 days of irrigation interval, (2) D1: 3 days of irrigation interval, and (3). D2: 5 days of irrigation interval. At first all the plants were watered equally from the first day after seedling emergence. This process was continued up to seedling establishment. After proper seedling establishment and hardening, the treatments were started to apply. In control treatments (D0), plants were not exposed to drought and watered at 1 day interval after first irrigation; whereas plants in D1 treatment were watered at 3 days interval and plants in D3 treatments were watered at 5 days interval after first irrigation which were exposed to mild and severe drought conditions respectively.

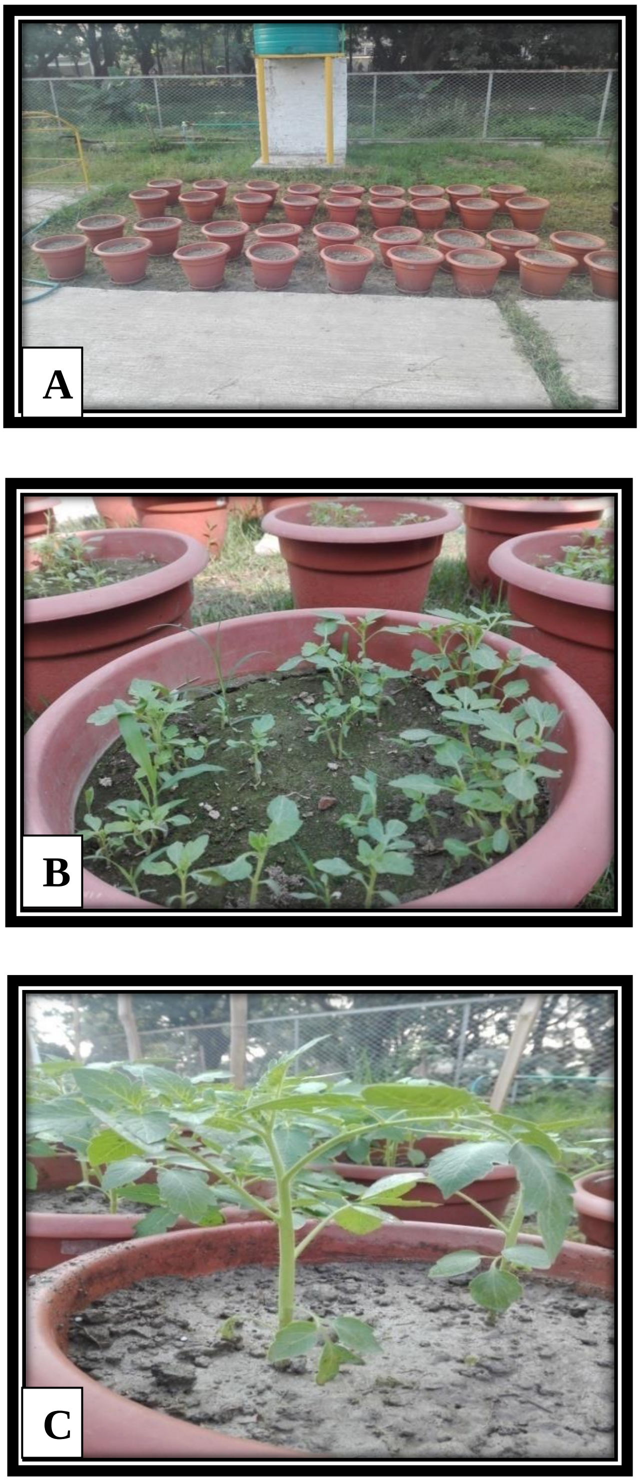


**Plate 1**. Steps of seed sowing to transplanting. A) Pot preparation, B) Emergence of seedlings, C) Established seedling

### 3.10 Intercultural operations

Recommended watering and intercultural operations were provided as and when required for different treatments (Plate 2). Weeding was performed in all pots at regular interval to keep plants free from weeds. Diseases and pest attack is a limiting factor to tomato growth and yield. Tomato plants were treated with Bavistin DF and Cupravit 50WP to prevent undesired diseases @1g/L and 2g/L respectively. Leaf miner and aphid were controlled by using Malathion 250EC @ 0.5ml/l. Those fungicide and pesticide were sprayed in two intervals, first dose at vegetative growth stage and another is during early flowering stage to manage pest and diseases. When plants were well established, staking was done to each plant by bamboo stick between 25-30 days after transplanting to keep the plants erect always and to avoid breakage of plants due to heavy fruit weights during fruiting stage. Proper tagging and labeling were done for each plant using thin sticks. All the steps of watering and intercultural operations are presented in Plate 2.

### 3.11 Harvesting and processing

Harvesting was done at the maturity stage of fruits. Mature fruits were harvested when fruits turned from medium to deep red in color. Harvesting was started from January 25, 2019 and completed by February 20, 2019.

### 3.12 Data recording

Data were recorded from each pot based on growth and yield parameters. Different data recording procedure and growth stages at which time data were recorded are shown in plate 3. Data were recorded in respect of the following parameters:

#### 3.12.1 Growth (vegetative) parameters

##### 3.12.1.1 Number of branches per plant

Branch number of each plant at mature stage was measured and mean was calculated.

##### 3.12.1.2 Plant height

Plant height of each plant was measured in cm unit after 4 weeks of seedling transplanting using meter scale and mean was calculated.


**Plate 2.** Different intercultural operations. A) Watering the plants, B) Hand weeding, C) Labeling ang tagging plants, D) Staking the plants

#### 3.12.1.3 Stem length

Stem length per plant was measured using Digital Caliper-515 (DC-515) in millimeter (mm) unit. Later it was converted to centimeter (cm) unit ant then mean was calculated for each treatment.

#### 3.12.1.4 Stem diameter

Stem diameter per plant was measured using Digital Caliper-515 (DC-515) in millimeter (mm) unit. Later it was converted to centimeter (cm) unit and then mean was calculated for each treatment.

#### 3.12.1.5 Relative growth rate

Relative growth rate per plant on plant height basis was counted in cm/week unit by using the following formula:

$$\text{Relative growth rate (cm/week)} = \frac{\text{Final plant height} - \text{Initial plant height}}{\text{Time interval between two heights}}$$

Initial plant height (average 25 cm) was measured at the time of seedling transplantation and final plant height for different plants was measured after 4 weeks of transplanting.

#### 3.12.1.6 SPAD value of leaf

Chlorophyll (Chl) content in terms of SPAD (soil plant analysis development) values was recorded using a portable SPAD 502 Plus meter (Konica-Minolta, Tokyo, Japan). In each measurement, the SPAD reading was repeated 5 times from the leaf tip to base, and the average was used for analysis.

#### 3.12.1.7 Plant fresh weight

Plant fresh weight excluding fruits was counted after uprooting plant using electrical balance machine and mean was calculated.

#### 3.12.1.8 Plant dry weight

Plant dry weight excluding fruits was counted after drying the uprooted plant sample using electrical balance machine and mean was calculated. Dry weight measuring procedure of tomato plant is shown in Plate 3.

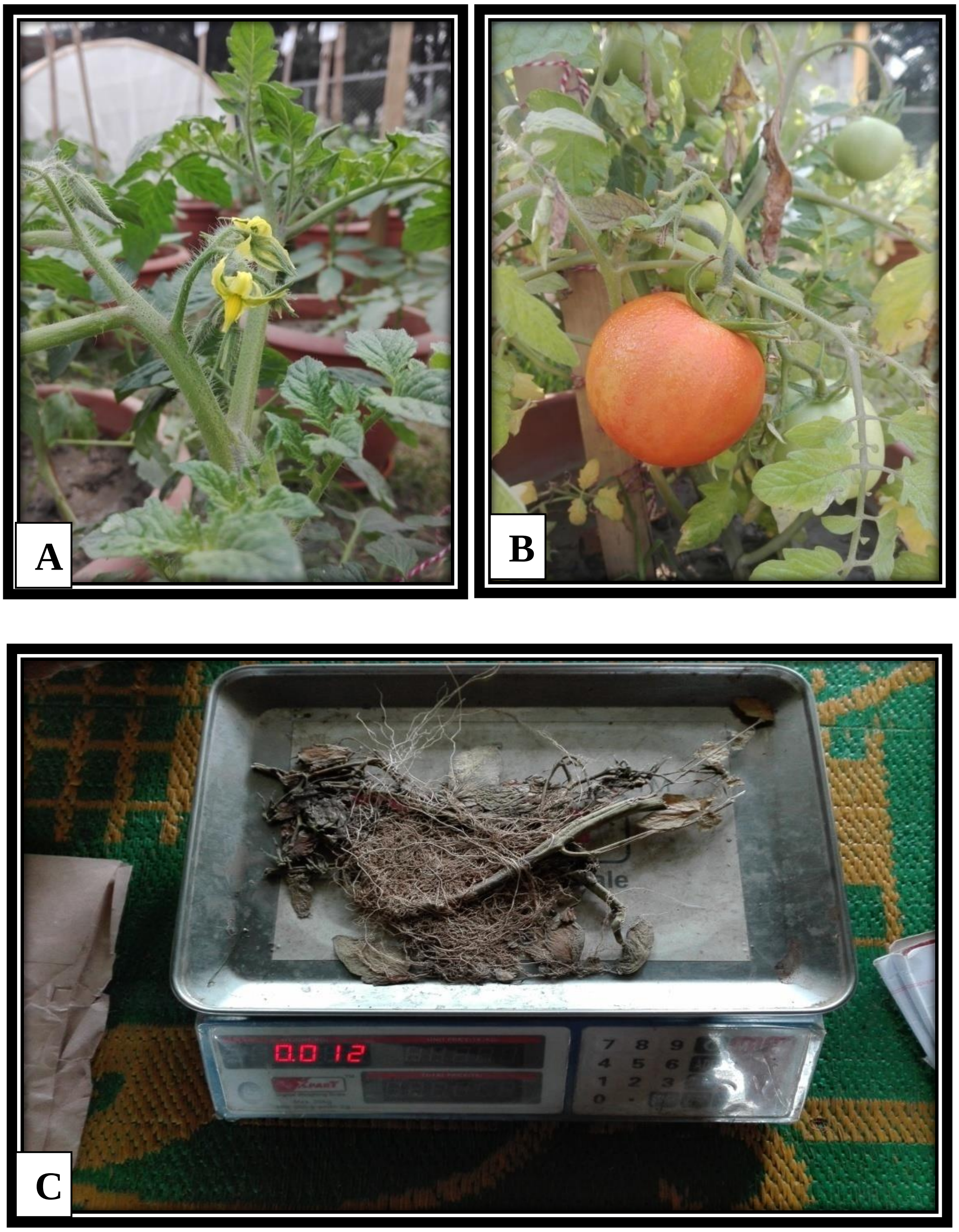


**Plate 3.** Data recording procedure and tomato growth stages A. Flowering stage, B. Fruit maturity stage, C. Plant dry weight measurement

### 3.12.2 Yield (reproductive) parameters

#### 3.12.2.1 Number of clusters per plant

The number of clusters per plant was recorded at the time of harvesting.

#### 3.12.2.2 First flowering time

The first flowering time in day unit was counted from the date of tomato seedlings transplanting to date of first flowering. Flowering stage of tomato is shown in plate 3.

#### 3.12.2.3 Number of fruits per cluster

All fruits per cluster were counted and then the average number of fruits per cluster was calculated by randomly selecting 3 clusters.

#### 3.12.2.4 Number of fruits per plant

The total number of mature and healthy fruits harvested from each plant was recorded and then mean was calculated.

#### 3.12.2.5 Fruit length

Fruit length was measured using Digital Caliper-515 (DC-515) in millimeter (mm) unit. Later it was converted to centimeter (cm) unit. Then mean was calculated for each treatment.

#### 3.12.2.6 Fruit diameter

Fruit length was measured using Digital Caliper-515 (DC-515) in millimeter (mm) unit. Later it was converted to centimeter (cm) unit. Then mean was calculated for each treatment.

#### 3.12.2.7 Individual fruit weight per plant

Randomly 5 fruits were collected from each plant and then 5 fruit weight was measured by using electrical balance machine. Then mean of individual fruit weight was calculated.

#### 3.12.1.8 Fruit maturity time

The number of days to maturity was counted from the date of tomato seedlings transplanting to date of first fruit harvesting. The maturity stage of fruit is shown in Plate 3.

#### 3.12.2.9 Yield per plant

Yield per plant was recorded from all harvests of each plant and expressed in kilogram (kg) per plant.

### 3.13 Statistical analysis

Collected data were statistically analyzed using Statistix 10 software. Mean for every treatments were calculated and analysis of variance and difference between treatments was assessed by Least Significant Difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984).

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Growth (vegetative) parameters

### 4.1.1 Number of branches per plant

Drought stress gradually decreased the number of branches per plant of all tested tomato varieties with the increase of drought level and there is a significant variation in the decreased number of branches per plant. In mild drought (D1), number of branches per plant significantly decreased most in V3 variety (8%) compared to control and no reduction occurred in V1 variety. Again in severe drought (D2), number of branches per plant significantly decreased most in V3 variety (20%) and least significant reduction occurred in V2 variety (10%) compared to control (Figure 1). Drought stress condition disturbs plant physiological processes which are reflected in low water absorption and transmission to different parts of the plant (Conti *et al.*, 2019, Lisar *et al.*, 2012); as a result fewer numbers of branches per plant occurred under drought condition. Similar results were also reported by Salama *et al.* (2017).

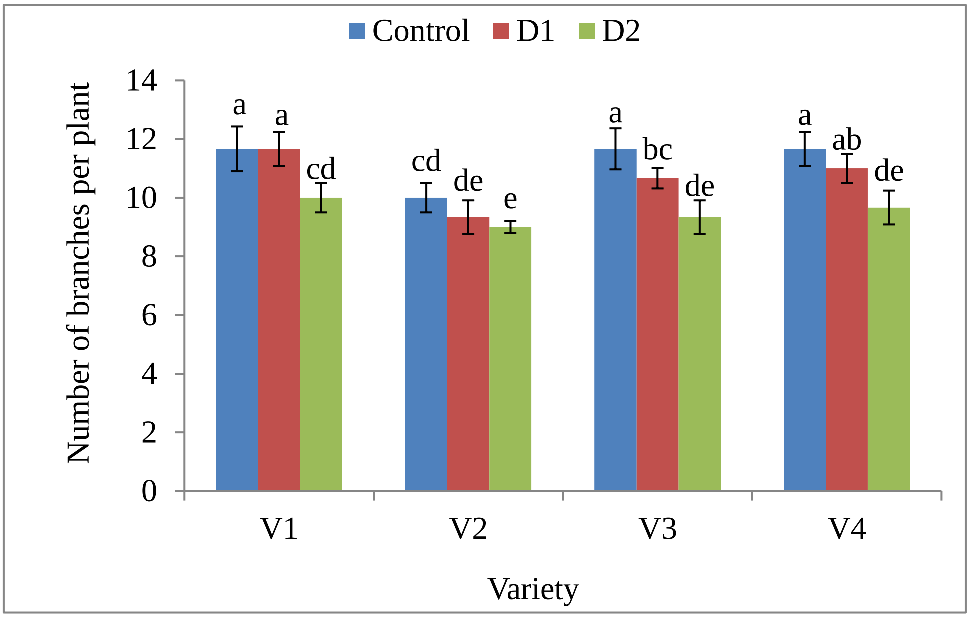


**Figure 1:** Effect of drought on number of branches per plant

### 4.1.2 Plant height

Drought stress significantly decreased the plant height of all tested tomato varieties with the increase of drought level. In case of mild drought (D1), plant height decreased most in V2 variety (14%) which is significantly different from control and least reduction occurred in V1 variety (0.3%) compared to control which showed non-significant variation from control. Again in severe drought (D2), plant height significantly decreased most in V4 variety (18%) and least reduction occurred in V1 variety (11%) significantly compared to control (Figure 2). Drought stress condition interferes plant physiological activities (Conti *et al.*, 2019; Lisar *et al.*, 2012) and that causes gradual plant height decrease with the increase of drought level due to disturbance in cell division and enlargement. Similar results were also reported by Khan *et al.* (2020) and Zhou *et al.* (2017).

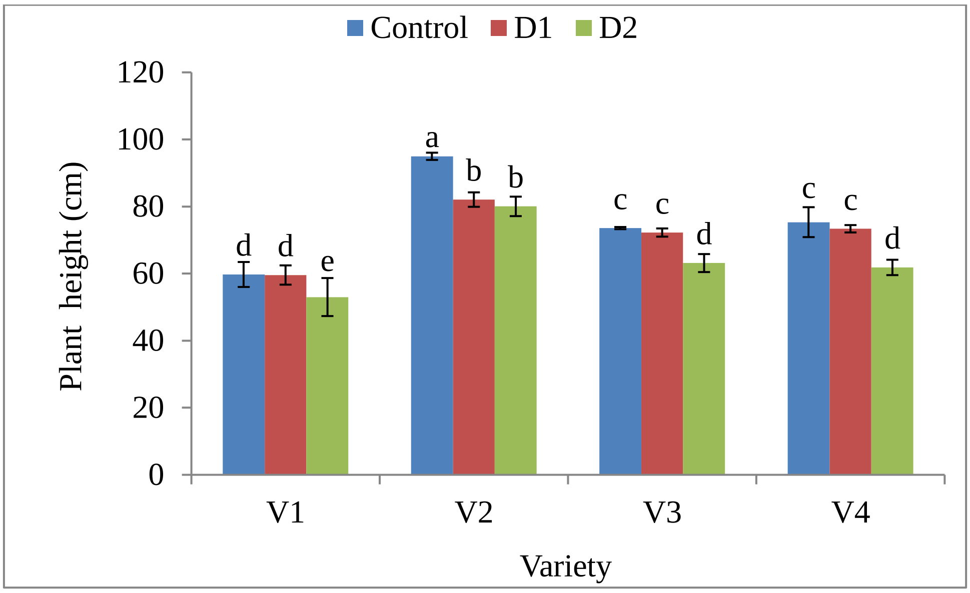


**Figure 2:** Effect of drought on plant height

### 4.1.3 Stem length

The stem length of all tested tomato varieties significantly decreased (non-significant in V1 only) with the increase of drought level. In case of mild drought (D1), stem length decreased most in V4 variety (14%) which is significantly different from control and least non-significant reduction occurred in V2 variety (6%) compared to control. Again in severe drought (D2), stem length significantly decreased most in V3 variety (30%) and least non-significant reduction occurred in V1 variety (12%)

compared to control (Figure 3). In tomato, reduced stem elongation under drought is associated with shorter internode lengths (Morales *et al.*, 2015). Reduction of cell elongation due to water deficit situation creates shorter internodes. As a result, reduction of stem length was observed under drought condition in my experiment. Similar results were also reported by Sibomana *et al.* (2013).

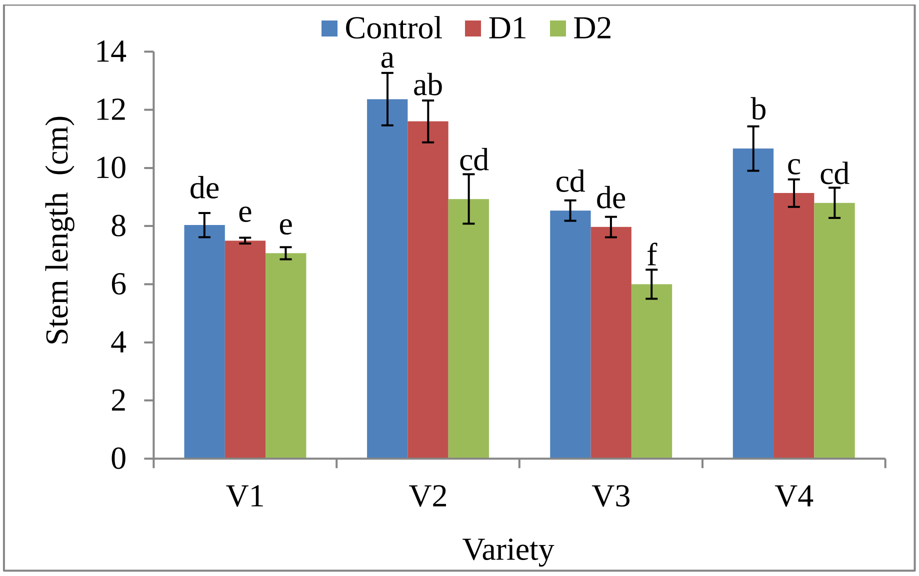


**Figure 3:** Effect of drought on stem length

### 4.1.4 Stem diameter

Drought stress showed a slight decrease in stem diameter of all tested tomato varieties (significant in V3 only) with the increase of drought level. In mild drought (D1), stem diameter non-significantly decreased most in V1 and V4 variety (3%) and no reduction occurred in V3 variety compared to control. Again in severe drought (D2), stem diameter significantly decreased most in V3 variety (11%) and least non-significant reduction occurred in V2 variety (3%) compared to control (Figure 4). Stem size elongation is facilitated by cell division and expansion. The reduction in stem size under drought stress is resulted from a reduction in cell division, expansion or both due to lack of water (Campbell, 1974; Farooq *et al.*, 2009; Hsiao, 1973). As a result, reduction of stem diameter was observed under drought condition in my experiment. Similar results were also reported by Conti *et al.* (2019).

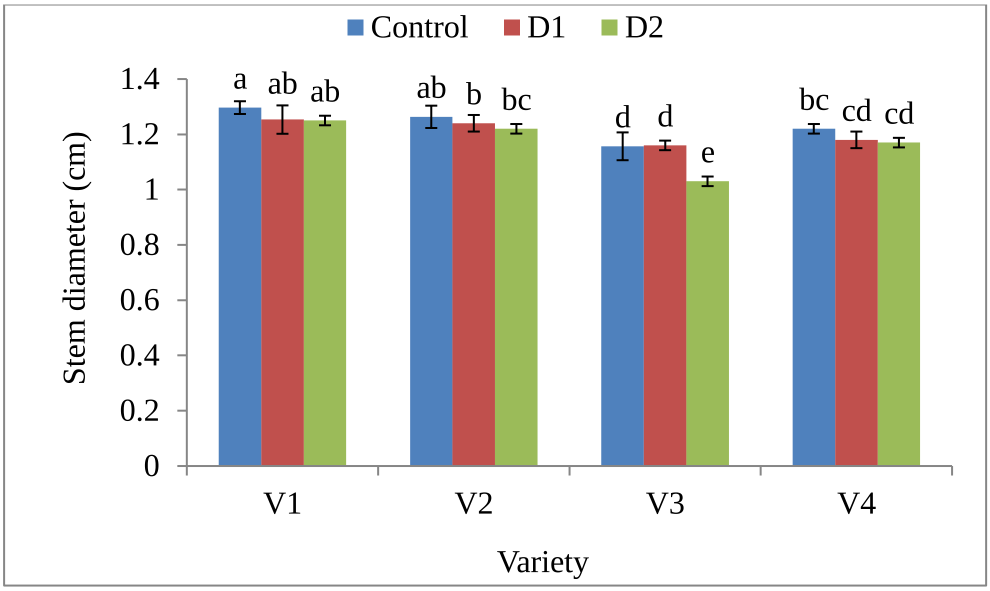


**Figure 4:** Effect of drought on stem diameter

### 4.1.5 Relative growth rate

Drought stress showed a significant variation in the relative growth rate values on plant height basis of all tested tomato varieties with the increase of drought level. In mild drought (D1), relative growth rate significantly decreased most in V2 variety (18%) and least non-significant reduction occurred in V1 variety (0.5%) compared to control. Again in severe drought (D2), relative growth rate decreased most significantly in V4 variety (26%) and least significant reduction occurred in V1 variety (19%) compared to control (Figure 5). So it is clear that V1 variety gave best performance in terms of relative growth rate in both mild and severe drought condition. Estimation of relative growth rate value on plant height basis is totally dependent on the rate of plant height increase or decrease over time. Increased drought level causes gradual reduction of plant height over time (Zhou *et al.*, 2017) and that's why plants facing drought condition show lower relative growth rate compared to control condition. Similar results were also reported by Khan *et al.* (2015).

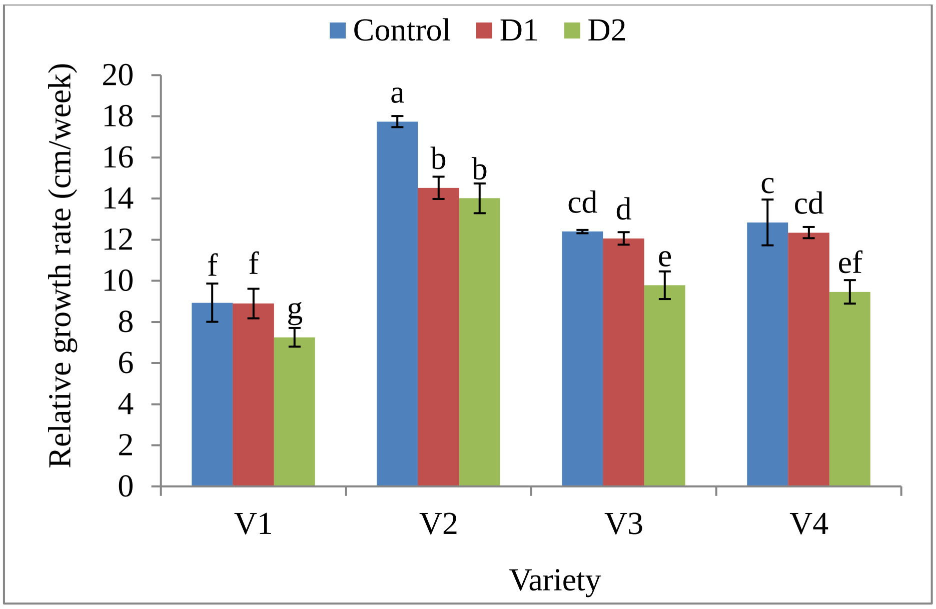


**Figure 5:** Effect of drought on relative growth rate

### 4.1.6 SPAD value of leaf

Drought stress significantly decreased the SPAD value of leaf of all tested tomato varieties with the increase of drought level. In mild drought (D1), SPAD value of leaf decreased most significantly in V1, V3 and V4 variety (12%) and least non-significant reduction occurred in V2 variety (5%) compared to control. Again in severe drought (D2), SPAD value of leaf decreased most significantly in V2 variety (26%) and least non-significant reduction occurred in V1 and V3 variety (17%) compared to control (Figure 6). A reason for decrease in chlorophyll content as affected by water deficit is that drought stress by producing reactive oxygen species (ROS), such as $O^{2-}$ and $H_2O_2$, can lead to lipid peroxidation and consequently chlorophyll destruction (Foyer *et al.*, 1994; Hirt and Shinozaki, 2004). Similar results were also reported by Sakya *et al.* (2018).

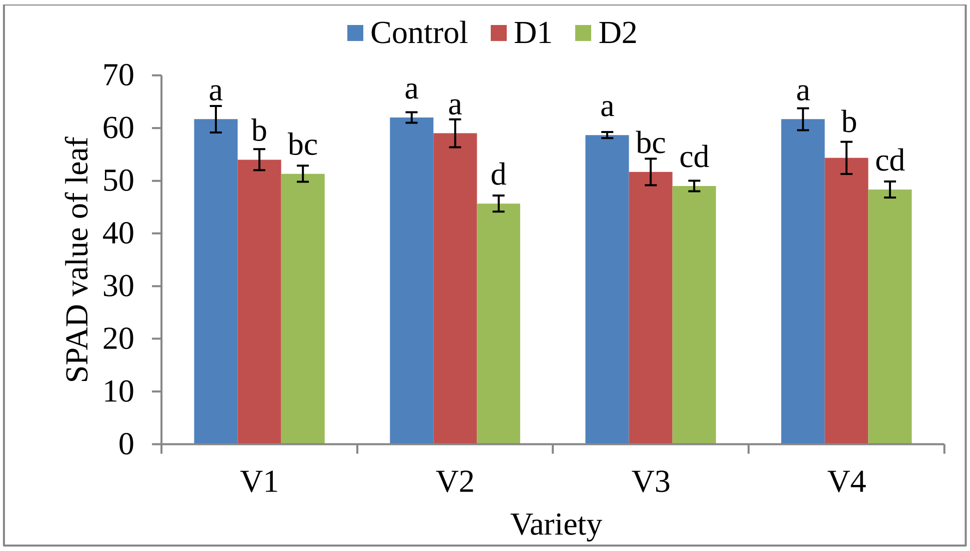


**Figure 6:** Effect of drought on SPAD value of leaf

### 4.1.7 Plant fresh weight

Drought stress significantly reduced the plant fresh weight of all tested tomato varieties with the increase of drought level. In mild drought (D1), plant fresh weight non-significantly decreased most in V1 variety (4%) and no reduction occurred in V3 variety compared to control. Again in severe drought (D2), plant fresh weight significantly decreased most in V1 variety (31%) and least significant reduction occurred in V2 variety (24%) compared to control (Figure 7). Drought stress condition reduces number of branches per plant, plant height and stem size (Zhou *et al.*, 2017; Salama *et al.*, 2017; Sibomana *et al.*, 2013), that results in lower plant fresh weight. Similar results were also reported by Zhou *et al.* (2017).

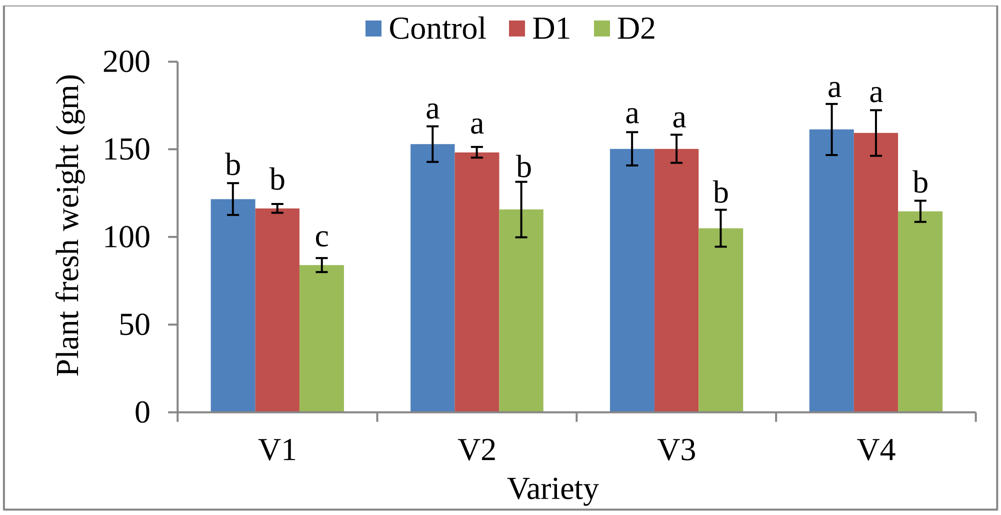


**Figure 7:** Effect of drought on plant fresh weight

#### 4.1.8 Plant dry weight

The plant dry weight of all tested tomato varieties significantly decreased with the increase of drought level. In mild drought (D1), plant dry weight non-significantly decreased most in V2 variety (9%) and least non-significant reduction occurred in V3 variety (2%) compared to control. Again in severe drought (D2), plant dry weight significantly decreased most in V4 variety (48%) and least significant reduction occurred in V2 variety (13%) compared to control (Figure 8). Drought stress condition reduces number of branches per plant (Salama *et al.*, 2017) and for this reason produces lower dry matter content in plant, which results in lower plant dry weight after drying (Ban *et al.*, 1994). Similar results were also reported by Giuliani *et al.* (2018).

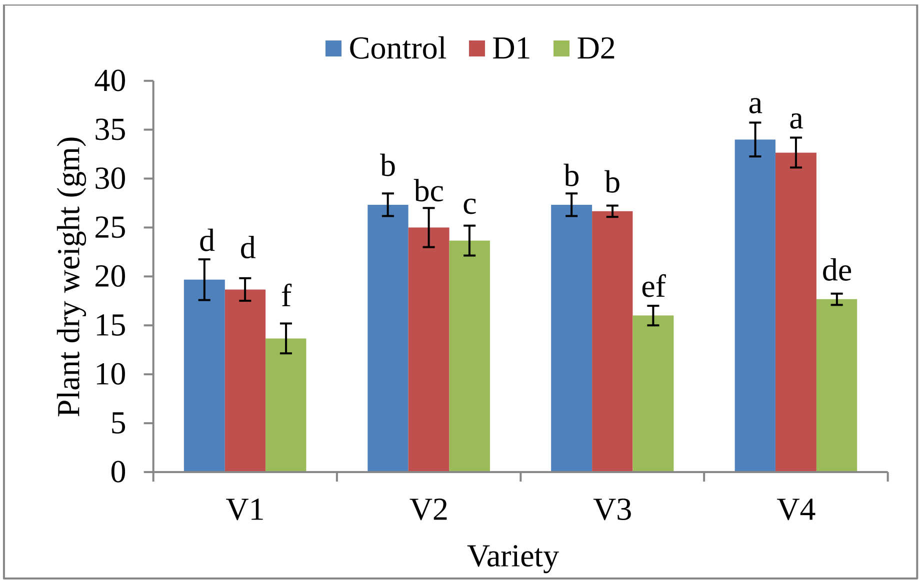


**Figure 8:** Effect of drought on plant dry weight

### 4.2 Yield (reproductive) parameters

#### 4.2.1 Number of clusters per plant

Drought stress decreased the number of clusters per plant of all tested tomato varieties with the increase of drought level. In mild drought (D1), number of clusters non-significantly decreased most in V2 variety (9%) and no reduction occurred in V4 variety compared to control. Again in severe drought (D2), number of clusters significantly decreased most in V4 variety (26%) and least non-significant reduction occurred in V1 variety (5%) compared to control (Figure 9). Water deficit leads to decrease in the number of flowers and flower drops (Buhroy *et al.*, 2017; Losada and Rincaon, 1994; Colla *et al.*, 1999; Rahman *et al.*, 1999; Veit-Kohler *et al.*, 1999) that is responsible for decreased number of clusters per plant. Similar results were also reported by Buhroy *et al.* (2017).

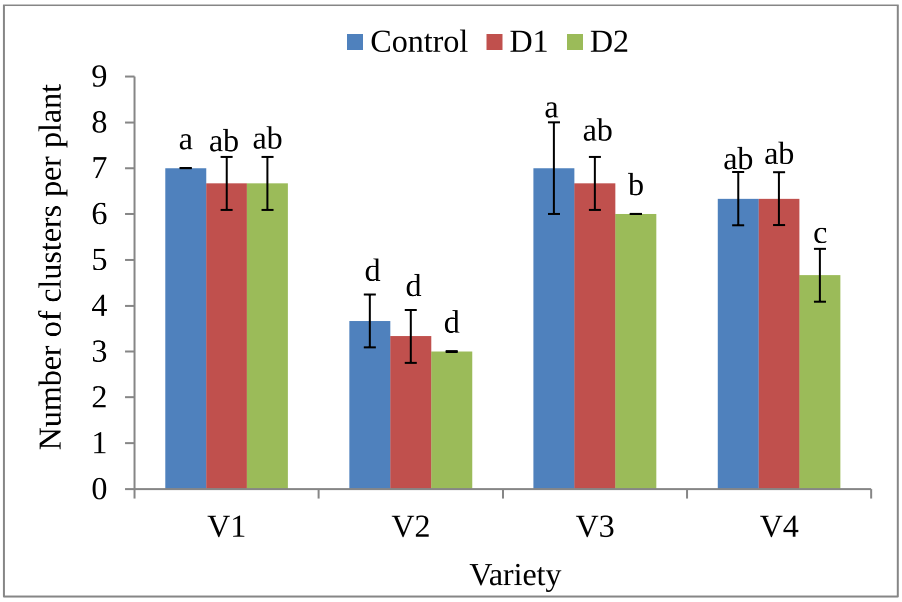


**Figure 9:** Effect of drought on number of clusters per plant

### 4.2.2 First flowering time

Drought stress slightly decreased the first flowering time of all tested tomato varieties in mild drought condition. But most of the varieties showed slightly increased first flowering time in severe drought condition. In mild drought (D1), first flowering time decreased most non-significantly in V1 variety (5%) and least non-significant reduction occurred in V4 variety (2%) compared to control. Again in severe drought (D2), first flowering time increased most non-significantly in V3 and V4 variety (4%) and no reduction occurred in V1 variety compared to control (Figure 10). Reproductive development at the period of flowering stage of tomato is highly sensitive to drought condition (Samarah *et al.*, 2009c; Zinselmeier *et al.*, 1999, 1995). Drought significantly interferes with flowering time, nectar production, flower opening mode and turgor maintenance of floral organs. As a result, drought condition brings a significant change in flowering time in all tomato varieties. In mild drought condition, tomato plants try to cope up with the changed water stressed condition and initiate early flowering compared to control. This early flowering under drought might be due to quick phonological development in order to complete the life cycle under an unfavorable environmental condition (Sivakumar and Srividhya, 2016). Again, in severe drought condition, the same plants show late flowering compared to control due to lack of ability of plants to survive anyway against drought stress. Similar results were also reported by Sivakumar and Srividhya (2016) and found that the plants under drought condition initiated flowers earlier (26 days) than plants in control condition (30 days).

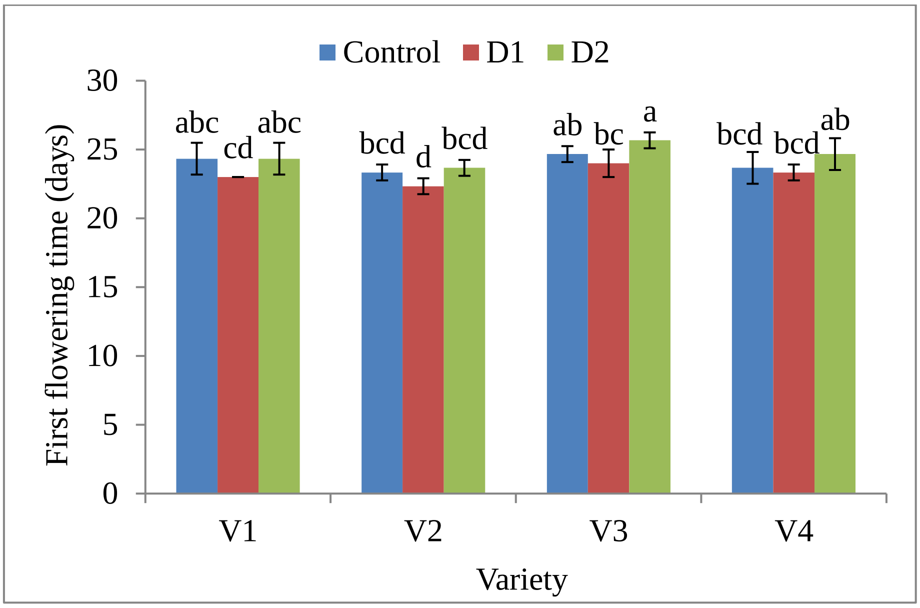


**Figure 10:** Effect of drought on first flowering time

### 4.2.3 Number of fruits per cluster

Drought stress reduced the number of fruits per cluster non-significantly (significant in V1 only) of all tested tomato varieties with the increase of drought level. In mild drought (D1), number of fruits non-significantly decreased most in V4 variety (15%) and no reduction occurred in V3 variety compared to control. Again in severe drought (D2), number of fruits decreased most significantly in V1 variety (34%) and least non-significant reduction occurred in V3 variety (14%) compared to control (Figure 11). Number of fruits per cluster is reduced since immature fruit dropping occurs when tomato plants face drought. Similar results were also reported by Nahar and Ullah (2012).

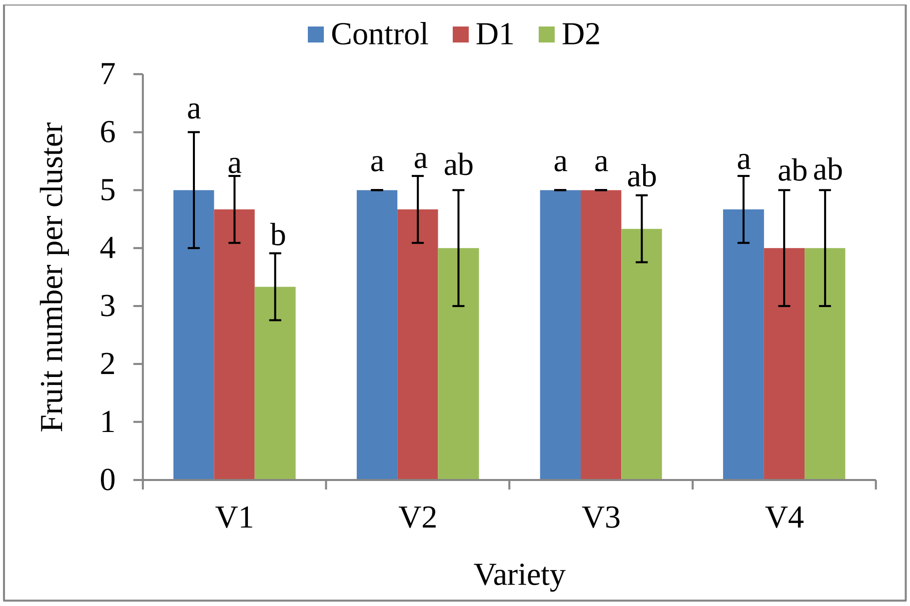


**Figure 11:** Effect of drought on number of fruits per cluster

### 4.2.4 Number of fruits per plant

Drought stress significantly decreased the number of fruits per plant of all tested tomato varieties with the increase of drought level. In mild drought (D1), number of fruits per plant decreased non-significantly (significant in V1 only) in V1, V2, V3 and V4 variety respectively 23%, 10%, 11% and 15% compared to control. Again in severe drought (D2), number of fruits per plant decreased significantly in V1, V2, V3 and V4 variety respectively 23%, 35%, 34% and 28% compared to control (Figure 12). It is clear that V2 variety shows better yield performance than others in mild drought, but its yield drastically reduced in severe drought condition. Again V1 variety showed no reduction of fruit number per plant when move from mild to severe drought than others in spite of having highest significant yield reduction in mild drought. Drought leads to a significant reduction in the number of flowers and consecutively flower number reduction causes lower number of fruit production and ultimately to less marketable yield (Buhroy *et al.*, 2017; Losada and Rincaon, 1994; Colla *et al.*, 1999; Rahman *et al.*, 1999; Veit-Kohler *et al.*, 1999). Similar results were also reported by Khan *et al.* (2020).

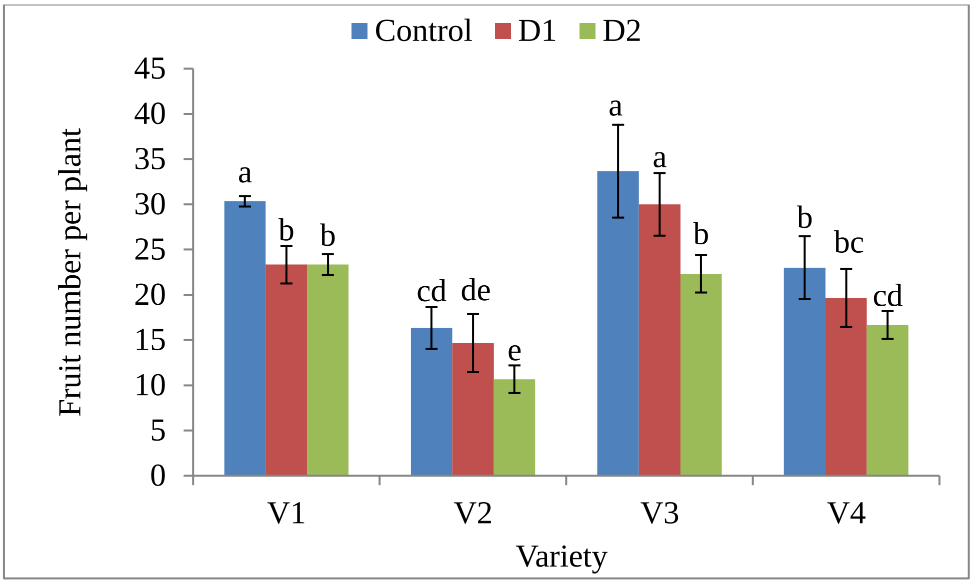


**Figure 12:** Effect of drought on number of fruits per plant

### 4.2.5 Fruit length

Drought stress significantly decreased the fruit length of all tested tomato varieties with the increase of drought level. In mild drought (D1), fruit length significantly decreased most in V1 variety (6%) and least non-significant reduction occurred in V2 variety (3%) compared to control. Again in severe drought (D2), fruit length significantly decreased most in V3 variety (11%) and least significant reduction occurred in V2 variety (4%) compared to control (Figure 13). From the observed data, it is clear that V2 variety gives best performance in terms of fruit length in drought and is highest drought adaptable than others. The effect of water stress on fruit growth could be explained by insufficient water for cell elongation, through which the fruit ensures its growth during the last stages and/or through photosynthesis, leading to a shortage in photosynthates preventing the fruit from satisfying its demand. The crop load effect on growth could be attributed to high competition existing among fruit toward a limited source (photosynthates) which resulted from water deficit (Mahhou *et al.*, 2006). As a result the fruit length decreases with the increase of drought level. Similar results were also reported by Rao *et al.* (2000).

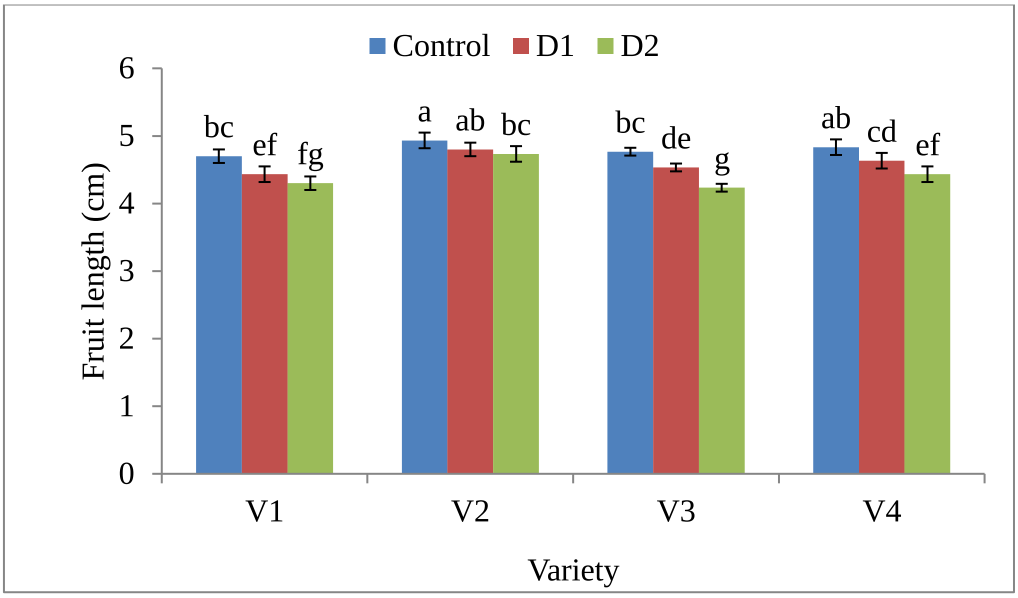


**Figure 13:** Effect of drought on fruit length

### 4.2.6 Fruit diameter

Drought stress significantly decreased the fruit diameter of all tested tomato varieties with the increase of drought level. In mild drought (D1), fruit diameter significantly decreased most in V3 variety (6%) and least non-significant reduction occurred in V2 variety (2%) compared to control. Again in severe drought (D2), fruit diameter significantly decreased most in V1 and V3 variety (10%) and least significant reduction occurred in V2 variety (5%) compared to control (Figure 14). From the obtained data, it is clear that V2 variety gives best performance in terms of fruit diameter in drought and is highest drought adaptable than others. Water stress on fruit growth causes insufficient water for cell elongation that leads to a shortage in photosynthates preventing the fruit from satisfying its demand (Mahhou *et al.*, 2006). As a result the fruit diameter decreases with the increase of drought level. Similar results were also reported by Rao *et al.* (2000).

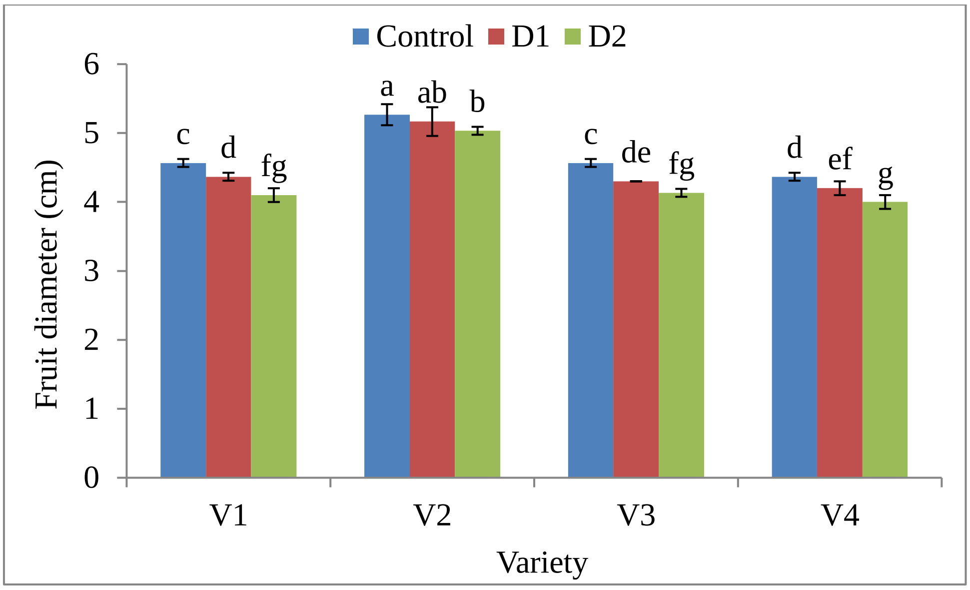


**Figure 14:** Effect of drought on fruit diameter

### 4.2.7 Individual fruit weight per plant

Drought stress significantly decreased the individual fruit weight per plant of all tested tomato varieties with the increase of drought level. In mild drought (D1), individual fruit weight per plant decreased non-significantly (significant in V1 only) in V1, V2, V3 and V4 variety respectively 11%, 3%, 4% and 6% compared to control. Again in severe drought (D2), individual fruit weight per plant significantly decreased in V1, V2, V3 and V4 variety respectively 15%, 28%, 20% and 31% compared to control (Figure 15). It is clear that V2 variety shows excellent fruit yield performance than others in mild drought, but its yield drastically reduced in severe drought condition. Again V1 variety showed better performance in severe drought as yield reduction is lowest than others in spite of having highest yield reduction in mild drought. Lack of water due to drought stress interferes with the normal activities of tomato plants through influencing the plant vigor and productivity at a great extent; this condition is responsible for individual fruit weight decrease of tomato plants in drought (Techawongstein *et al.*, 1992). Similar results were also reported by Sakya *et al.* (2018) and mentioned that tomato fruit weight in the drought conditions decreased from 3-148% compared to control.

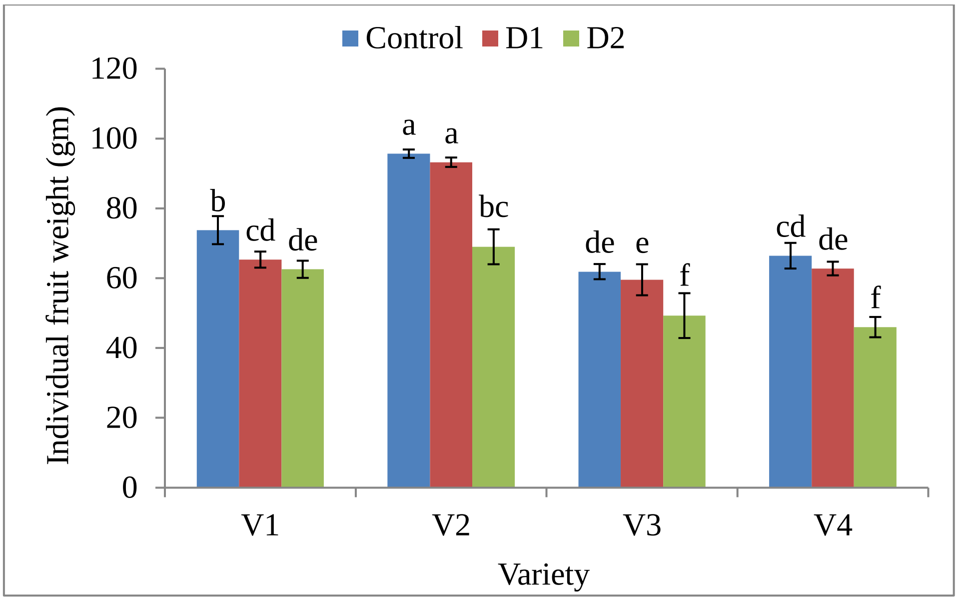


**Figure 15:** Effect of drought on individual fruit weight per plant

### 4.2.8 Fruit maturity time

Drought stress slightly decreased the fruit maturity time of all tested tomato varieties in mild drought condition, but two varieties showed increased fruit maturity time in severe drought. In mild drought (D1), fruit maturity time decreased most non-significantly in V1 variety (2%) and least non-significant reduction occurred in all V2, V3 and V4 varieties (1%) compared to control. Again in severe drought (D2), fruit maturity time decreased non-significantly in V2 variety (0.4%) and no reduction occurred in V1 variety and fruit maturity time increased in V3 variety (1%) non-significantly and in V4 variety (2%) significantly compared to control (Figure 16). Ripening is the most sensitive stage of plant during drought and that's why a variation occurs in fruit maturity time under water stress. This early ripening in mild drought may be the consecutive result of early flowering initiation of tomato plants under mild drought condition. Similar results were also reported by Akter *et al.* (2019) and Sibomana *et al.* (2013).

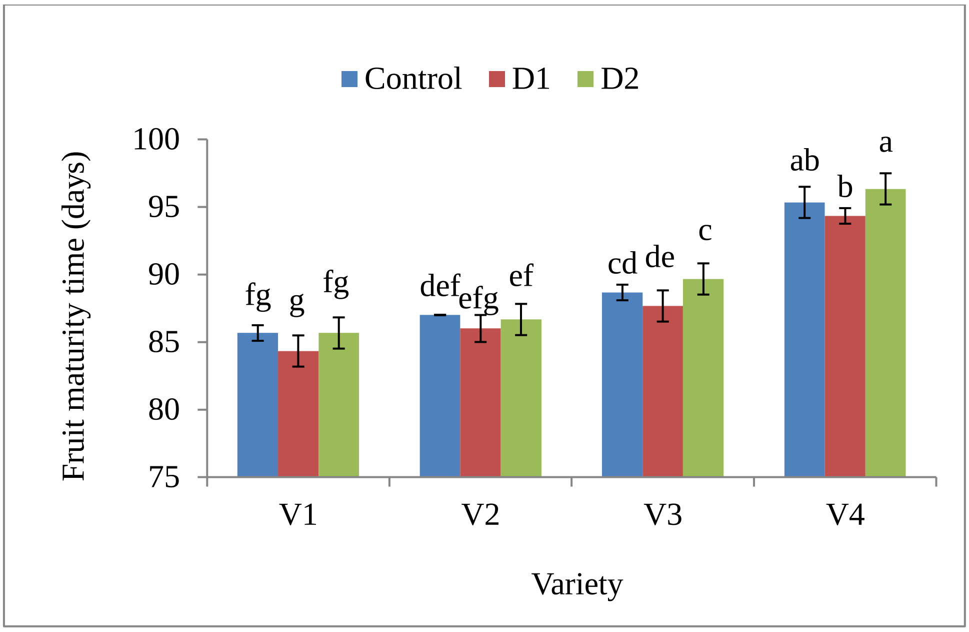


**Figure 16:** Effect of drought on fruit maturity time

### 4.2.9 Yield per plant

Drought stress significantly decreased the yield per plant of all tested tomato varieties with the increase of drought level. In mild drought (D1), yield per plant decreased non-significantly (significant in V1 only) in V1, V2, V3 and V4 variety respectively 32%, 8%, 14% and 20% compared to control. Again in severe drought (D2), yield per plant significantly decreased in V1, V2, V3 and V4 variety respectively 35%, 52%, 47% and 51% compared to control (Figure 17). This result is showing that in mild drought stress V2 variety showed best performance compared to others. Again V1 variety showed better performance in severe drought as yield reduction is lowest compared the others in spite of having highest yield reduction in mild drought. This observation ensured that V2 variety is the most adaptable variety for mild drought and V1 variety is the most suitable variety for severe drought condition. Drought during flowering stage induced fruit drops and lower number of fruit sets; again drought stress during fruiting stage induced highest decrease of fruit size, this incidents cause lower yield production of tomato plants. Rahman *et al.* (1999) also found similar result of my study where fruit yield decreased with increased level of water stress.

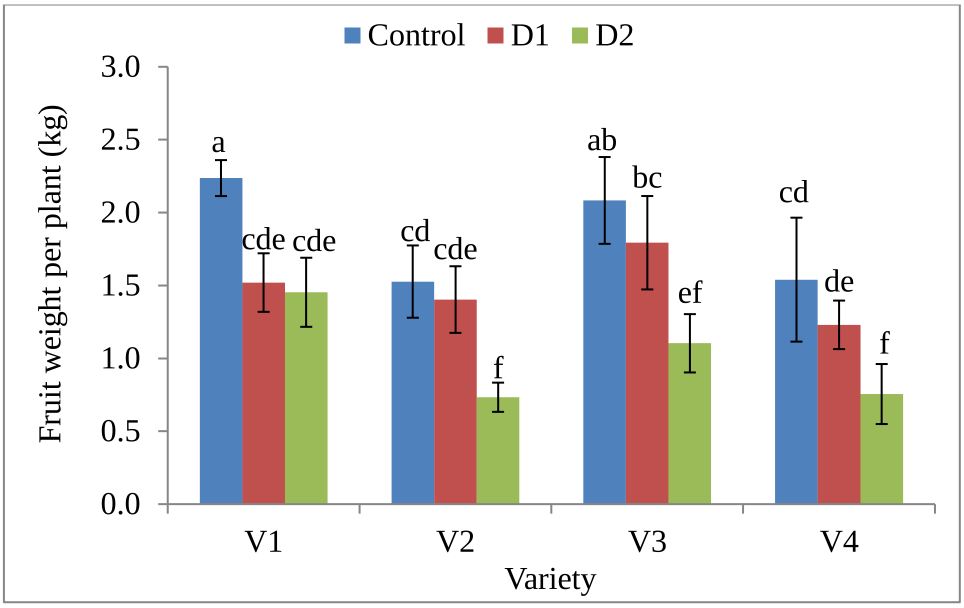


**Figure 17:** Effect of drought on yield per plant

# CHAPTER 5

# SUMMARY AND CONCLUSION

## SUMMARY

A pot experiment was conducted to observe the changes of growth, yield of four tomato genotypes under three different drought treatments and to find out the drought suitable genotype of tomato. The experiment was conducted at the net house of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, during the months of October 2018 to February 2019. Two factorial experiment including four tomato varieties viz. V1 (BARI Tomato 2), V2 (BARI Tomato 14), V3 (BARI Tomato 15), V4 (BARI Tomato 16) and three drought treatments, D0 [1 days of irrigation interval (control)], D1 [3 days of irrigation interval (mild drought stress)] and D2 [5 days of irrigation interval (severe drought stress)] were outlined in completely randomized design (CRD) with 3 replications.

Collected data were statistically analyzed for the evaluation of tomato varieties under different drought treatments. Among interactions of tomato varieties and drought treatments, in case of number of branches per plant, in mild drought (D1), number of branches per plant decreased most in V3 variety (8%) compared to control and no reduction occurred in V1 variety. Again in severe drought (D2), number of branches per plant decreased most in V3 variety (20%) and least significant reduction occurred in V2 variety (10%) compared to control. In case of plant height, in mild drought (D1), plant height decreased most in V2 variety (14%) and least reduction occurred in V1 variety (0.3%) compared to control. Again in severe drought (D2), plant height decreased most in V4 variety (18%) and least reduction occurred in V1 variety (11%) compared to control. In case of stem length, in mild drought (D1), stem length decreased most in V4 variety (14%) and least non-significant reduction occurred in V2 variety (6%) compared to control. Again in severe drought (D2), stem length decreased most in V3 variety (30%) and least reduction occurred in V1 variety (12%). In case of stem diameter, in mild drought (D1), stem diameter decreased most in V1 and V4 variety (3%) and no reduction occurred in V3 variety compared to control. Again in severe drought (D2), stem diameter decreased most in V3 variety (11%) and

least reduction occurred in V2 variety (3%) compared to control. In case of relative growth rate, in mild drought (D1), relative growth rate decreased most in V2 variety (18%) and least reduction occurred in V1 variety (0.5%) compared to control. Again in severe drought (D2), relative growth rate decreased most in V4 variety (26%) and least reduction occurred in V1 variety (19%). In case of SPAD value of leaf, in mild drought (D1), SPAD value of leaf decreased most in V1, V3 and V4 variety (12%) and least reduction occurred in V2 variety (5%) compared to control. Again in severe drought (D2), SPAD value of leaf decreased most in V2 variety (26%) and least reduction occurred in V1 and V3 variety (17%) compared to control. In case of plant fresh weight, in mild drought (D1), plant fresh weight decreased most in V1 variety (4%) and no reduction occurred in V3 variety compared to control. Again in severe drought (D2), plant fresh weight decreased most in V1 variety (31%) and least reduction occurred in V2 variety (24%) compared to control. In case of plant dry weight, in mild drought (D1), plant dry weight non-significantly decreased most in V2 variety (9%) and least non-significant reduction occurred in V3 variety (2%) compared to control. Again in severe drought (D2), plant dry weight significantly decreased most in V4 variety (48%) and least significant reduction occurred in V2 variety (13%) compared to control.

In case of number of clusters per plant, in mild drought (D1), number of clusters decreased most in V2 variety (9%) and no reduction occurred in V4 variety compared to control. Again in severe drought (D2), number of clusters decreased most in V4 variety (26%) and least reduction occurred in V1 variety (5%). In case of first flowering time, in mild drought (D1), first flowering time decreased most in V1 variety (5%) and least reduction occurred in V4 variety (2%) compared to control. Again in severe drought (D2), first flowering time increased most in V3 and V4 variety (4%) and no reduction occurred in V1 variety. In case of number of fruits per cluster, in mild drought (D1), number of fruits decreased most in V4 variety (15%) and no reduction occurred in V3 variety compared to control. Again in severe drought (D2), number of fruits decreased most in V1 variety (34%) and least reduction occurred in V3 variety (14%). In case of number of fruits per plant, in mild drought (D1), number of fruits per plant decreased in V1, V2, V3 and V4 variety respectively 23%, 10%, 11% and 15% compared to control. Again in severe drought (D2), number of fruits per plant decreased in V1, V2, V3 and V4 variety respectively 23%, 35%, 34% and 28% compared to control. In case of fruit length, in mild drought (D1), fruit length decreased most in V1 variety (6%) and least reduction occurred in V2 variety (3%) compared to control. Again in severe drought (D2), fruit length decreased most in V3 variety (11%) and least reduction occurred in V2 variety (4%). In case of fruit diameter, in mild drought (D1), fruit diameter decreased most in V3 variety (6%) and least reduction occurred in V2 variety (2%) compared to control. Again in severe drought (D2), fruit diameter decreased most in V1 and V3 variety (10%) and least reduction occurred in V2 variety (5%) compared to control. In case of individual fruit weight per plant, in mild drought (D1), individual fruit weight per plant decreased in V1, V2, V3 and V4 variety respectively 11%, 3%, 4% and 6% compared to control. Again in severe drought (D2), individual fruit weight per plant decreased in V1, V2, V3 and V4 variety respectively 15%, 28%, 20% and 31% compared to control. In case of fruit maturity time, in mild drought (D1), fruit maturity time decreased most in V1 variety (2%) and least reduction occurred in all V2, V3 and V4 varieties (1%) compared to control. Again in severe drought (D2), fruit maturity time decreased in V2 variety (0.4%) and no reduction occurred in V1 variety and fruit maturity time increased in V3 variety (1%) and in V4 variety (2%) compared to control. In case of yield per plant, in mild drought (D1), yield per plant decreased in V1, V2, V3 and V4 variety respectively 32%, 8%, 14% and 20% compared to control. Again in severe drought (D2), yield per plant decreased in V1, V2, V3 and V4 variety respectively 35%, 52%, 47% and 51% compared to drought.

Considering the yield performance, V2 variety was the best tomato variety for cultivation in mild drought condition; again V1 variety was proved as best tomato variety for cultivation in severe drought condition.

## CONCLUSION

Drought is one of the most critical environmental hazards of the world. Tomato is one of the important vegetable crops of Bangladesh and is very sensitive to drought stress. Large amounts of land in west-northern region of Bangladesh remain uncultivable due to high level of drought in both summer and winter season and become unsuitable for the cultivation of tomato as well as other crops. To overcome the drought problem, drought adaptable tomato varieties must be selected. Evaluation followed by screening can be an easier method to determine drought adaptive varieties. From this experiment, the conclusion is-

- ↔ Drought disturbs the plant physiological activities which have negative effects on growth and yield performances of tomato.
- ↔ BARI Tomato 14 variety is the best tomato variety for mild drought condition.
- ↔ Again BARI Tomato 2 variety is the best tomato variety for cultivation in severe drought condition.
- ↔ These drought adaptive tomato varieties can also be grown with other plant species in agroforestry system where water stress is common.

# RECOMMENDATIONS

Following recommendations and suggestions related to this experiment should be followed for future research activities regarding on this similar topic-

- Further more growth and yield based researches on this similar topic should be done in future to get more accurate results.
- More researches on physiological, biochemical and molecular mechanisms of drought tolerance should be undertaken.
- Researches on other two abiotic resource pools (light and nutrient stress) should be done in future.

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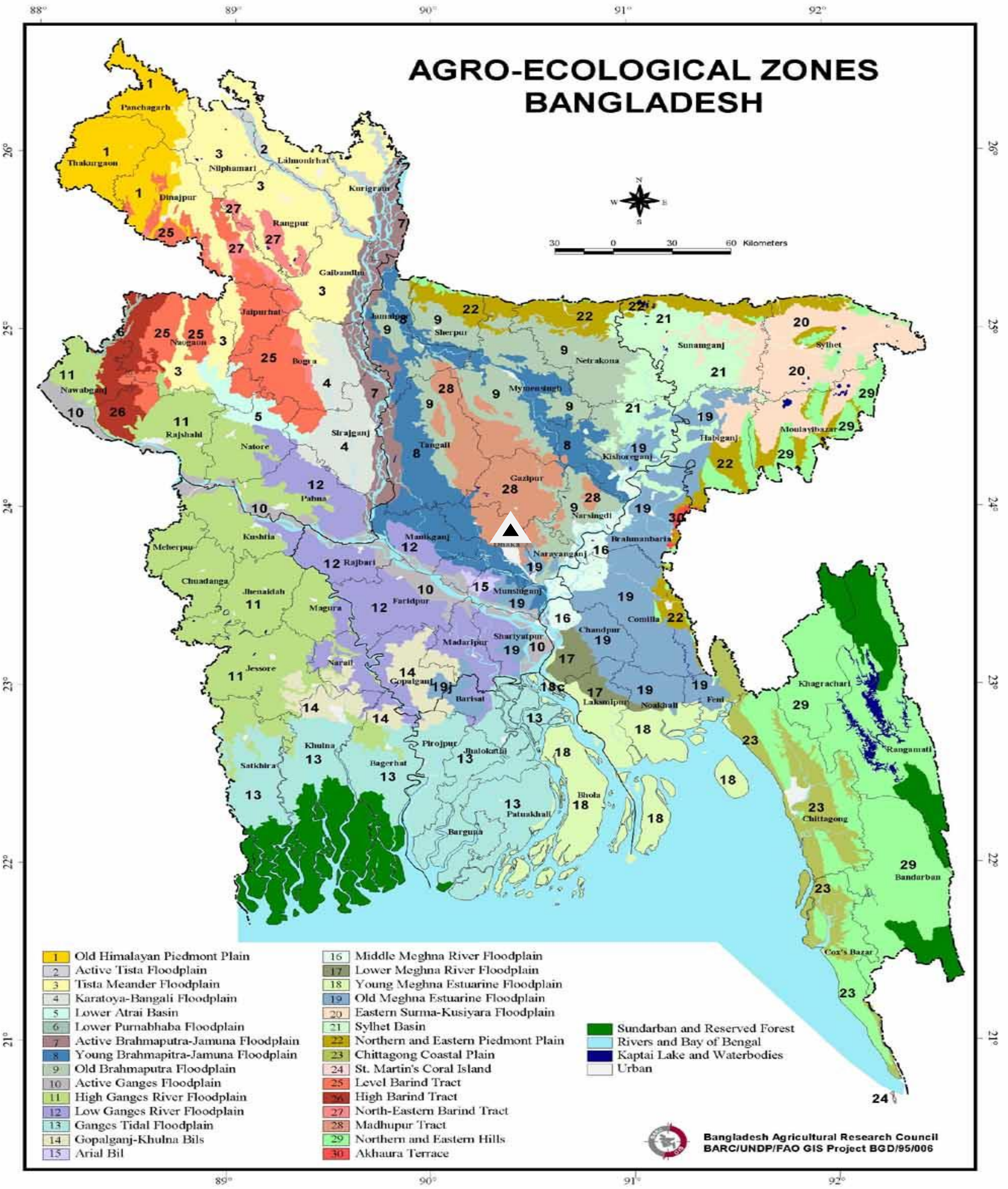
## APPENDICES

**Appendix 1.** Map showing the experimental site under the study




▲ The experimental site under study

**Appendix 2.** Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from October 2018 to March 2019.

| Month | Year | Monthly average air temperature (°C) | | | Average relative humidity (%) | Total rainfall (mm) | Total sunshine (hours) |
|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Mean | | | |
| Oct. | 2018 | 36 | 21 | 28 | 69 | Trace | 219 |
| Nov. | 2018 | 31 | 18 | 24 | 63 | Trace | 216 |
| Dec. | 2018 | 28 | 16 | 22 | 61 | Trace | 212 |
| Jan. | 2019 | 27 | 13 | 20 | 57 | Trace | 198 |
| Feb. | 2019 | 29 | 18 | 23 | 70 | 3 | 225 |
| Mar. | 2019 | 32 | 22 | 25 | 73 | 4 | 231 |

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

**Appendix 3.** The mechanical and chemical characteristics of soil of the experimental site as observed prior to experimentation (0 -15 cm depth).

**Mechanical composition:**

| **Particle size** | **Constitution** |
|---|---|
| Texture | Loamy |
| Sand | 40% |
| Silt | 40% |
| Clay | 20% |

**Chemical composition:**

| Soil characters | Value |
|---|---|
| Organic matter | 1.44 % |
| Potassium | 0.15 meq/100 g soil |
| Calcium | 1.00 meq/100 g soil |
| Magnesium | 1.00 meq/100 g soil |
| Total nitrogen | 0.072 |
| Phosphorus | 22.08 µg/g soil |
| Sulphur | 25.98 µg/g soil |
| Boron | 0.48 µg/g soi |
| Copper | 3.54 µg/g soil |
| Iron | 262.6 µg/g soil |
| Manganese | 164 µg/g soil |
| Zinc | 3.32 µg/g soil |

**Source:** Soil Resources Development Institute (SRDI), Khamarbari, Dhaka

**Appendix 4.** Mean values of different growth and yield contributing traits of four tomato varieties under control and drought stress treatment

| | Number of branches per plant | Plant height (cm) | Stem length (cm) | Stem diameter (cm) | Relative growth rate (cm/week) | SPAD value of leaf |
|---|---|---|---|---|---|---|
| V1D0 | 11.67 | 59.73 | 8.03 | 1.3 | 8.93 | 61.7 |
| V1D1 | 11.67 | 59.57 | 7.5 | 1.25 | 8.89 | 54 |
| V1D2 | 10 | 53 | 7.07 | 1.25 | 7.25 | 51.3 |
| V2D0 | 10 | 94.97 | 12.37 | 1.26 | 17.74 | 62 |
| V2D1 | 9.33 | 82.07 | 11.6 | 1.24 | 14.52 | 59 |
| V2D2 | 9 | 80.03 | 8.93 | 1.22 | 14.01 | 45.7 |
| V3D0 | 11.67 | 73.57 | 8.53 | 1.16 | 12.39 | 58.7 |
| V3D1 | 10.67 | 72.23 | 7.97 | 1.16 | 12.06 | 51.7 |
| V3D2 | 9.33 | 63.13 | 6 | 1.03 | 9.78 | 49 |
| V4D0 | 11.67 | 75.33 | 10.67 | 1.22 | 12.84 | 61.7 |
| V4D1 | 11 | 73.37 | 9.13 | 1.18 | 12.34 | 54.3 |
| V4D2 | 9.67 | 61.83 | 8.8 | 1.17 | 9.46 | 48.3 |

D0: control; D1: Mild drought; D2: Severe drought

**Appendix 4. (cont.)**

| | Plant fresh weight (gm) | Plant dry weight (gm) | Number of clusters per plant | First flowering time (days) | Number of fruits per cluster | Number of fruits per plant |
|---|---|---|---|---|---|---|
| V1D0 | 121.67 | 19.67 | 7 | 24.33 | 5 | 30.33 |
| V1D1 | 116.33 | 18.67 | 6.67 | 23 | 4.67 | 23.33 |
| V1D2 | 84 | 13.67 | 6.67 | 24.33 | 3.33 | 23.33 |
| V2D0 | 153 | 27.33 | 3.67 | 23.33 | 5 | 16.33 |
| V2D1 | 148.33 | 25 | 3.33 | 22.33 | 4.67 | 14.67 |
| V2D2 | 115.67 | 23.67 | 3 | 23.67 | 4 | 10.67 |
| V3D0 | 150.33 | 27.33 | 7 | 24.67 | 5 | 33.67 |
| V3D1 | 150.33 | 26.67 | 6.67 | 24 | 5 | 30 |
| V3D2 | 105 | 16 | 6 | 25.67 | 4.33 | 22.33 |
| V4D0 | 161.33 | 34 | 6.33 | 23.67 | 4.67 | 23 |
| V4D1 | 159.33 | 32.67 | 6.33 | 23.33 | 4 | 19.67 |
| V4D2 | 114.67 | 17.67 | 4.67 | 24.67 | 4 | 16.67 |

D0: control; D1: Mild drought; D2: Severe drought

**Appendix 4. (cont.)**

| | Individual fruit weight (g) | Fruit length(cm) | Fruit diameter (cm) | Fruit maturity time (days) | Yield per plant (kg) |
|---|---|---|---|---|---|
| V1D0 | 73.77 | 4.7 | 4.57 | 85.67 | 2.24 |
| V1D1 | 65.33 | 4.43 | 4.37 | 84.33 | 1.52 |
| V1D2 | 62.55 | 4.3 | 4.1 | 85.67 | 1.45 |
| V2D0 | 95.67 | 4.93 | 5.27 | 87 | 1.53 |
| V2D1 | 93.22 | 4.8 | 5.17 | 86 | 1.40 |
| V2D2 | 69 | 4.73 | 5.03 | 86.67 | 0.73 |
| V3D0 | 61.88 | 4.77 | 4.57 | 88.67 | 2.08 |
| V3D1 | 59.55 | 4.53 | 4.3 | 87.67 | 1.79 |
| V3D2 | 49.29 | 4.23 | 4.13 | 89.67 | 1.1 |
| V4D0 | 66.45 | 4.83 | 4.37 | 95.33 | 1.54 |
| V4D1 | 62.78 | 4.63 | 4.2 | 94.33 | 1.23 |
| V4D2 | 45.99 | 4.43 | 4 | 96.33 | 0.75 |

D0: control; D1: Mild drought; D2: Severe drought

**Appendix 5.** Factorial ANOVA Table for all the growth and yield parameters of four tomato varieties under control and drought stress treatment

**Factorial ANOVA Table for Number of branches per plant**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Rep | 2 | 0.1172 | 0.05861 | | |
| Variety | 3 | 14.0833 | 4.69444 | 14.35 | 0.0000 |
| Drought | 2 | 19.0556 | 9.52778 | 29.13 | 0.0000 |
| Variety*Drought | 6 | 2.5000 | 0.41667 | 1.27 | 0.3094 |
| Error | 22 | 7.1961 | 0.32710 | | |
| Total | 35 | 42.9522 | | | |

Grand Mean 10.472
CV 5.46

**Factorial ANOVA Table for Plant height (cm)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 67.04 | 33.52 | | |
| Variety | 3 | 3618.48 | 1206.16 | 189.30 | 0.0000 |
| Drought | 2 | 800.45 | 400.23 | 62.81 | 0.0000 |
| Variety*Drought | 6 | 194.16 | 32.36 | 5.08 | 0.0021 |
| Error | 22 | 140.18 | 6.37 | | |
| Total | 35 | 4820.30 | | | |

Grand Mean 70.736
CV 3.57

**Factorial ANOVA Table for Stem length (cm)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 0.065 | 0.0325 | | |
| Variety | 3 | 76.490 | 25.4967 | 73.34 | 0.0000 |
| Drought | 2 | 29.540 | 14.7700 | 42.49 | 0.0000 |
| Variety*Drought | 6 | 7.907 | 1.3178 | 3.79 | 0.0096 |
| Error | 22 | 7.648 | 0.3477 | | |
| Total | 35 | 121.650 | | | |

Grand Mean 8.8833
CV 6.64

**Factorial ANOVA Table for Stem diameter (cm)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 0.00187 | 0.00093 | | |
| Variety | 3 | 0.11989 | 0.03996 | 43.96 | 0.0000 |
| Drought | 2 | 0.02712 | 0.01356 | 14.91 | 0.0001 |
| Variety*Drought | 6 | 0.01693 | 0.00282 | 3.10 | 0.0234 |
| Error | 22 | 0.02000 | 0.00091 | | |
| Total | 35 | 0.18580 | | | |

Grand Mean 1.2033
CV 2.51

**Factorial ANOVA Table for Relative growth rate (cm/week)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 4.877 | 2.4384 | | |
| Variety | 3 | 226.259 | 75.4195 | 372.10 | 0.0000 |
| Drought | 2 | 50.034 | 25.0169 | 123.43 | 0.0000 |
| Variety*Drought | 6 | 12.117 | 2.0195 | 9.96 | 0.0000 |
| Error | 22 | 4.459 | 0.2027 | | |
| Total | 35 | 297.745 | | | |

Grand Mean 11.685
CV 3.85

**Factorial ANOVA Table for SPAD value of leaf**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 5.06 | 2.528 | | |
| Variety | 3 | 37.56 | 12.519 | 3.12 | 0.0467 |
| Drought | 2 | 925.06 | 462.528 | 115.27 | 0.0000 |
| Variety*Drought | 6 | 118.28 | 19.713 | 4.91 | 0.0025 |
| Error | 22 | 88.28 | 4.013 | | |
| Total | 35 | 1174.22 | | | |

Grand Mean 54.778
CV 3.66

**Factorial ANOVA Table for Plant fresh weight (gm)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 118.2 | 59.08 | | |
| Variety | 3 | 7553.6 | 2517.85 | 25.36 | 0.0000 |
| Drought | 2 | 13014.5 | 6507.25 | 65.55 | 0.0000 |
| Variety*Drought | 6 | 247.9 | 41.32 | 0.42 | 0.8602 |
| Error | 22 | 2183.8 | 99.27 | | |
| Total | 35 | 23118.0 | | | |

Grand Mean 131.67
CV 7.57

**Factorial ANOVA Table for Plant dry weight (gm)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 4.22 | 2.111 | | |
| Variety | 3 | 564.08 | 188.028 | 94.49 | 0.0000 |
| Drought | 2 | 611.56 | 305.778 | 153.66 | 0.0000 |
| Variety*Drought | 6 | 207.33 | 34.556 | 17.37 | 0.0000 |
| Error | 22 | 43.78 | 1.990 | | |
| Total | 35 | 1430.97 | | | |

Grand Mean 23.528
CV 6.00

**Factorial ANOVA Table for Number of clusters per plant**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 0.3889 | 0.1944 | | |
| Variety | 3 | 67.2222 | 22.4074 | 70.99 | 0.0000 |
| Drought | 2 | 5.3889 | 2.6944 | 8.54 | 0.0018 |
| Variety*Drought | 6 | 2.6111 | 0.4352 | 1.38 | 0.2668 |
| Error | 22 | 6.9444 | 0.3157 | | |
| Total | 35 | 82.5556 | | | |

Grand Mean 5.6111
CV 10.01

**Factorial ANOVA Table for First flowering time (days)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 1.1667 | 0.58333 | | |
| Variety | 3 | 12.5278 | 4.17593 | 5.93 | 0.0040 |
| Drought | 2 | 12.1667 | 6.08333 | 8.63 | 0.0017 |
| Variety*Drought | 6 | 1.3889 | 0.23148 | 0.33 | 0.9147 |
| Error | 22 | 15.5000 | 0.70455 | | |
| Total | 35 | 42.7500 | | | |

Grand Mean 23.917
CV 3.51

**Factorial ANOVA Table for Number of fruits per cluster**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 1.0556 | 0.52778 | | |
| Variety | 3 | 1.6389 | 0.54630 | 1.17 | 0.3439 |
| Drought | 2 | 6.2222 | 3.11111 | 6.66 | 0.0055 |
| Variety*Drought | 6 | 1.7778 | 0.29630 | 0.63 | 0.7016 |
| Error | 22 | 10.2778 | 0.46717 | | |
| Total | 35 | 20.9722 | | | |

Grand Mean 4.4722
CV 15.28

**Factorial ANOVA Table for Number of fruits per plant**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 18.00 | 9.000 | | |
| Variety | 3 | 1157.56 | 385.852 | 51.55 | 0.0000 |
| Drought | 2 | 345.17 | 172.583 | 23.06 | 0.0000 |
| Variety*Drought | 6 | 64.61 | 10.769 | 1.44 | 0.2450 |
| Error | 22 | 164.67 | 7.485 | | |
| Total | 35 | 1750.00 | | | |

Grand Mean 22.000
CV 12.44

**Factorial ANOVA Table for Individual fruit weight (g)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 42.00 | 21.00 | | |
| Variety | 3 | 4817.22 | 1605.74 | 139.96 | 0.0000 |
| Drought | 2 | 2059.02 | 1029.51 | 89.73 | 0.0000 |
| Variety*Drought | 6 | 432.19 | 72.03 | 6.28 | 0.0006 |
| Error | 22 | 252.40 | 11.47 | | |
| Total | 35 | 7602.83 | | | |

Grand Mean 67.124
CV 5.05

**Factorial ANOVA Table for Fruit diameter (cm)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 0.02056 | 0.01028 | | |
| Variety | 3 | 5.20556 | 1.73519 | 179.41 | 0.0000 |
| Drought | 2 | 0.84389 | 0.42194 | 43.63 | 0.0000 |
| Variety*Drought | 6 | 0.05611 | 0.00935 | 0.97 | 0.4700 |
| Error | 22 | 0.21278 | 0.00967 | | |
| Total | 35 | 6.33889 | | | |

Grand Mean 4.5056
CV 2.18

**Factorial ANOVA Table for Fruit length (cm)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 0.05389 | 0.02694 | | |
| Variety | 3 | 0.65556 | 0.21852 | 25.83 | 0.0000 |
| Drought | 2 | 0.88389 | 0.44194 | 52.24 | 0.0000 |
| Variety*Drought | 6 | 0.09611 | 0.01602 | 1.89 | 0.1272 |
| Error | 22 | 0.18611 | 0.00846 | | |
| Total | 35 | 1.87556 | | | |

Grand Mean 4.6111
CV 1.99

**Factorial ANOVA Table for Fruit maturity time (days)**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Replication | 2 | 1.056 | 0.528 | | |
| Variety | 3 | 544.111 | 181.370 | 184.63 | 0.0000 |
| Drought | 2 | 14.389 | 7.194 | 7.32 | 0.0036 |
| Variety*Drought | 6 | 2.722 | 0.454 | 0.46 | 0.8288 |
| Error | 22 | 21.611 | 0.982 | | |
| Total | 35 | 583.889 | | | |

Grand Mean 88.944
CV 1.11

**Factorial ANOVA Table for Yield per plant (kg)**

| **Source** | **DF** | **SS** | **MS** | **F** | **P** |
|---|---|---|---|---|---|
| Replication | 2 | 0.09082 | 0.04541 | | |
| Variety | 3 | 2.28797 | 0.76266 | 12.48 | 0.0001 |
| Drought | 2 | 4.21329 | 2.10665 | 34.48 | 0.0000 |
| Variety*Drought | 6 | 0.46957 | 0.07826 | 1.28 | 0.3063 |
| Error | 22 | 1.34401 | 0.06109 | | |
| Total | 35 | 8.40566 | | | |

Grand Mean 1.4482
CV 17.07