EFFECTS OF VARYING CONCENTRATIONS OF POTASSIUM ON THE GROWTH AND YIELD OF TOMATO PLANTS AT DROUGHT CONDITION

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CERTIFICATE

This is to certify that the thesis entitled,**" EFFECTS OF VARYING CONCENTRATIONS OF POTASSIUM ON THE GROWTH AND YIELD OF TOMATO PLANTS AT DROUGHT CONDITION"**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 ENVIRONMENTAL SCIENCE**, embodies the result of a piece of bona fide research work carried out by **ANIKA TABASSUM HOQUE** Registration No. **18-09176** under my supervision and my 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 this investigation has duly been acknowledged.

Dr. Nazmun Naher
Professor
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Dated: DECEMBER , 2020

Dhaka, Bangladesh

DEDICATED

TO

MY BELOVED

FATHER MD. EMDADUL HOQUE

AND

MOTHER HAFSA NAHER

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ABSTRACT

Drought is one of the most important limiting factors for agricultural crops and vegetable production all around the world. Potassium (K) is one of the vital elements required for plant growth and physiology. So, the experiment was conducted at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka to determine effects of different dose of potassium in drought condition on growth and yield contributing characters of different tomato varieties. BARI Tomato 2, BARI Tomato 15 and BARI Tomato 16 were used in this experiment. Different levels of potassium applied at drought condition. The treatments were T_1 (control), T_2 (0. 4g K/pot + 200ml water/kg soil) and T_3(0.9 g K/pot + 50 ml water/kg soil) applied at vegetative(40days), flowering (64 days) and fruiting stage (78 days) days after transplanting (DAT). The two factors experiment was laid out in Randomized Complete Block Design (RCBD) with 3 replications. The morphological growth, physiological and yield components of BARI tomato 15 showed the best performance with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination, then BARI Tomato 2 and BARI tomato 16. The lowest yield was showed in T_3 (0.9g K/Pot+50ml water/kg soil) treatment combination.

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	Bangladesh Bureau of Statistics	BBS
Food and Agriculture Organization	FAO	Soil Resource Development Institute	SRDI
Biology	Biol.	North	N
Biotechnology	Biotechnol.	Nutrition	Nutr.
Botany	Bot.	Pakistan	Pak.
Randomized Complete Block Design	RCBD	*Mean* sea level	*MSL*
Cultivar	cv.	Research and Resource	Res.
Degrees of freedom	DF	Regulation	Regul.
Degree Celsius	°C	Review	Rev.
Department	Dept.	Science	Sci.
Development	Dev.	Society	Soc.
Soil plant analysis development	SPAD	Triple super phosphate	TSP
Environment	Environ.	Technology	Technol.
Editors	Eds.	University	Univ.
Entomology	Entomol.	Thailand	Thai.
And others	*et al.*	Tropical	Trop.
United Kingdom	U.K.	United States of America	USA
Number	No.	Serial	Sl.
Gram	g	Liter	L
Horticulture	Hort.	Kilogram	Kg
International	Intl.		
Journal	J.	Percentage	%

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CHAPTER 1

INTRODUCTION

Bangladesh is one of the most climate vulnerable countries in the world. Located between the Himalayas and the Bay of Bengal, the country is very prone to natural disasters. Climate change accelerated the intensity and frequency of occurrences of drought, irregular rainfall, high temperature etc. that resulted from global warming that is directly and indirectly related to crop production. Ensuring food security for all is one the major challenges that Bangladesh faces today. Despite important achievement in food grain production and food availability, food security at national, household, and individual levels remains a matter of main concern for the government mainly due to drought (Kashem and Faroque, 2013). Drought is one of the main problems for many nations, and the severity of such issue goes big when it comes as obstacle to ensure an optimum agricultural production for a country like Bangladesh. Drought is being considered as the main cause which hampers the estimated agricultural production in Bangladesh over the last few decades (Dey e*t al.*, 2011).

Tomato (*Lycopersicon esculentum Mill*.) belongs to Solanaceae (nights hade) family and considered as one of the most important, popular, and nutritious vegetables that has achieved tremendous popularity around the world (FAOSTAT, 2014). It is native to topical America where is an indigenous name was tomato. It is an important vegetable crop. It is grown in most home gardens and commercial farmers. It is also produced by forcing in green houses. Tomatoes are very helpful in healing wounds because of the antibiotic properties found in the ripe fruit. Tomato being rich source of photochemical such as lycopene, β carotene, flavonoids, potassium, vitamins E and C, folic acid, which collectively play beneficial role in human health (Najla *et al*., 2009; Behrooj *et al*., 2012). It contains 2.7 mg Iron, 4.5 g Protein, 0.15 mg Riboflavin, 50 mg Calcium, 3.2mg Niacin, 123 mg Phosphorus and 102 mg Ascorbic acid per one-pound edible portion (Lester, 2006). It is widely used in salad as well as for culinary purposes. Tomato gain popularity very rapidly and attain the status of widely consumed. Although, tomato is a tender perennial crop, which is susceptible to frost as well as high temperature, but it is being growing a variety of climatic condition (Malik *et al.*, 1994). Tomato fruit is consumed in fresh, after processed forms such as canning, juice, pulp, paste, or as a variety of sauces. In Bangladesh, it is cultivated in total area of 75602 acres with annual production reaches to 387653 metric tons in 2018-19. (BBS, 2019)

Potassium is essential nutrient for plant growth and reproduction. Plants deficient in potassium are less resistant to drought, excess water, and high and low temperatures. They are also less resistant to pests, diseases and nematode attacks. Because potassium improves the overall health of growing plants and helps them fight against disease, it is known as the "quality" nutrient. Potassium affects quality factors such as size, shape, color and vigor of the seed or grain. Potassium (K) is a key element for crops growth and productivities (Munns, 2002). However, plant growth is limited if the Potassium supply is interrupted, such as excessive potassium outflow caused by increasing of cellular membrane permeability (Tomemori *et al.,* 2002). Potassium increases crop yields because it increases root growth and improves drought tolerance. Potassium builds cellulose and reduces lodging and activates at least 60 enzymes involved in growth. It helps in photosynthesis for food formation, translocate sugars and starches. It improves grains starch, protein content of plants, maintains turgor pressure and reduces water loss and wilting.

Plant growth is seriously affected by abiotic stresses such as drought, salinity, or temperature. Drought is one of the most important limiting factors for agricultural crops and vegetable production all around the world. Drought stress during vegetative or early reproductive growth usually reduces yield by reducing the number of seeds, seed size and seed quality. Drought can occur in any climate of the world and cause harmful impacts on human beings and natural ecosystems (Saadati *et al.,* 2009). Drought may be meteorological (problematic weather patterns), hydrological (lack of rain), agricultural (low commodity production) and socio-economic (low incomes and social consequences) explanations; that it is drought's impact on people and their activities (Wangai, 2013). Rangpur is one the most severe drought prone area in Bangladesh with an average rainfall of about 1430 mm per year. Irregular characteristics of rainfall and global climate changes are the main causes of drought. In recent decades, agriculture production and livestock production are significantly reduced.

Potassium has significant effect on quantity and quality of tomato yield because of its vital roles in photosynthesis, favoring high energy status and appropriate nutrient translocation and water uptake in plants. Tomato crop responds very well to manure and fertilizer application (Ramyabharathi *et al*., 2014). The potassium (K) requirements of tomato are high due to the fast growth of the plant in combination with higher fruit production (Chapagain and Wiesman, 2004). So, the exact amount to be applied need to be determined based on fertility status and water stress condition of the soil and variety used. Therefore, the experiment was conducted to fulfill the following objectives:

Objectives:

1. To determine the changes of morphological and yield parameter of different tomato varieties under water stress condition; and
2. To determine effect of different doses of potassium in drought condition on morphological and yield contributing characters of different tomato varieties.

CHAPTER 2

REVIEW OF LITARATURE

2.1 Tomato

The tomato (*Solanum lycopersicum* L.) is an autogenous species which is 1-3 m tall. It has a woody stem. Tomato is synonymous with the word of *"wolf peach"*. This species was under nightshade family, European's thoughts tomato poisonous due to the leaf toxicity. Tomato originated from part of Chile, Bolivia, Ecuador, Colombia, and Peru. Mexico has been considered as the domestication of the origin of tomato and from Mexico it was transferred to Europe and then to Asia. Secondary origin of tomato is in Spain and Germany (Gentilcore, 2010; and Smith, 1994). But cultivated tomato was originated in Peru-Ecuador-Bolivia (Vavilov, 1951). Domestication of tomato had reached in its advance stage before taking to Europe. According to Khan *et al*. (2015) Spain, Brazil, Iran, Mexico, Greece, Russia, China, USA, India, Turkey, Egypt, and Italy are the main tomato growing countries.

There are one cultivated species and 12 wild relatives under *Solanum lycopersicon L*. (Peralta *et al*., 2006). Tomato is considered as the most popular vegetables as soups, juice, ketchup, pickles, sauces, conserves, puree, paste, powder, and other products can be produced from tomato. (Nahar *et al.*, 2002). Nutritious value of tomato is high, due to presence of health building substances such as vitamins and minerals. Vitamin C, total soluble solids (TSS), pH, Lycopene contents are commonly considered as fruit quality determining properties in tomato. Among them Vitamin C is considered as principal nutrient of tomato fruit. Among all vegetables tomato counts more than 7% vitamin C in Bangladesh. Other constitutes are present in Tomato 94 g water, 0.5 g minerals, 0.8 g fiber, 0.9 g protein, 0.2 g fat and 3.6 g carbohydrate. Tomato has some other elements like 48 mg calcium, 0.4 mg iron, 356 mg carotene, 0.12 mg vitamin B1, 0.06 mg vitamin B2 and 27 mg vitamin C in each 100 g edible ripen tomato (BARI, 2010).

Tomato has also some medicinal value due to the presence of lycopene which is considered as the most powerful natural antioxidant that prevents lung, stomach, pancreatic, colorectal, esophageal, oral, breast and cervical cancers, etc. Lycopene is related to beta carotene which has natural cancer-fighting properties (Anonymous, 2016**)**. The red color of tomato responsible for presence of lycopene (Helyes *et al*., 2012).

2.2 Drought

Period of dryness when prolonged, that causes extensive damage of crops and prevents their successful growth. A drought is defined as a period of abnormally dry weather sufficiently prolonged and cause serious hydrologic imbalance in the affected area (Wilhite and Glantz, 1985).

A drought can stay prolong time like months or years. It causes substantial impact on the ecosystem and agriculture. Annual dry seasons in the tropics, significantly increase the chances of a drought. Periods of heat can significantly worsen drought conditions by hastening evaporation of water vapor. Drought usually occurs with continuous periods of heat, and it reduce soil moisture and water supply (Wang *et al.,* 2011).

Nowadays, drought is examined from several perspectives that are meteorological, agricultural, hydrological, and economic. From a meteorological perspective, a drought is a period of reduction water from natural precipitation and moisture sources (Mueller *et al., 2005*). From an agricultural perspective, a drought is a period, when soil moisture is insufficient for growing crops. From a hydrological perspective, a drought is a period, in which the flow of streams is lower than its normal level and water reservoirs decrease. Finally, the economic drought refers to its effects on human activities and consequently physical processes in the area (William *et al*., 1989). Many drought definitions are adopted in different fields (meteorology, hydrology, economy of water resources), with reference to various hydro-meteorological variables.

Meteorological drought

Meteorological drought is the most prevalent. Drought based on the degree of dryness and the duration of the dry period. Thus, meteorological drought has been defined as a period, more than a particular number of days and precipitation less than some specified amount of water (Wilhite and Glantz,1985).

Hydrologic Drought

Definitions of hydrologic drought are concerned with the effects of dry spells on surface or subsurface hydrology. The frequency and severity of hydrologic drought is often defined based on its influence on river basins. Hydrologic droughts are often out of phase with both meteorological and agricultural drought.

Agricultural Drought

Agricultural drought occurs when soil moisture is depleted, for that crop and pasture yields are significantly affected. Agricultural drought definitions linked with various characteristics of meteorological drought. For example, precipitation shortages from normal, numerous meteorological factors such as evapotranspiration (Wilhite and Glantz, 1985).

Socio-economic Drought

Definitions which express features of the socio-economic drought can also incorporate features of meteorological, agricultural, and hydrological drought (Wilhite and Glantz, 1985). They are usually associated with the supply and demand of some economic good. YevJevich (1967) was suggested that the time of supply and demand are the two basic processes that should be considered for an objective definition of socio- economic drought.

2.3 Potassium (K)

Potassium is one of the vital elements required for plant growth and physiology. Potassium is not only a constituent of the plant structure, but it also has a regulatory function in several biochemical processes related to protein synthesis, carbohydrate metabolism, and enzyme activation (Hasanuzzaman *et al*., 2018).

Several physiological processes depend on K, such as stomatal regulation and photosynthesis. In recent decades, K was found to provide abiotic stress tolerance. Under drought stress conditions, K regulates stomatal opening and helps plants to adopt water. Potassium enhances antioxidant defense in plants and protects them from oxidative stress under various environmental adversities. In addition, this element provides some cellular signaling alone or association with other molecules and phytohormones. Potassium is a mineral element taken up large amounts from soil and plays an important role in the regulation of water status (Mengel and Kirkby, 2001).

Potassium is characterized by high mobility in plants (within individual cells and tissues as well as in long-distance transport via the xylem and phloem). Potassium is the most abundant cation in the cytoplasm. Its salts make a major contribution to the osmotic potential of cells and tissues in glycophytic species. It is accumulated passively by both the cytosol and vacuole except when extracellular K+ concentrations are very low (Taiz and Zeiger, 2006).

2.4 Drought around the world

Drought is one of the major stress factors among the abiotic stresses. Water plays a vital role in the production of vegetables. It is a condition without water creates difficulties completing normal physiological functions (Lisar *et al*., 2012). Dry lands (5.1 billion ha) cover 40% of the world's land surface that serves more than 1 billion people (Roy *et al*., 2009).

Within the tropics, distinct wet, and dry seasons emerge due to the movement of the Monsoon trough. The dry season greatly increases drought and characterized by low humidity with watering holes and rivers drying up (Vijendra *et al.,* 2005). Because lack of these watering holes, many grazing animals are forced to migrate due to the lack of water. Since water vapor becomes increasing temperature, more water vapor increases relative humidity. Periods of increase evaporation and transpiration from plants and worsen drought conditions.

Approximately 2.4 billion people live in the drainage basin of the Himalayan rivers. India, China, Pakistan, Bangladesh, Nepal, and Myanmar will be experienced by droughts in coming decades. Drought in India is affecting the Ganges particular concern, as it provides drinking water and agricultural irrigation more than 500 million people. The west coast of North America, which gets much water from glaciers mountain ranges. Rocky Mountains and Sierra Nevada also will be affected.

2.5 Drought Condition in Bangladesh

All over the world, Bangladesh is well known as a flood- and cyclone-affected country. But in the recent years the slow onset disaster of drought is more frequent in Bangladesh due to climatic as well as non-climatic variability (Habiba, *et al.*, 2014). Every five years, Bangladesh is affected by the major country-wide droughts. However, local droughts occur regularly and affect crop production. The agricultural drought, linked to soil moisture scarcity, occurs at different stages of crop growth, development, and reproduction. Northwestern regions of Bangladesh are particularly exposed to droughts. A strong drought can cause greater than 40% damage to broadcast *Aus*. During the *kharif* season, it causes significant destruction to the T. *aman* crop in approximately 2.32 million ha every year. In the *rabi* season, about 1.2 million ha of agricultural land face droughts of different magnitudes.

Dey *et al.* (2011) found that in agricultural losses through drought effects on livestock population, land degradation, health, and employment. Between 1960 and 1991, drought events occurred 19 times in Bangladesh. Very strong droughts hit the country in 1961, 1975, 1981, 1982, 1984, 1989, 1994, and 2000. Past droughts have naturally affected about 53% of population and 47% of the country.

Kashem and Faroque (2013) said that Bangladesh is one of the most climate vulnerable countries in the world located between the Himalayas and the Bay of Bengal. The country is prone of natural disasters. Climate change accelerated the intensity and frequency occurrences of drought, irregular rainfall, high temperature etc. Ensuring food security for all is one the major challenges for Bangladesh.

Devastating and recurrent droughts caused by varying rainfall occur in many parts of Bangladesh. Drought associated with late or early monsoon and complete failure of monsoon spreads over a large geographical area. Drought can affect the rice crop in three different seasons, which accounts for more than 80 percent of the total cultivated area in the country. Droughts in March and April inhibit timely land preparation and tillage, delaying planting of crops during monsoon season (Paul, 1998).

Increased climate variability means additional threats of drought-prone environments and it is considered a major crop production risk factor. It forces farmers to depend on low-input and low-risk technologies, leaving them incapable to adopt new technologies that would allow them to get maximum gains during favorable seasons and less able to recover quickly after disasters. Drought is the most complex and least understood of all-natural disasters in Bangladesh. It is a natural disaster which causes the greatest loss in the world (Chunqiang, 2010). It is one of the major causes of crop loss worldwide, reducing average yields for most crop more than 50% (Islam *et al*., 2014 and Wang *et al.*, 2003).

In recent years, concern has grown worldwide that droughts may be increase frequently and causes climatic change. It has documented that climate change increases in extreme events though characteristics will vary from one climate regime to another (Sivakumar *et al.*, 2014; Peterson *et al*., 2013 and Iglesias e*t al*., 2012). Wilhite *et al.* (2005) said that it can cause widespread damage of agricultural production. Additionally, droughts have a multidimensional effect on human being in terms of several socio-economic parameters like human health, scarcity of labor, etc. It triggers to food insecurity and poverty level. Like other countries of the world, Bangladesh also faces the adverse impact of drought (Zimmerman *et al.*, 2003 and Adger, 1999)

2.6 Fertility Status of Soil in Drought Condition

Agriculture accounts for approximately 70% of global water use and irrigation accounts up to 90% of total water withdrawals in arid nations (Jewell *et al*., 2010). Agricultural water withdrawal in Bangladesh was 31.5×109 m^3 /year during 2008-2012, which was 87.82% of total water withdrawals (FAO, 2016).

Abiotic stress particularly drought stress is a common problem occurring all over the world, seriously limiting global crop production. It is one of the main causes for yield loss in the world. Drought stress decreases the average yield more than 50% of many crops and it affects 26% arable area and reduce production up to 25% throughout the world (Bayoumi *et al*., 2008; George *et al*., 2013; Alqudah *et al.*, 2011; Roy and Wu, 2001 and Farooq *et al.*, 2009).

Laylin (2014) observed that Vital 12 biochemical processes including photosynthesis, respiration protein synthesis and assimilation of organic nitrogen have been demonstrated to be adversely affected by water stress. In rain fed agriculture, the short-term water stress (10- 20 days) is very common, and it reduces productivity. In the last several decades, productive agricultural regions were exposed due to drought stress. Barnabas *et al.* (2008) said that drought stress with extreme temperature causes serious damage crop physiology.

According to FAO (2007) drought reduced income of farmers, reduced yield of aus, T. aman and boro rice and reduce inputs and investment for the agricultural sector. In addition, it causes increases prices of staple food, and increases chances of seasonal food crises, illness, reduction of drinking water sources, migration, and loss of livestock. Region in Bangladesh affected by drought during Rabi and Kharif season. Water resources for irrigating crops are declining worldwide. Hence, the development of more drought-resistant cultivars and water-use efficient crops is a global concern.

2.7 Physiological Mechanisms of Drought Stress on Plant

Drought stress induces a wide range of physiological and biochemical alterations in plants for cell growth, photosynthesis, and enhanced respiration. Genome expression is extensively remodeled, activating and repressing a variety of genes with diverse functions (Shinozaki and Yamaguchi, 2007). Plants must cope with various environmental stresses during their life cycle.
Aroca *et al.* (2008) and Loukehaich *et al*. (2012) represented that in drought conditions, 80–90% of water loss occurs via stomata in the leaf epidermis. The phytohormone, abscisic acid (ABA) induced stomatal closure is considered as a crucial mechanism for preventing water loss from plants. Expression of many stress-responsive genes, including the late embryogenesis abundant (LEA) proteins. Drought stress tolerance plants is regulated by ABA. The ABA and drought stresses exerted the strongest effects on all hormones. Drought conditions dramatically increase the ABA level, which induce the expression of many stress-related genes and activate signal transduction pathways that leads stomatal movement.

Many studies have shown the decreased photosynthetic activity under drought stress due to stomatal or non-stomatal mechanisms (Samarah *et al*., 2009 and Anjum *et al*., 2011). From a physiological perspective, leaf chlorophyll content is interest. Majority of chlorophyll loss in plants responses water deficit occurs in the mesophyll cells (Anjum *et al*., 2011). A decrease in the relative water content (RWC) in response to drought stress has been noted in wide variety of plants as reported by Nayyar and Gupta (2006), that when leaves are subjected to drought, leaves exhibit large reductions in RWC and water potential. Drought-tolerant species maintain water use efficiency by reducing the water loss. However, in the events where plant growth was hindered to a greater extent, water use efficiency was also reduced significantly (Anjum *et al*., 2011).

During drought, reactive oxygen species (ROS) levels increase. It causes oxidative damage of proteins, DNA, and lipids (Apel and Hirt, 2004). Highly reactive ROS can seriously damage plant. It increases lipid peroxidation, protein degradation, DNA fragmentation and ultimately cell death. The ROS such as O^{2-}, H_2O_2 and •OH radicals.It directly attack membrane lipids and increases lipid peroxidation (Mittler, 2002). Drought induced overproduction of ROS increases the content of malondialdehyde (MDA). The content of MDA has been considered an indicator of oxidative damage (Moller *et al*., 2007). This damage may be minimized or prevented by increased antioxidant activity.

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. They found that the plants under drought condition-initiated flowers earlier (26 days) than plants in control condition (30 days). 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).

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 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 The study showed that plant height of all the cultivars significantly decreased under drought stress compared to control.

2.8 Fertility Status of Soil in Potassium (K) Condition

Potassium is one of the essential mineral nutrients for plant. It was taken by roots from the soil solution in its ionic form. It is involved in numerous physiological processes that control plant growth, yield, and quality parameters such as sugar, total soluble solids, taste, color, and firmness reported by Lester *et al*. (2005). High levels of available K improve the physical quality, disease resistance, and shelf life of fruits and vegetables. However, it is very important for the life process of plant (Haji *et al*., 2011) and it is often referred as the quality element for crop production (Usherwood, 1985). Production of quality fruits is controlled by the interaction of genetic, environmental, and cultural factors including plant nutrients (Dorais *et al.,* 2001, Mengel and Kirkby, 1987).

Potassium is more stable in the soil than nitrogen. Lower yield caused by drought and excess fertilizer is not to use at this type of field. This will impact fertilizer management in field. It is important to determine levels of nutrients use in soil to avoid applying excess fertilizer, which is improve soil quality.

2.9 Physiological Mechanism of Potassium (K) on Plant

K development process in the plant is well known. The regulation of K decreases reactive ROS in plants. Potassium reduces the activity of nicotinamide adenine dinucleotide phosphate (NADPH) oxidases and retains the photosynthetic electron transport activity, which helps to reduce ROS. Potassium deficiencies can decrease the photosynthetic CO_2 fixation and transport and utilization of assimilates (Waraich, *et al.*, 2012).

Membrane and chlorophyll degradation are favored in K deficient plants. The regulation of K is associated with the activity of the enzymes involved in ROS detoxification (Cakmak, 2005**).** Potassium triggers the activation of the adenosine triphosphate (ATP) synthase enzyme. The plasma membrane bound H+-ATPPase influenced by K content (Neill,1984). Potassium deficient plants have been reported to be light sensitive, thus they exhibit chlorotic and necrotic symptoms (Cakmk, 2005).

Waraich *et al.* (2012) and Halford, (2009) reported that drought tolerance induced by potassium. The role of K as a nutrient has been recognized for a long time. However, its arrays of biological functions in plant physiological processes have not been fully explored. In recent years, the correlation between phytohormones and K has been studied (Wang *et al.* 2013). Phytohormones interact with one another and signaling molecules, which regulate biochemical processes and metabolism. Auxin-regulated genes, proteins that affect the transcriptional repressors of stress responses in plants (Shani *et al*., 2017) Abscisic acid (ABA) influences the expression of genes that modulate complex stress-responsive regulatory networks (Song *et al.*, 2016).

Quddus *et al.* (2019) conducts an experiment Influence of Potassium Addition on Productivity, Quality and Nutrient Uptake of Mungbean (*Vigna radiata L*). The experiment was laid out in randomized complete block design considering six treatments with thrice replicates. The treatments were T_1 = Control, T_2 = 30 kg, T_3= 40 kg, T_4= 50 kg K, T_5= 60 kg K and T_6= 70 kg K per hector. Application of different levels of potassium showed significant effects on the plant height, number of pods per plant, number of seeds per pod and thousand seed weight which were influenced to obtain higher yield of mungbean. The highest yield (39.5%) of mungbean were produced from the treatment T_5. Proper use of K with other nutrients facilitated to improve the productivity and quality of mungbean and K played a significant role in maintaining soil fertility. Pranav Kumar *et al*. (2014) and Singh *et al*. (2002) found similar findings.

Mazed *et al.* (2015) reported that application of potassium fertilizer improved the number of fruits per plant, Weight of individual fruit, Diameter of fruit and yield of tomato plant.Akand *et al.* (2016) conduct an experiment on the effect of potassium and gibberellic acid on growth and yield of tomato at the farm of Sher-e-Bangla Agricultural University, Dhaka. They found Number of leaves per plant, number of flowers per plant, branch per plant, Flower cluster per plant, Number of fruits per plant, Average fruit weight, Yield of fruits per plot, Yield was increased.

2.10 Potassium and Drought Stress on Plant

According to Cakmak (2005), the major limitation for plant growth and crop production in arid and semi-arid regions is availability of soil water. Plants that are continuously exposes drought stress can form, which leads leaf damage.It has been reported that adequate supply of potassium in soil improves the water relations of plant and photosynthesis, helps in osmotic regulation of plant cell, assists in opening and closing of stomata, activates the enzymes, nodulation and synthesizes the protein (Grag *et al.*, 2005 and Yang *et al*., 2004). Hussain *et al*. (2011) observed that maximum plant height of mungbean (49.9 cm) obtained in application of 90 kg K ha^{-1}. The dwarf plant (43.6 cm) was obtained in K control plot which might be due to the reason that root shoot ratio is associated with potassium uptake (Yang *et al.*, 2004).

Drought stress restricted root growth and the rates of K^+ diffusion in the soil, thus limiting K acquisition. The resulting of lower K concentrations can further depress the plant. In drought condition Maintaining adequate K is critical for plant. A close relationship between K nutritional status and plant drought resistance has been demonstrated. The roles of K in physiological and molecular mechanisms of plant for drought resistance have explored.

2.11 Present Scenario of Tomato Cultivation

Hossain *et al*. (1986) and Karim *et al*. (2009) said that in Bangladesh congenial atmosphere remains for tomato production during low temperature. Winter season that is early November, best time for tomato planting in our country. Vegetable production can help farmers to generate income which eventually alleviate poverty. Tomato is one of the most important vegetables in terms of acreage, production, yield, commercial use, and consumption. Bangladesh is producing a good number of tomatoes but not to meet demand. Here, tomato has great demand throughout the year, but it is available and cheaper during the winter season.

The best tomato growing areas in Bangladesh are Dinajpur, Comilla, Faridpur, Dhaka, Chittagong and Jamalpur (BBS, 2016). Global demand for tomatoes has increased at the rate of 3.25 percent for the last several years, and demand in Bangladesh is increasing. Bangladesh imported equivalent to 10 percent of its' total tomato production to meet local consumption requirements (Anonymous, 2016). Approximately 22,605 tons of tomato and products were imported in (FAOSTAT, 2016). In the Southern Delta, approximately 40,000 farmers are involved in winter tomato farming, though less than 500 are involved in summer tomato farming. The Bangladesh Agricultural Research Institute (BARI) developed new varieties of tomatoes that can grow in summers. that is presenting an opportunity for AVC (Agricultural Value Chain) to promote year-round tomato farming. (Anonymous, 2016).

2.12 Socio Economic Importance of Tomato

World vegetable production has boosted up and increase 330% growth last 50 years (Weinberger and Genova, 2005). Among different vegetables, tomato production has reached in 177042 thousand tons in 2016 that occupies about 60% of total fresh vegetable production in the world. This massive productivity growth amplifies incomes for laborers, empowered women and created new employment opportunities particularly for landless farmers in developing countries (SOFA team *et al.*, 2011). Production of tomato and its nutritional importance is the blessing for a developing country like Bangladesh.

Mitra and Prodhan (2018), reported that, production of tomato has increased in Bangladesh about 6.5 times after 1971. Tomato production has experienced tremendous growth in last 10 years because of high yielding varieties adoption, timely use of pesticides, training, and extension facilities. In Bangladesh tomato is cultivated in a larger area due to its adaptability and it is the most popular vegetable in Bangladesh (Brown *et al.*, 2013). Tomato is rich in higher contents of vitamins A, B and C including calcium. In Bangladesh more than 7% of vitamin C comes from tomato.

2.13 Effect on Drought on Tomato Cultivation

Rauf (2007) said that Water is a major constraint for tomato production under rainfed condition in case of dry spell during production. Drought stress elevated osmotic pressure from the root zone and reduces availability of water and nutrients for plant. Plants can be affected by drought at any time of their life. Most tomato cultivars are drought sensitive at all development stage. The characters of seed germination and seedling growth are extremely important factor for determination yield.

Ragab *et al*. (2007) reported deleterious effects of drought in different crops such as tomato, potato, chili, rice, wheat, groundnut, mustard, colt cherry, sugarcane etc. Water is an essential element for the survival of plants and without water, every morphological, biochemical, and physiological process of plants are arrested different levels. Different agro-morphogenic traits such as plant height, number of leaves, leaf area, number of branches per plant, days to first flowering, days to first fruit setting, days to maturity, number of clusters per plant, yield per plant, fruit length and diameter, root length, root shoot ratio etc. are affected by drought stress.

Wahb-Allah *et al.* (2011) reported drought of tomato under field condition. Plant height, primary branches, cluster/plant, fruit/cluster, number of fruits and total yield/plant, individual fruit weight, amino acid content in leaves are decreased in drought condition. Drought stress is limiting the crop production hampering the pollen grain availability, increasing pollen sterility, pollen grain germination. 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 and Hsiao, 1973).

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. 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).

2.14 Effect of Potassium (K) on Tomato Cultivation

Tomato crop responds very well application of manure and fertilizer (Ramyabharathi *et al*., 2014). Potassium (K) requirements of tomato plants are high due to the fast growth and high fruit production (Chapagain and Wiesman, 2004). However, the exact amount of potassium needs to be applied, based on fertility status of the soil and variety used. K is one of the major nutrients, for plant growth and development. It is involved in activation of enzymes, energy utilization, starch synthesis, N metabolism and respiration.

K plays an important role in photosynthesis, opening and closing of stomata. which helps in appropriate nutrient translocation and water uptake. (Havlin *et al*., 2005). Prajapati and Modi, (2012) also reported that K plays significant roles to enhance crop quality, disease resistance, and shelf-life of fruits. Besides, Javaria *et al*. (2012) founded that application of 375 kg/ha of K_2O had 27.44% and 101.23% increase of total solids and total soluble solids (TS and TSS), respectively as compared to control.

Total soluble solids of tomato are predominantly sugars, which determine flavor and other fruit quality. Increase of TSS in the fruits with the increase of K levels. It is confirmed that K played an important role in the configuration of tomato fruits (Caretto *et al*., 2008). Besides, Wuzhong (2002) reported that an increase of K fertilizer application increased sugar content of tomato fruit. Higher import and accumulation of sugar may be enhanced TSS content in tomato fruits (Balibrea *et al*., 2006).

Sultana *et al*. (2015) conducted an experiment in the farm of Sher-e-Bangla Agricultural University, Dhaka-1207 to find out optimum level of potassium (K) for maximum yield of tomato. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The experiment consisted of four levels of potassium K0: 0 kg K/ha, K1: 124.5 kg

K/ha, K2: 132.8 kg K/ha and K3: 141.1 kg K/ha. In case of potassium, K3 produced the maximum fruits per plant (37.08), number of flower cluster per plant, number of flower cluster per plant, maximum fruits height, diameter, and use optimum level of potassium (65.96 t/ha). Plant height varied significantly due to the application of different levels of potassium at 40, 50, 60, 70 DAT and at maturity. At 40 DAT, the longest (57.51 cm) plant height was recorded from K3. Application of potassium progressively increased plant height up to maximum doses. Probably, potassium ensured the availability of other essential nutrients as a result maximum growth was occurred and the ultimate results is the maximum plant height. Murphy (1964) found that application of potassium increased plant height by up to 65%. Clarke (1944) found little effect of potassium application on flower production. Excess level of potassium use reduces the fruit production.

2.15 Effect of Drought and Potassium for Yield

Kozlowski *et al.* (2011) conducted an experiment, they estimated the fruit number of tomatoes under drought stress. He found that at fruiting stage, number of fruits per plant was reduced significantly. The fruit size of the treated plants was also smaller than the control plant. He reported that fruit number was reduced due to the dropping of flower and fruit ripe at immature stage. plant height, number of leaves, leaf area, number of branches per plant, days to first flowering, days to maturity, number of fruits per plant, yield per plant, fruit length and diameter, root length, root shoot ratio etc. are affected by drought stress.

(Techawongstein *et al.* (1992) and 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.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). 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.

Sibomana and Aguyoh (2013) determine effects of drought stress on growth and yield of tomato. They reported that fruits per plant and average fruit diameter were significantly reduced in treated plants than control plants. They also reported that maturity time decreases with the increase of drought stress. About 25 to 34 % reduction of number of fruits per plant was also reported. Fruit diameter was reduced by 11.5% to 19% in drought stress.

Iqbal *et al*. (2011) reported that K had significant effect on tomato yield and maximum yield was obtained from application of K2O. In addition, Ahmad *et al*., (2015) reported that tomato yield was significantly increased 35.55 % over then control. Sufficient supplement of K helps to plants for photosynthetic activities and translocation of photosynthates from sites of production to storage organs.

CHAPTER 3

MATERIALS AND METHODS

The experiment was conducted in pots at the experimental site of Agroforestry and Environmental Science Field Lab, Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, during the period of October 2019 to March 2020. This chapter consists of materials used and methods followed during the experimental period narrated below:

3.1 Experimental site

The experiment was conducted at the Agroforestry and Environmental Science Field Lab, of Sher-e-Bangla Agricultural University (SAU), Dhaka-1207, Bangladesh. The experiment was carried out during rabi season (November 2019 to March 2020). It is in $23^{0}74^{/}$ N latitude and $90^{0}35^{/}$ E longitude and an elevation of 8.2 m from the sea level (Anon., 1989).

3.2 Climate

The experimental site is situated in the subtropical monsoon climatic zone, which is characterized by heavy rainfall during the months from April to September (Kharif season) and scanty of rainfall during rest of the year (Rabi season). Plenty of sunshine and moderately low temperature prevail during October to March (Rabi season), which are suitable for growing of tomato in Bangladesh.

3.3 Soil

The soil of the experimental site was collected from SAU Field which was sandy loam. The mechanical and chemical characteristics of soil of the experimental site was added in Appendices.

3.4 Materials

In this experiment BARI Tomato 2, BARI tomato 15, BARI tomato 16 were used. The seedlings of tomato were grown at the nursery of Agroforestry and Environmental Science Field Lab in Sher-e-Bangla Agricultural University. BARI Tomato 2 is a high yielding tomato variety and duration is about 95-100 days after transplanting. BARI Tomato 15 was high yielding tomato variety and lifetime is 100-110 days. BARI Tomato 16 is a high yielding Tomato variety.

3.5 Raising of seedlings

For raising tomato seedlings, the soil was well prepared and converted into loose friable. All weeds and dead stubbles were removed, and the soil mixed with well rotten cow dung. Hundred seeds of tomato were shown in an iron tray of 91.5 × 61 cm. After sowing, the seeds were covered with light soil. Proper care was taken to raise healthy seedlings.

3.6 Pot preparation

Plastic pots were used in this experiment. The height of each pot was 22cm and wide 25cm. Topsoil was collected from the experimental field then pulverized. Inert materials, visible insects and pests were removed from the soil. The soil was thoroughly mixed with compost ($1/4^{th}$ of the soil volume) and 1.2 g urea, 0.8g TSP, 0.23g Mop per pot were incorporate uniformly into the soil. Clean and dried 10-liter size plastic pots were used for experiment. Each pot was then filled with 8 kg previously prepared growth media (soil and cow dung mixture).

3.7 Uprooting and Transplanting of Seedlings

Healthy and uniform 30 days old seedlings were uprooted separately from the seedbed and transplanted in the experimental pots in the afternoon of 7 December 2019. Soil pH was 5.7 and moisture was 1.6. The seedbed was watered before uprooting the seedlings from the seedbed to minimize damage roots with ensuring maximum retention of roots. The seedlings were watered after transplanting. Shading was provide using banana leaf sheath.

3.8 Design and layout of the experiment

The two factors experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications.

3.9 Treatment of the experiment

Two factors were used in the experiment.

Factor A. 3 doses of K with drought condition

1. T_1 = Control (Without K)
2. T_2= (0.4g K/pot + 200ml water/kg soil)
3. T_3= (0.9g K/pot + 50 ml water/kg soil)

Factor B. Tomato varieties (3 Tomato varieties)

1. V_1: BARI Tomato 2
2. V_2: BARI Tomato 15
3. V_3: BARI Tomato 16

There were 9(3×3) treatment combinations as follows: V_1T_1, V_1T_2, V_1T_3, V_2T_1, V_2T_2, V_2T_3, V_3T_1, V_3T_2, V_3T_3

3.10 Application of the treatments

Three tomato varieties were treated under drought condition with different dose of potassium. Water was applied in different amount after 5 days interval. Treatments such as T_1 (control), T_2 (0. 4g K/pot + 200ml water/kg soil) and T_3 (0. 9 g K/pot + 50 ml water/kg soil) were applied in plant in vegetative (40 days), flowering (64 days), and fruiting stage (78 days).

3.11 Intercultural operation

Proper intercultural operations were done for better growth and development of tomato plants. Weeding and mulching were accomplished when necessary. For better soil aeration soil crust was break down.

3.11.1 Staking

At pre flowering stage, the juvenile plants were stacked with bamboo sticks to keep them erect and protect from damage, caused by storm and strong wind. The plants were tied by plastic ropes to the stems with bamboo slices which are hung above them.

3.11.2 Weeding

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

3.11.3 Plant protection measures

Plant protection measures were done whenever it was necessary.

3.11.4 Insect pests

As a preventive measure against as the insect pest Malathion 57 EC was applied @ 2 ml L^{-1}. To prevent plants from fungal infection, Diathane M 45 was applied @ 2g1L^{-1} at the early stage of tomato (Mohanta, 2005).

3.11.5 Diseases

Dithane M-45 was applied @ 2 g/L at the early stage against late blight of tomato (Mohanta, 2005).

3.12 Harvesting

Fruits were harvested at 3-day intervals during early ripe stage when they attained slightly red color. Harvesting was started from 27 February 2020 and was continued up to 24 March 2020.

3.13 Data collection

Data on the following parameters were recorded:

3.13.1 Plant height (cm)

Plant height was measured at vegetative, reproductive and maturity stage. The height was measured from base to tip of the plant.

3.13.2 Number of branches per plant

Number of branches was counted at vegetative, reproductive and maturity stage.

3.13.3 Number of leaves per plant

Leaf number was counted at vegetative and flowering stage.

3.13.4 SPAD value

Chlorophyll 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 3 times from the leaf tip to base, and the average was used for analysis.

3.13.5 No. of flower per plant

The number of flower plant^{-1} was counted and recorded at flowering stage.

3.13.6 No. of clusters per plant

The number of flower clusters produced plant^{-1} was counted and recorded at flowering stage.

3.13.7 No. of fruits per plant

The number of fruits plant^{-1} was counted and recorded.

3.13.8 Fruit weight(gm)

Fruit weight was measured by electric precision balance.

3.13.9 Fruit length (cm)

Fruit length was measured with a slide caliper from the neck of the fruit to the bottom of 10 fruits from each plant and their average was taken and expressed in cm.

3.13.10 Fruit diameter (cm)

Diameter of fruit was measured at middle portion of 10 fruits from each plant with a slide caliper. Their average was taken and expressed in cm.

3.13.11 Yield

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

3.13.12 Soil temperature (^{0}C)

Soil temperature is an important factor it was measured on digital soil thermometer at 11 A.M at the morning at flowering stage.

3.13.13 Soil Moisture

Soil moisture content was measured with moisture meter at flowering stage.

3.13.14 Soil pH

Soil pH content was measured with pH meter at flowering stage.

3.14 Statistical analysis

Collected data were statistically analyzed using Statistix 10 software. Mean for every treatment 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

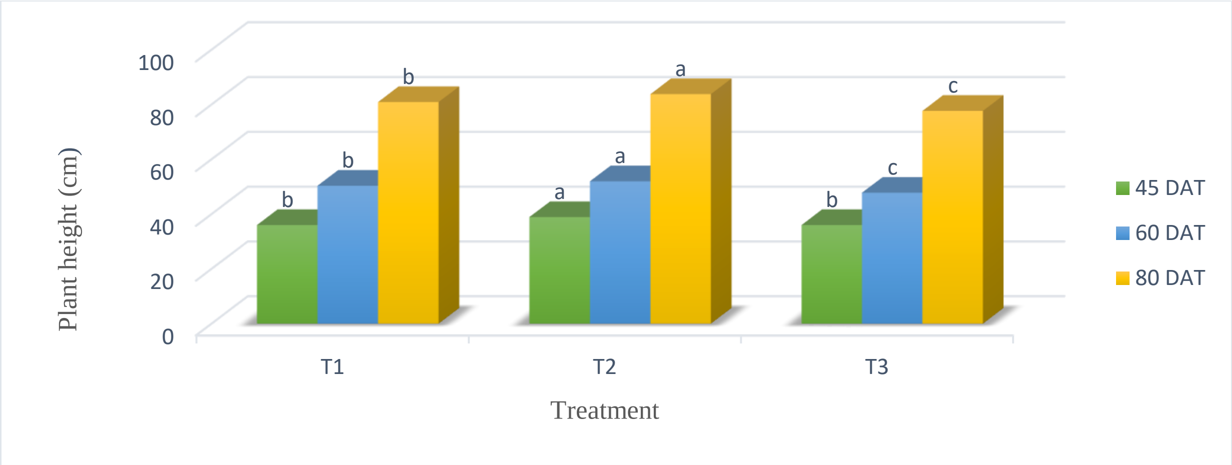
RESULTS AND DISCUSSION

This Chapter includes the experimental results with discussions combined effects of drought and Potassium on morphological, physiological and yield contributing characters of tomato varieties. The findings of experimental work were presented and discussed. Data was presenting in table(s) for easy discussion, comprehension and understanding. Results of each parameter was discussed and possible interpretation, where necessary.

4.1 Plant height (cm)

4.1.1 Effects of drought with potassium levels on plant height

Plant height is an important growth index of plant. Plant height of three tomato varieties were measured on different stage 45,60 and 85 DAT (Figure 1). Effects of drought with potassium on plant height was statistically significant ($P>0.05$) at 60 and 85 DAT. At vegetative stage (45 DAT) the tallest plant (40 cm) was obtained from T_2 (0.4g K/Pot +200 ml water/kg Soil) treatment. The smallest plant (33 cm) was recorded from T_3 (0.9g K/ Pot+50ml water/kg Soil) treatment and T_1 (control) treatment condition. At flowering stage (60 DAT), the tallest plant (52.5cm) was obtained from T_2 (0.4g K/ Pot + 200ml water/kg Soil) treatment condition. The smallest plant (47 cm) was recorded from T_3 (0.9g K/ Pot+50ml water/kg Soil) treatment condition. At reproductive stage (85 DAT) the tallest plant (86cm) was obtained from T_2 (0.4g K/Pot + 200ml water/kg soil) treatment condition. The smallest plant (76cm) was recorded from T_3 (0.09gK/Pot +50ml water/kg soil) treatment condition. Khan *et al.* (2015) found that plant height of tomato variety was lower in drought stress condition compared to stress free condition.

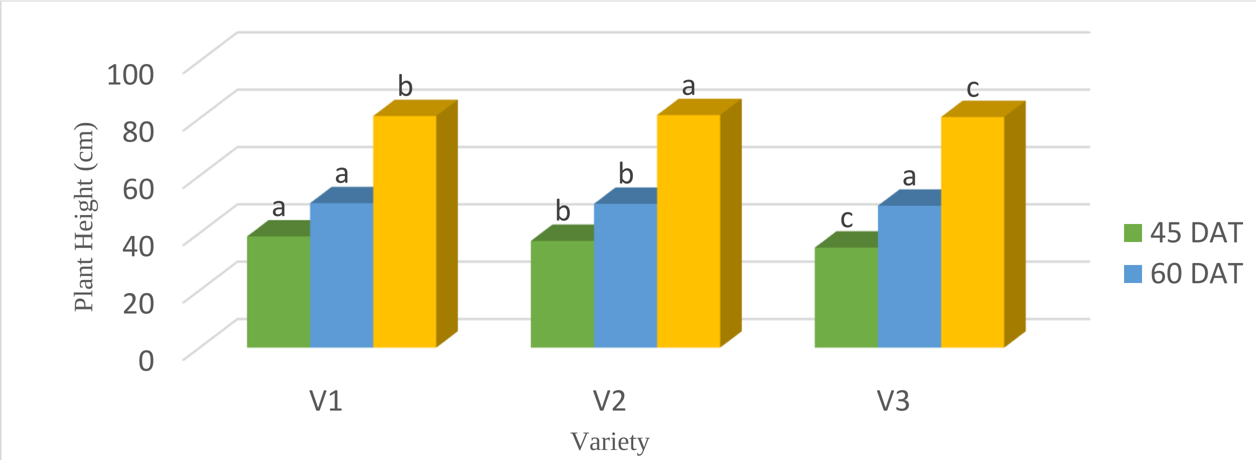


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure 1. Effects of drought with potassium levels on plant height at different days after transplanting

4.1.2 Varietal effects on plant height

Effects of drought with the potassium on different genotype were statistically significant (P>0.05) at 45 and 85 DAT. At vegetative stage (45 DAT) the tallest plant (40 cm) was recorded from BARI Tomato 15. The smallest plant (33 cm) was recorded from BARI Tomato 16. At flowering stage (60 DAT) tallest plant (52.5cm) was recorded from BARI Tomato 2. The smallest plant (47 cm) was recorded from BARI Tomato 16. At reproductive stage (85 DAT) tallest plant (86cm) was obtained from BARI Tomato 15 and the smallest plant (76 cm) was recorded BARI Tomato16.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 2. Varietal effects on plant height at different days after transplanting

4.1.3 Interaction effects of drought with potassium levels and tomato varieties on plant height (cm)

Interaction effect on plant height between varieties and drought condition with potassium levels was found significant differences at 45, 60 and 85 DAT. The tallest plant (40 cm, 52.5 cm, and 85.667 cm) was found from BARI Tomato 15 and BARI tomato 16, with T_2 (0.04g K/Pot+200ml water/kg soil) treatment combination. The smallest plant (33.000 cm, 47.000 cm, 76.333 cm) was found from BARI Tomato 16 and BARI Tomato 2 at T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination.

Khan *et al.* (2020) resulted that tomato plant height decreases in drought condition. Zhou *et al.* (2017); Ragab *et al.* (2007) and Whab *et al.* (2011) found similar result in tomato plant at drought condition. Nuruddin *et al.* (2003); Bhattarai and Midmore (2005); Zgallai *et al.* (2005) and Singh *et al.* (1995) found drought reduce chickpea plant height. Similar type of result also reported by Hossain (2003) at mungbean and Taub (2003) at chickpea plant Quddus *et al*. (2019) found application of different levels of potassium increased the plant height of mungbean plant. Sultana *et al.* (2015) found use optimum level of potassium (K) for maximum height of tomato. Murphy (1964) resulted that application of potassium increased plant height. Hossain *et al.* (2009) found similar result. Lester *et al*. (2005) found available K improve the physical quality of plants. Chapagain and Wiesman (2004), found Potassium increases tomato plant growth. Drought stress condition interferes plant physiological activities and causes gradual decrease of plant height (Conti *et al.,* 2019; Lisar *et al.,* 2012). Application of Potassium fertilizer on drought condition improve plant height. Potassium ensured the availability of other essential nutrients. As a result, maximum growth and plant height was occurred. Excess level of potassium use reduces the plant height (Sultana *et al.,* 2015).

Table 1. Interaction effects between drought condition with potassium levels and tomato varieties on plant height

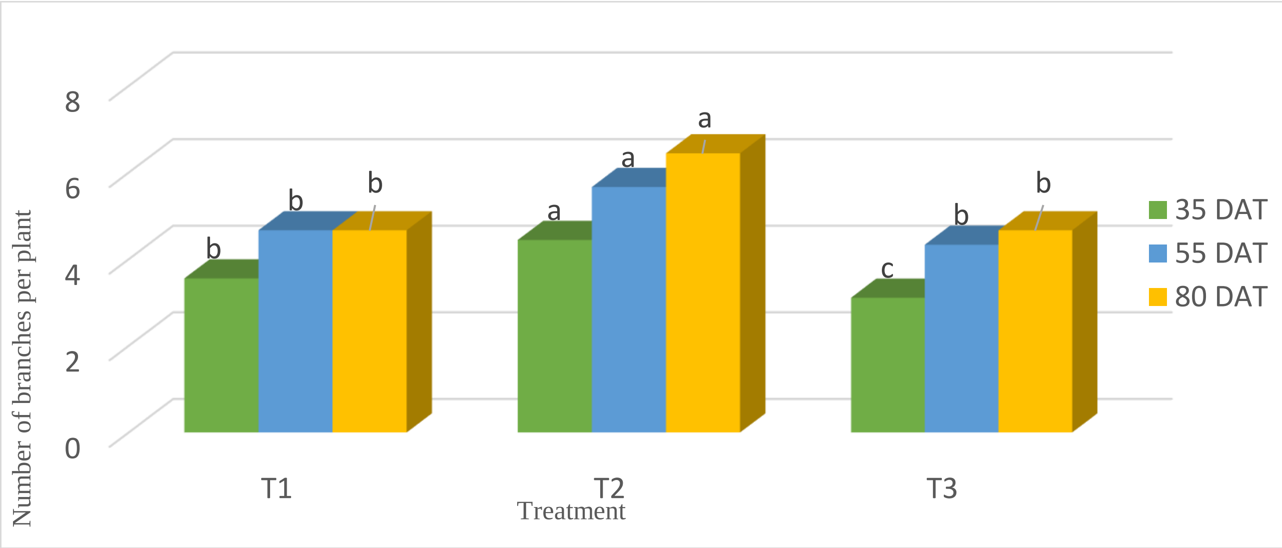
Treatment combinations	Plant height(cm) at different days after transplanting (DAT)		
	45	**60**	**85**
$T_1 \times V_1$	38.00 c	50.50 c	82.00 c
$T_2 \times V_1$	39.00 b	51.66 b	84.00 b
$T_3 \times V_1$	39.33 b	49.00 d	76.33 h
$T_1 \times V_2$	37.66 d	49.50 d	80.00 e
$T_2 \times V_2$	40.00 a	51.66 b	85.66 a
$T_3 \times V_2$	34.66 e	47.33 e	77.66 g
$T_1 \times V_3$	33.00 g	51.00 c	80.66 d
$T_2 \times V_3$	37.66 c	52.50 a	81.66 c
$T_3 \times V_3$	34.00 f	47.00 e	79.00 f
CV (%)	0.82	0.61	0.41

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.2 Number of branches per plant

4.2.1 Effects of drought with potassium levels on number of branches per plant

Number of branches of three tomato varieties were measured on different stage 35,55 and 80 DAT (Figure 3) and found statistically significant (P>0.05) at 35 DAT. At 35 DAT, highest number of branches (6) were obtained from T_2 (0.4g K/Pot +200 ml water/kg Soil) treatment and the lowest number of branches (3) were recorded from T_3 (0.9g K/ Pot+50ml water/kg Soil) treatment condition. At 55 DAT, highest number of branches (7) were obtained from T_2 (0.4g K/ Pot + 200ml water/kg Soil) treatment condition and the lowest number of branches (3) were recorded from T_3 (0.9g K/ Pot+50ml water/kg Soil) treatment condition. At 80 DAT, highest number of branches (9) were found from T_2 (0.4g K/Pot + 200ml water/kg soil) treatment condition and the lowest number of branches (4) were recorded from T_3 (0.9g K/pot+50ml water/kg soil) treatment and T_1 treatment condition. At Drought condition number of branches per plant was reduce but application of potassium fertilizer improve the branches number. Salama *et al.* (2017) found that branch number per plant reduced due to the presence of drought condition.

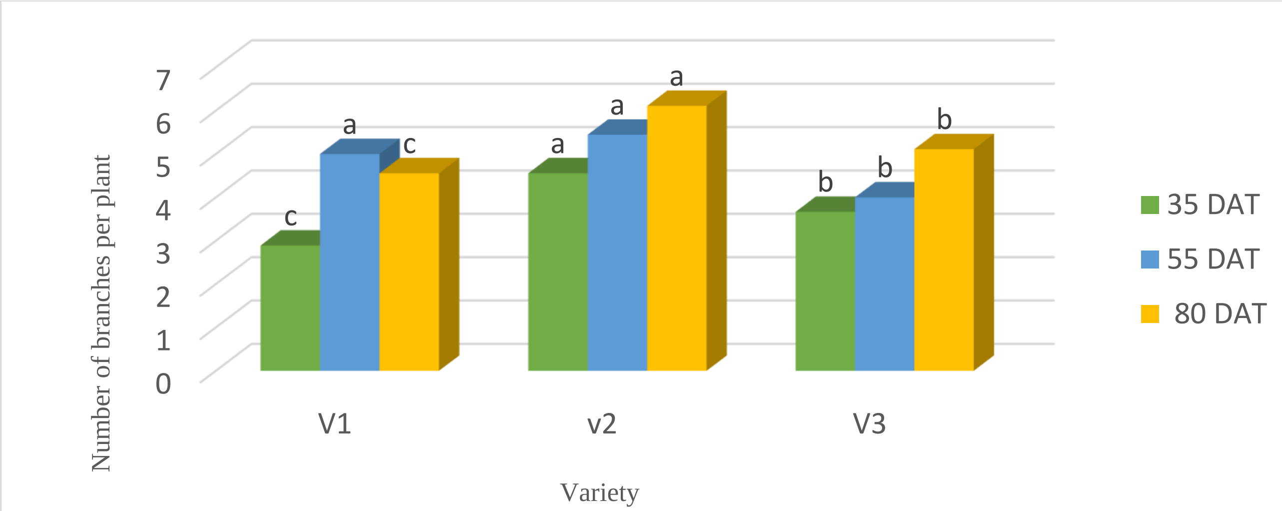


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure 3. Effects of drought with potassium levels on number of branches per plant at different days after transplanting

4.2.2 Varietal effects on number of branches per plant

Effects of drought with potassium levels on different genotype statistically significant (P>0.05) at 35 DAT. At the 35 DAT, highest number of branches (6) were recorded from BARI Tomato 15 and the lowest number of branches (3) were recorded from BARI Tomato 2. At 55 DAT, highest number of branches (7) were recorded from BARI Tomato 15 and the lowest number of branches (3) were recorded from BARI Tomato 16. At 80 DAT, highest number of branches (9) were obtained from BARI Tomato 15 and the lowest number of branches (4) were recorded BARI Tomato 2.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 4. Varietal effects on number of branches per plant at different days after transplanting

4.2.3. Interaction effects of drought with potassium levels and tomato varieties on number of branches per plant

The interaction effect on number of branches per plant between varieties and drought condition with potassium levels was found significant differences on plant of tomato at 35, 55 and 80 DAT. At 35, 55 and 80 DAT, the highest number of branches (6,7,9) were found from BARI Tomato 15 with (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest number of branches (3,3,4) were found from BARI Tomato 2 at (0.9g K/pot + 50ml water/kg soil) treatment combination (Table 2).

Salama *et al.* (2017) found fewer numbers of branches per plant occurred under drought condition. Mahapara *et al.* (2018) and Rao *et al.* (2000) found similar result in case of tomato. Rao *et al.* (2000) found that branch number per tomato plants were decrease 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). Ragab *et al*. (2007) and Whab *et al.* (2011) found similar result in tomato plant in case of drought condition. Kozlowski *et al.* (2011) found that number of branches per tomato plant affected by drought stress. Quddus *et al.* (2019) found application of different levels of potassium showed significant effects on the plant number of branches per plant in mungbean. Drought stress condition disturbs plant physiological processes which are reflected in low water absorption (Conti *et al*., 2019, Lisar *et al.*, 2012). Aroca *et al.* (2008) and Loukehaich *et al*. (2012) represented that in drought conditions, water loss occur in the leaf epidermis. Decreased photosynthetic activity under drought stress due to stomatal or non-stomatal mechanisms (Samarah *et al*., 2009; Anjum *et al*., 2011). Several physiological processes depend on K, such as stomatal regulation and photosynthesis. K regulates stomatal opening and helps plants to adopt water. Potassium enhances antioxidant defense in plants and protects them from oxidative stress under various environmental adversities (Mengel and Kirkby, 2001). Potassium requirements of tomato are high due to the fast growth of the plant. (Chapagain and Wiesman 2004; Munns, 2002 and Ramyabharathi *et al*., 2014).

Table 2. Interaction effects between drought with different potassium levels and tomato varieties on number of branches per plant

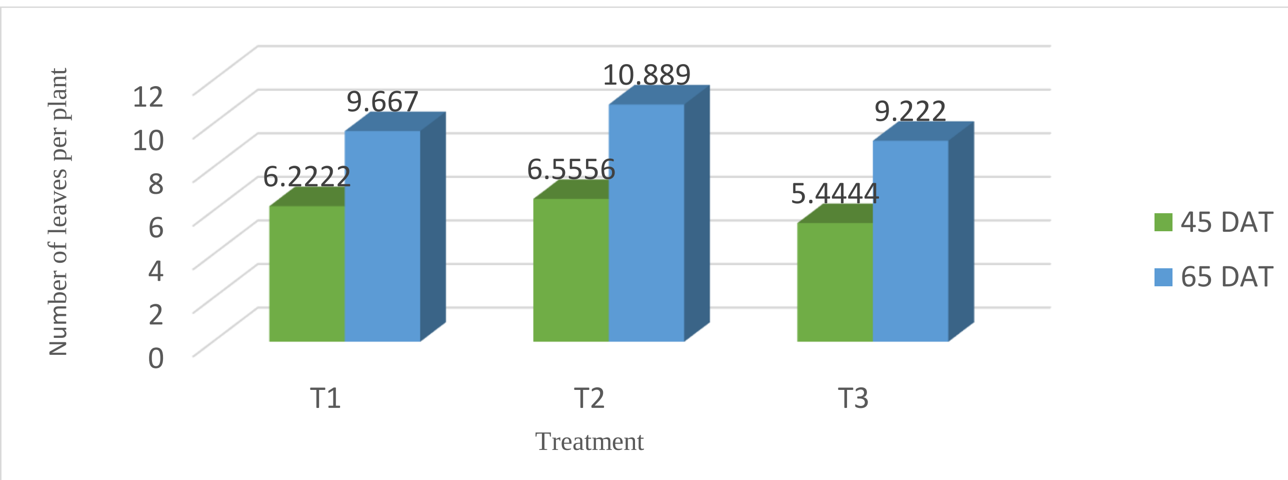
Treatment combinations	**Number of branches plant^{-1} at different days after transplanting (DAT)**		
	35	**50**	**80**
$T_1 \times V_1$	3.00 cd	4.00 cd	4.33 cd
$T_2 \times V_1$	3.33 bc	5.00 bc	5.66 b
$T_3 \times V_1$	2.33 d	3.00 d	3.66 d
$T_1 \times V_2$	4.00 b	4.33 bc	5.00 bc
$T_2 \times V_2$	6.00 a	7.00 a	8.33 a
$T_3 \times V_2$	3.66 bc	5.00 bc	5.00 bc
$T_1 \times V_3$	3.66 bc	4.66 bc	4.66 bcd
$T_2 \times V_3$	4.00 b	5.00 bc	5.33 bc
$T_3 \times V_3$	3.33 bc	5.33 b	5.33 bc
CV (%)	11.32	13.55	14.1

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.3 Number of leaves per plant

4.3.1 Effects of drought with potassium on number of leaves per plant

Plant leaves of three tomato variety was measured on different stage 45 and 65 DAT (Figure 5). Drought stress gradually decreased the number of leaves per plant of all tomato varieties application of potassium increases the leaf number. Effects of drought with potassium on Number of leaves per plant was statistically non-significant (P>0.05) at 45 and 65 DAT. At the vegetative stage 45 DAT, highest number of leaves per plant (7) was obtained from T_2 treatment (0.4g K/Pot +200 ml water/kg Soil) and the lowest number of leaves per plant (5) was recorded from T_3 treatment (0.9g K/ Pot+50ml water/kg Soil). At flowering stage 65 DAT, highest number of leaves per plant (12) was recorded from T_2 (0.4g K/ Pot + 200ml water/kg Soil) treatment condition and the lowest number of leaves per plant (9) was recorded from T_3 (0.9g K/ Pot+50ml water/kg Soil) condition.

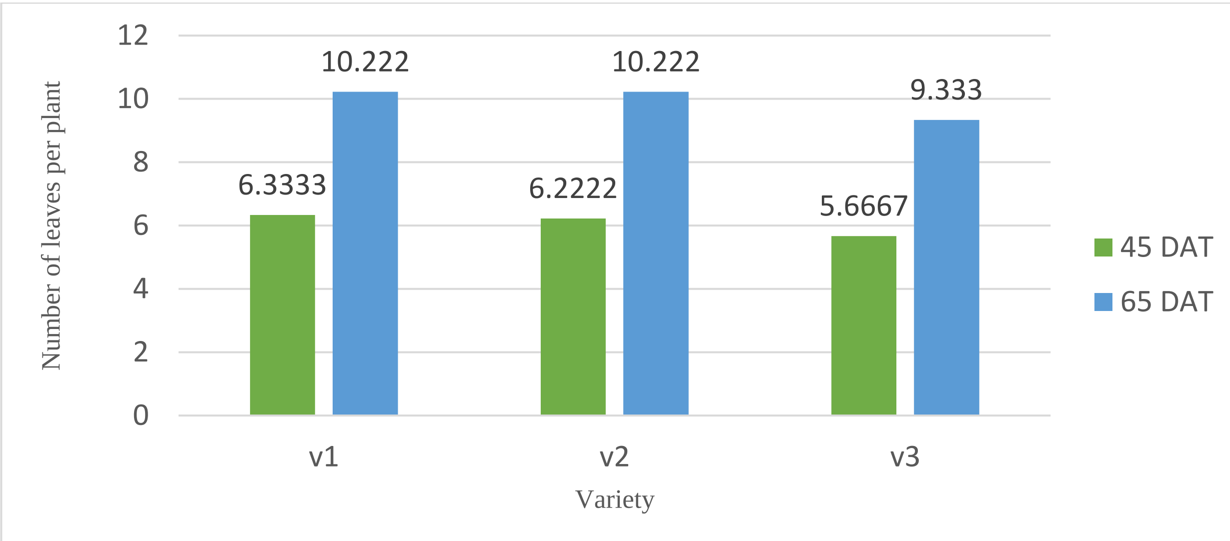


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure 5. Effects of drought with potassium on number of leaves per plant at different days after transplanting

4.3.2 Varietal effects on Number of leaves per plant

Effects of drought and potassium on different genotype was found non-significant. At the vegetative stage 45 DAT, highest and lowest plant leaves per plant (7, 5) was recorded from BARI Tomato 2 and BARI Tomato-16. At flowering stage 65 DAT, highest plant leaves per plant (12) was recorded from BARI Tomato 2 and BARI Tomato 15, The lowest plant leaves per plant (9) was recorded from BARI Tomato 16.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 6. Varietal effect on Number of leaves per plant at different days after transplanting

4.3.3 Interaction effects of drought with potassium levels and varieties on number of leaves per plant

Interaction effect on plant leaves between varieties and drought condition with potassium levels were found significant differences at 45 and 65 DAT. At 45 and 65 DAT, the highest number of leaves (7 and 12) were found from BARI Tomato-2 and BARI Tomato-15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest plant leaves (5 and 9) were found from BARI Tomato-16, at T_3 (0.9g/pot + 50ml water/kg soil) treatment combination (table 3). Application of K fertilizer in drought condition improve the plant but excess use of K fertilizer reduces it.

Kozlowski *et al.* (2011) found that number of leaves per plant reduced due to drought condition. Weershinghe *et al.* (2003) found same result in case of check pea. Ibrahim (1990) reported similar findings for chickpea in case of drought. Ragab *et al.* (2007) and Whab *et al.* (2011) found similar result in tomato plant in case of drought condition. Hossain *et al.* (2009) who found that increasing potassium fertilizer levels increased number of leaves per plant and shoot fresh weight in carrot. Akand et al. (2016) found that application of potassium fertilizer improved leaf number per plant. Potassium protects leaves from dehydration by inducing accumulation of solute such as proline, thus lowering osmotic potential that maintains plant cell turgor under osmotic stress (Egilla, *et al.*, 2005).

Table 3. Interaction effects between drought with potassium levels and tomato varieties on number of leaves per plant

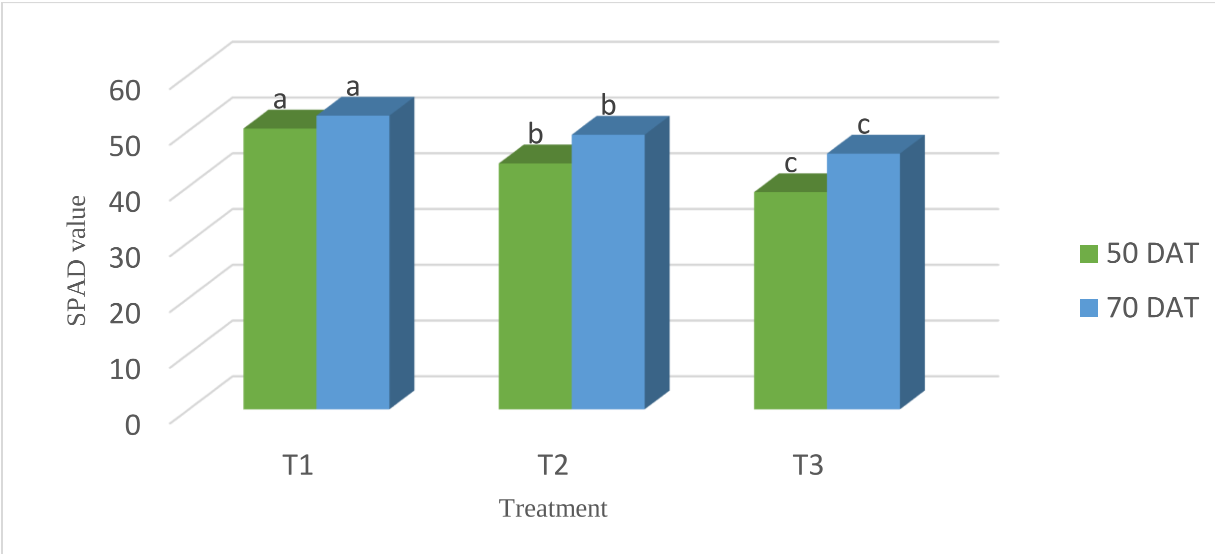
Treatment combinations	**Number of leaves per plant at different days after transplanting (DAT)**	
	45	**65**
$T_1 \times V_1$	6.00	10.00
$T_2 \times V_1$	7.00	11.00
$T_3 \times V_1$	6.00	9.66
$T_1 \times V_2$	6.66	10.00
$T_2 \times V_2$	6.66	11.66
$T_3 \times V_2$	5.33	9.00
$T_1 \times V_3$	6.00	9.00
$T_2 \times V_3$	6.00	10.00
$T_3 \times V_3$	5.00	9.00
CV (%)	9.16	5.21

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.4 SPAD value

4.4.1 Effects of drought with potassium levels on SPAD value

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). SPAD value was measured on different stage at 50 and 70 DAT (Figure 9) and found statistically significant ($P>0.05$) at 50 and 70 DAT. SPAD value decreased with increasing of drought condition and potassium level. At 50 DAT, highest SPAD value (54.9) was obtained from T_1 treatment and the lowest SPAD value (37.7) was recorded from application of T_3 (0.9g K/ Pot+50ml water/kg Soil) treatment. At 70 DAT, highest SPAD value (55) was obtained from T_1 treatment. The lowest SPAD value (44.7) was recorded from T_3 (0.9g K/ Pot+50ml water/kg Soil) treatment application. Drought condition gradually decreases plant chlorophyll content and gives a lower SPAD value of leaves compared to normal condition.

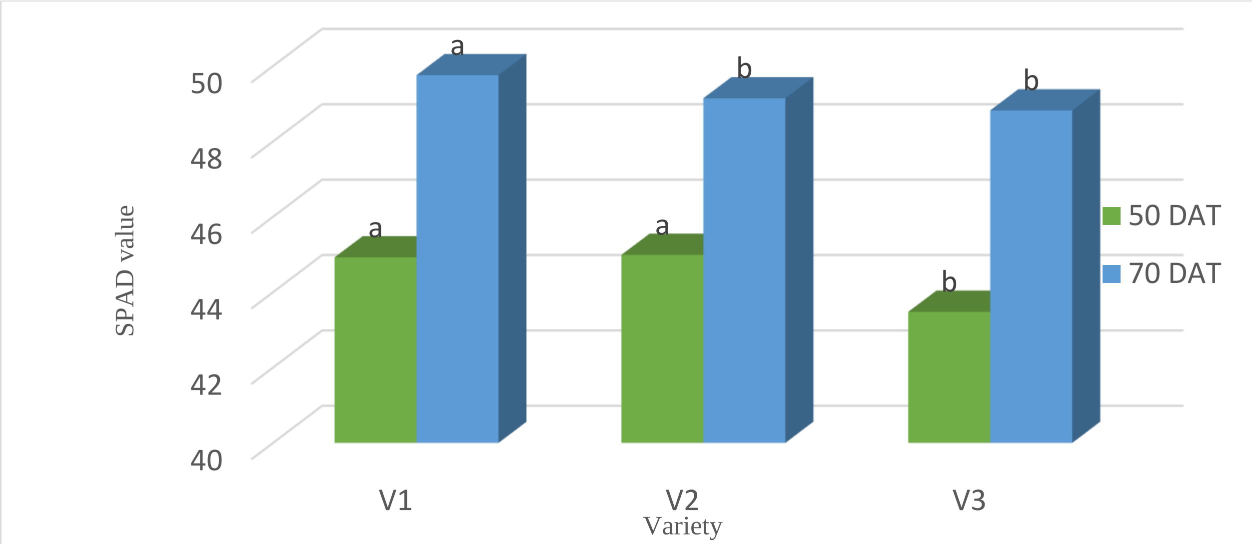


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure 7. Effect of drought with potassium levels on SPAD value at days after transplanting

4.4.2 Varietal effects on SPAD value

Varietal effect was found significant. At 50 DAT, highest SPAD value (54.9) was recorded from BARI Tomato 2 The lowest SPAD value (37.7) was recorded from BARI Tomato 16. At 70 DAT, SPAD value (55) was recorded from BARI Tomato 2 and the lowest SPAD value (47.7) was recorded from BARI Tomato 16. Potassium level affected development and yield of tomato Zhou *et al.* (2017) showed that Chlorophyll a/b content of leaves significantly decreased under drought stress in comparison with control. Anuradha and Sarmo (1995) reported that increase leaf chlorophyll content in soybean due to application of potassium. In wheat applying potassium increased leaf chlorophyll content (Yu *et al.*, 1996).



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 8. Varietal effects on SPAD value at days after transplanting

4.4.3 Interaction effects of drought with different potassium levels and tomato varieties on SPAD value

Interaction effect on SPAD value between varieties and drought condition with potassium levels were found significant at 50 and 70 DAT. At 50 and DAT, the highest SPAD Value (54.9 and 55) was found from BARI Tomato 2 with T_1 (control) treatment combination. The lowest SPAD value (37.7 and 47.7) was found from BARI Tomato 15 and BARI Tomato 16 at T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination (table 5).

Sakya *et al.* (2018) reported that drought stress decreases total chlorophyll content. Zhou *et al.* (2017) found similar finding in case of drought. Khan *et al.* (2020) found maximum chlorophyll content found in case of drought condition in tomato plant. Similar type of result was also found by Salama *et al.* (2017) in case of drought condition. 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). K plays an important role in photosynthesis, opening and closing of stomata. which helps in appropriate nutrient translocation and water uptake. (Havlin *et al*., 2005; Prajapati and Modi, (2012). It has been reported that adequate supply of potassium in soil improves the water relations of plant and photosynthesis, helps in osmotic regulation of plant cell, assists in opening and closing of stomata, activates the enzymes, nodulation and synthesizes the protein (Grag *et al.*, 2005; Yang *et al.*, 2004).

Table 4. Interaction effects between drought with potassium levels and tomato varieties on SPAD value

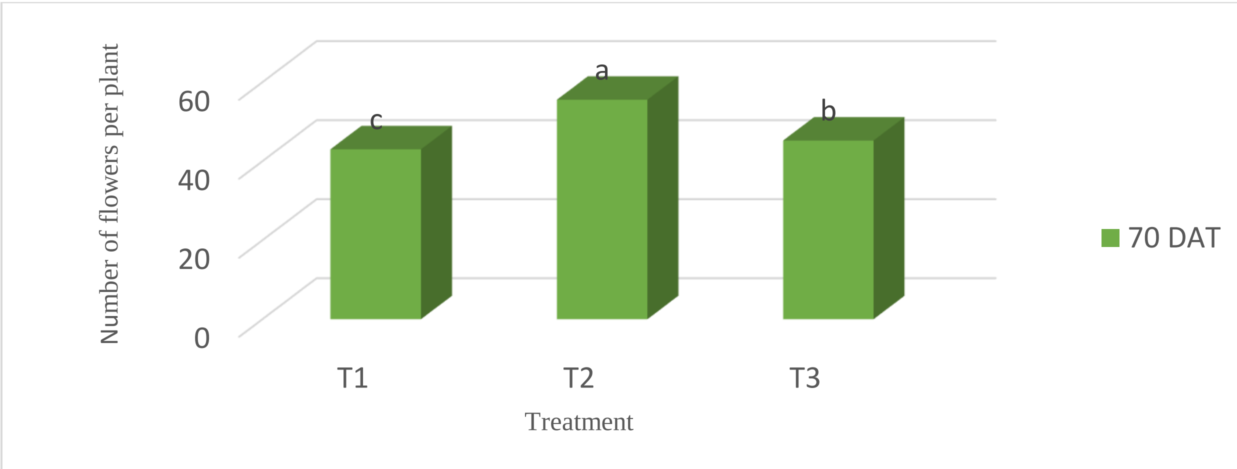
Treatment combinations	**Chlorophyll content (SPAD units) at different days after transplanting**	
	50	**70**
$T_1 \times V_1$	54.40 a	54.40 a
$T_2 \times V_1$	42.83 e	50.23 c
$T_3 \times V_1$	37.53 g	44.63 g
$T_1 \times V_2$	50.40 b	52.50 b
$T_2 \times V_2$	44.93 d	49.03 d
$T_3 \times V_2$	39.63 f	45.90 f
$T_1 \times V_3$	46.26 c	50.96 c
$T_2 \times V_3$	44.50 d	48.46 d
$T_3 \times V_3$	39.66 f	47.03 e
CV (%)	1.33	1.19

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.5 Number of flowers per plant

4.5.1 Effects of drought with potassium levels on number of flowers per plant

Number of flowers per plant was measured on flowering stage at 70 DAT. Effects of drought with the potassium on number of flowers per plant was statistically significant (P>0.05). 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. For this reason, drought condition brings a significant change in flowering time in all tomato varieties. At flowering stage 70 DAT, highest number of flowers per plant (64) were obtained from the plant treated with T_2 treatment (0.4gk/pot+ 200 ml water/kg Soil). The lowest flowers per plant (36) were recorded from T_1 (control) treatment applied plant. 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. potassium fertilizers increase the flower of plant.

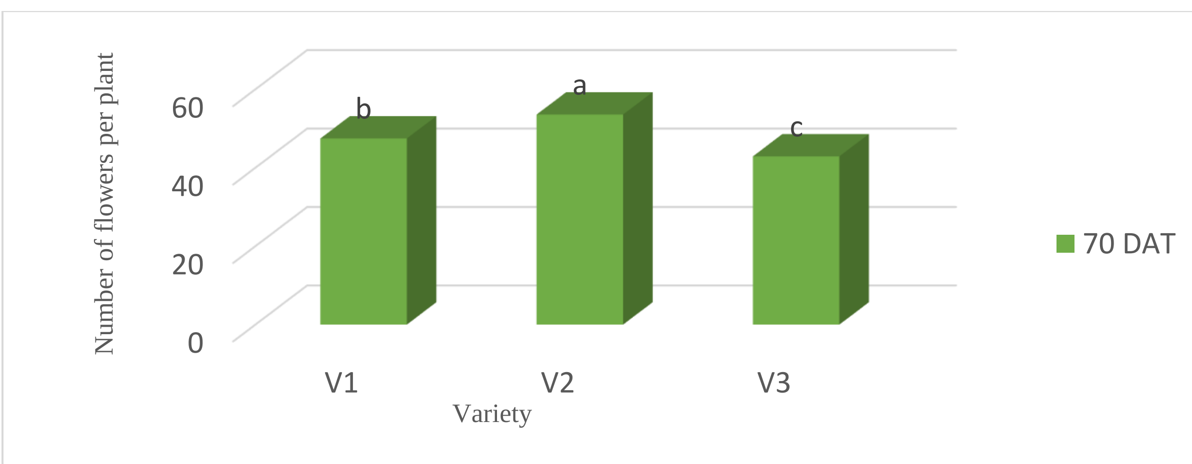


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure 9. Effect of drought with potassium levels on number of flowers per plant at days after transplanting

4.5.2 Varietal effects on number of flowers per plant

Effects of drought with potassium on different genotype statistically significant (P>0.05) at 70 DAT. At 70 DAT, highest number of flowers per plant (64) was recorded from BARI Tomato 15, The lowest number of flowers per plant (36) was recorded from BARI Tomato 16.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 10. Varietal effects on number of flowers per plant at days after transplanting

4.5.3 Interaction effect of drought with potassium levels and tomato varieties on number of flowers per plant

The interaction effects on number of flowers per plant between varieties and drought condition with potassium levels was found significant differences at flowering stage at 70 DAT. At flowering stage 70 DAT, the highest number of flowers per plant was found from BARI Tomato 15 with T_2(0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest of flowers per plant was found from BARI Tomato 16 at T_1 treatment combination.

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) found early flower production in case of drought condition in tomato plant. Akter *et al.* (2019) found similar finding in case of drought. Ragab *et al*., (2007) found flowering decreased in drought condition. Sultana et al., (2015) found maximum flowering in case of application of K fertilizer. Clarke (1944) found little effect of potassium application on flower production. Akand et al. (2016) found similar finding in case of application of potassium fertilizer. 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 on flowering time of tomato varieties. Potassium plays roles in flowering, phenological development, physiological maturity was delayed due to the lower application of K (Fan, *et al.*, 2001; Iqbal, *et al*., 2016). (Sadiq and Jan 2001). Asif *et al.* (2007) found the same result in maize.

Table 5. Interaction effects between drought with potassium levels and tomato varieties on number of flowers per plant

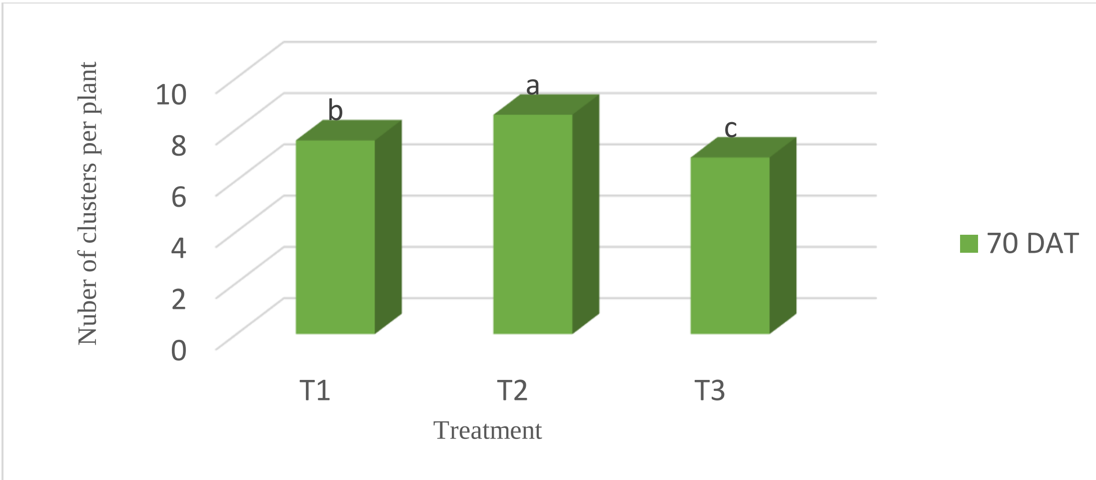
Treatment combinations	Number of flowers plant^{-1} at days after transplanting (DAT)
	70
$T_1 \times V_1$	43.00 de
$T_2 \times V_1$	55.00 b
$T_3 \times V_1$	44.33 d
$T_1 \times V_2$	48.00 c
$T_2 \times V_2$	63.33 a
$T_3 \times V_2$	49.33 c
$T_1 \times V_3$	38.00 f
$T_2 \times V_3$	48.66 c
$T_3 \times V_3$	42.00 e
CV (%)	2.80

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.6 Number of clusters per plant

4.6.1 Effects of drought with potassium levels on number of clusters per plant

Number of clusters per plant was measured on flowering stage at 70 DAT and it was statistically significant (P>0.05). Number of clusters per plant decreased when drought condition and potassium level was increased. At flowering stage 70 DAT, highest number of clusters per plant (10) was recorder from T_2 treatment (0.4g K/pot+ 200 ml water/kg Soil) condition. Drought causes the negative impact on the number cluster per plant. Different levels of potassium showed significant differences on number clusters per plant. The less number of clusters per plant (6) was recorded from T_3 treatment (0.9g k/ Pot+50ml water/kg Soil) condition. Potassium fertilizer application increases the flower number, the peduncle length, the fruit set and the number of fruit (Besford and Maw, 1975).

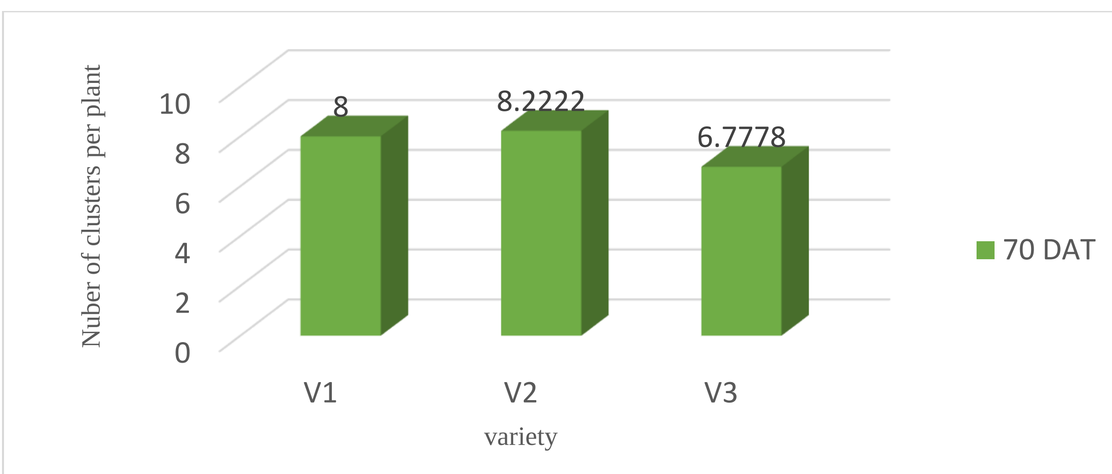


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure11. Effects of drought with potassium levels on number of clusters per plant at different days after transplanting

4.6.2 Varietal effects on number of clusters per plant

Effects of drought along and potassium on different genotype was found significant 70 DAT. At flowering stage 70 DAT, highest and less number of clusters per plant (10, 6) was recorded from BARI Tomato 15 and BARI Tomato 16. Rahman *et al.* (1999) found same result in case of drought. Drought sensitive and tolerant varieties was giving lower number of clusters. Sivakumar and Srividhya (2016) found that plants under drought condition-initiated flowers earlier.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 12. Varietal effects on number of flower cluster per plant at days after transplanting

4.6.3 Interaction effects of drought with potassium levels and Tomato varieties on number of flower cluster per plant

The interaction effect on number of flower cluster per plant between varieties and drought condition with potassium levels were found significant differences. 70 DAT, the highest number of clusters per plant was found from BARI Tomato15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The less number of clusters per plant was found from BARI Tomato 16 at T_3 (0.9g/pot + 50ml water/kg soil) treatment combination.

Buhroy *et al.* (2017) found that number of clusters per plant decreased with increased level of drought in tomato plant. Akter *et al.* (2019) and Rahman *et al.* (1999) found similar result. Similar result was also found in tomato by different research (Lutfor-Rahman *et al.*, 2000 and Nuruddin *et al.*, 2003). Hernandez-Aarmenta (1985) found fewer cluster production per plant in case of bell pepper plant. Sultana *et al*. (2015) and akand *et al*. (2016) found similar finding in case of application of potassium fertilizer. Water deficit leads to decrease in the number of flowers and flower drops (Losada and Rincaon, 1994; Colla *et al.*, 1999; Rahman *et al.*, 1999 and Veit-Kohler *et al.*, 1999) that is responsible for decreased number of clusters per plant. Clarke (1944) found effect of potassium application on flower production, the proportion of flowers that matured into marketable fruit which supported to the present experiment.

Table 6. Interaction effects between drought with potassium levels and tomato varieties on number of clusters per plant

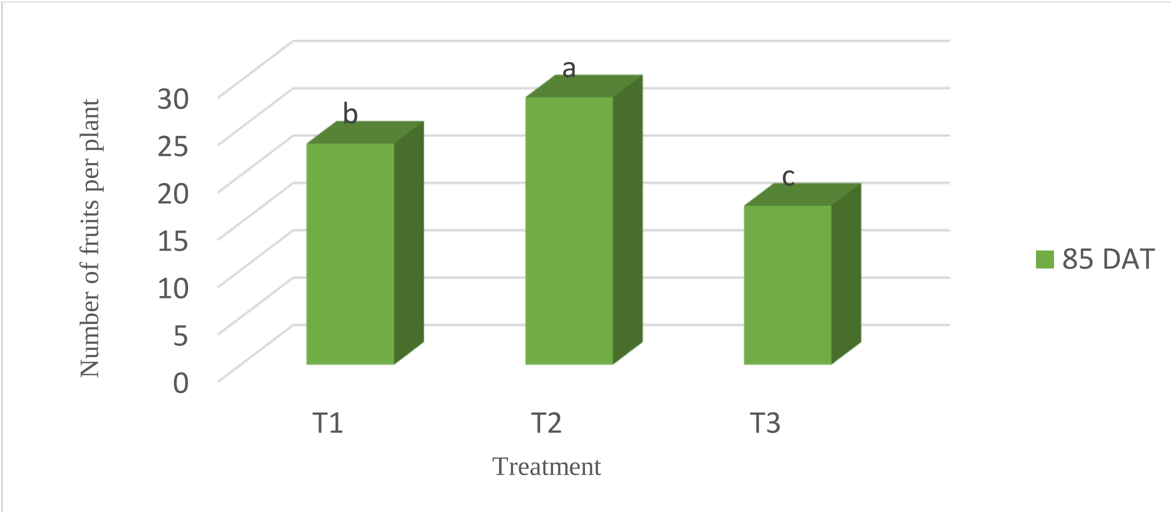
Treatment combinations	Number of flower cluster per plant at days after transplanting (DAT)
	70
$T_1 \times V_1$	8.00 c
$T_2 \times V_1$	9.00 b
$T_3 \times V_1$	7.66 bc
$T_1 \times V_2$	7.66 bc
$T_2 \times V_2$	9.66 a
$T_3 \times V_2$	6.66 d
$T_1 \times V_3$	7.00 cd
$T_2 \times V_3$	7.00 cd
$T_3 \times V_3$	6.33 d
CV (%)	5.75

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.7 Number of fruits per plant

4.7.1 Effects of drought with potassium on number of fruits per plant

Effects of drought and potassium on number of fruits per plant was statistically significant ($P>0.05$). Number of Fruits per plant was measured on Fruiting stage. At fruiting stage highest number of fruits were obtained from T_2 treatment (0.4gK/pot+ 200 ml water/kg Soil) application and T_3 (0.9g K/ Pot+50ml water/kg Soil) treatment recorded the lowest. Application of K fertilizer increase the fruit number. Akter *et al.* (2019) resulted those days of fruit harvest were significantly affected by drought treatments and maturity time decreases with the increasing drought levels in tomato plants.

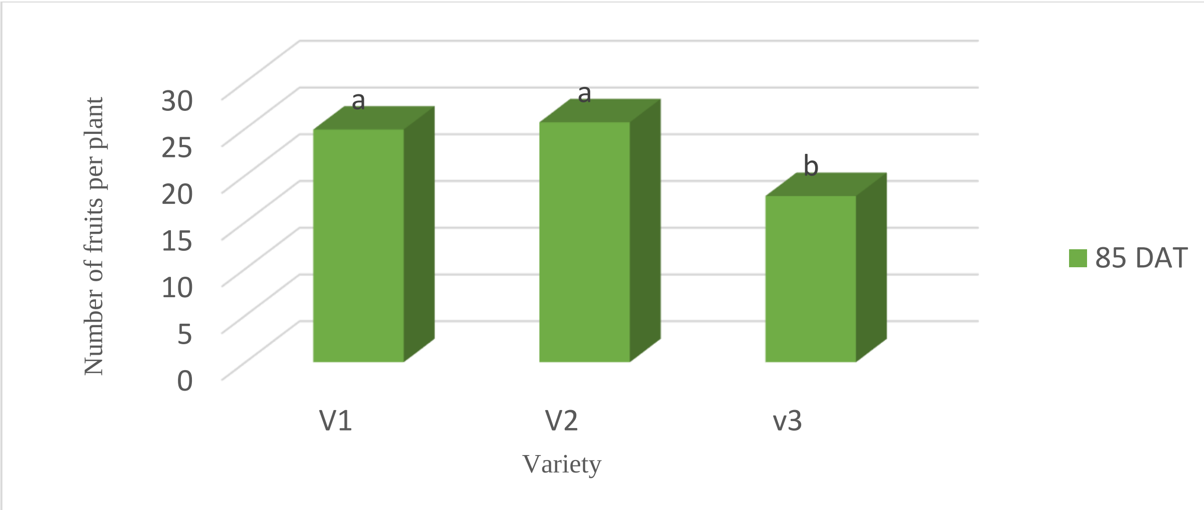


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure 13. Effects of drought with potassium on number of fruits per plant at days after transplanting

4.7.2 Varietal effects on number of fruits per plant

Effects of drought and potassium on different genotype was statistically significant (P>0.05) at fruiting. At fruiting stage highest number of fruits (34) were recorded from BARI Tomato 15 and the lowest number of fruits (11) were recorded from BARI Tomato16. Potassium fertilizers increase fruit per plant. 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.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 14. Varietal effects on number of fruits per plant at different days after transplanting

4.7.3 Interaction Effect of Drought with potassium levels and Tomato varieties on number of fruits per plant

The interaction effect on number of fruits per plant between varieties and drought condition with potassium was found significant differences at fruiting stage. At fruiting stage, the highest number of fruits per plant was found from BARI Tomato 15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest fruits per plant was found from BARI Tomato 16, at T_3 (0.9g/pot + 50ml water/kg soil) treatment combination.

Khan *et al.* (2020) found that plant under water stress condition reduce fruit number. Akter *et al.* (2019) reported that highest number of fruit produce in control condition lowest number found in drought condition. Weershinghe *et al.* (2003) found that fruit number per tomato plant decreased in drought condition. Nuruddin *et al.* (2003) found similar result in case of tomato plant. Similar type result was also found by other researchers (Rahman *et al.*, 1998a, Bhattarai and Midmore, 2005 and Zgallai *et al.*, 2005). Gupta *et al.* (1995) found similar result in case of checkpea. Ragab *et al*. (2007) found similar result drought condition of tomato plant. Mazed, *et al.* (2015) resulted that application of potassium fertilizer improve the number of fruits per plant. Sultana *et al.* (2015) resulted that optimum level of potassium use increase fruits per plant, but Excess level of potassium use reduces the fruit production. Quddus *et al*. (2019) found application of different levels of potassium showed significant increased number of pods per plant in mungbean. Akand *et al.* (2016) found potassium increase number of fruit in tomato plant. However, the excessive application of K fertilizer might have resulted negative influence on the fruit production capacity of the plants. Pervez *et al*., (2013) who confirmed that excessive doses of K have negative impacts on potato tubers per plant. Besides, balance potassium fertilizer improved tomato production (Zia-ul-Hassan, 2016).

Table 7. Interaction effects between drought with potassium levels and tomato varieties on number of fruits per plant

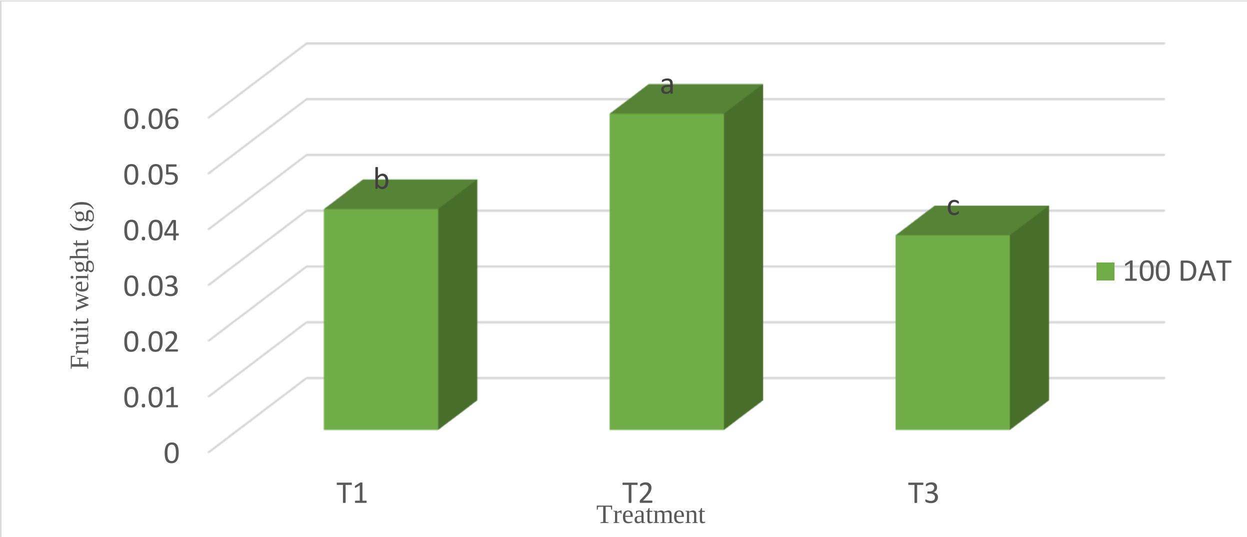
Treatment combinations	**Number of fruits per plant at days after transplanting**
$T_1 \times V_1$	26.33 c
$T_2 \times V_1$	28.00 b
$T_3 \times V_1$	20.33 e
$T_1 \times V_2$	26.00 c
$T_2 \times V_2$	33.00 a
$T_3 \times V_2$	18.00 f
$T_1 \times V_3$	17.66 f
$T_2 \times V_3$	23.66 d
$T_3 \times V_3$	12.00 g
CV (%)	3.87

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.8 Fruit weight(g)

4.8.1 Effects of drought with potassium levels on fruit weight

Fruit weight was measured on Fruiting stage at 100 DAT. It was found statistically significant ($P>0.05$). 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. At fruiting stage 100 DAT, extensive fruit weight (0.064g) was found from T_2 (0.4gk/pot+ 200 ml water/kg Soil) condition and lightest fruit weight (0.028g) was recorded from application of T_3 (0.9g k/Pot+50ml water/kg Soil) treatment. Techawongstein *et al.*, (1992). Sakya *et al.*, (2018) showed that tomato fruit weight in the drought conditions decreased from 3-148% yield. Supplied K was alleviating effects of stresses. Botrini *et al.,* (2000) observed increased fruit production and fruit quality of tomato in response of potassium. It improved plant growth, fruit yield, and fruit quality. Fruit yield and quality improved by potassium, and it was useful for production, postharvest preservation, and processing of tomato.

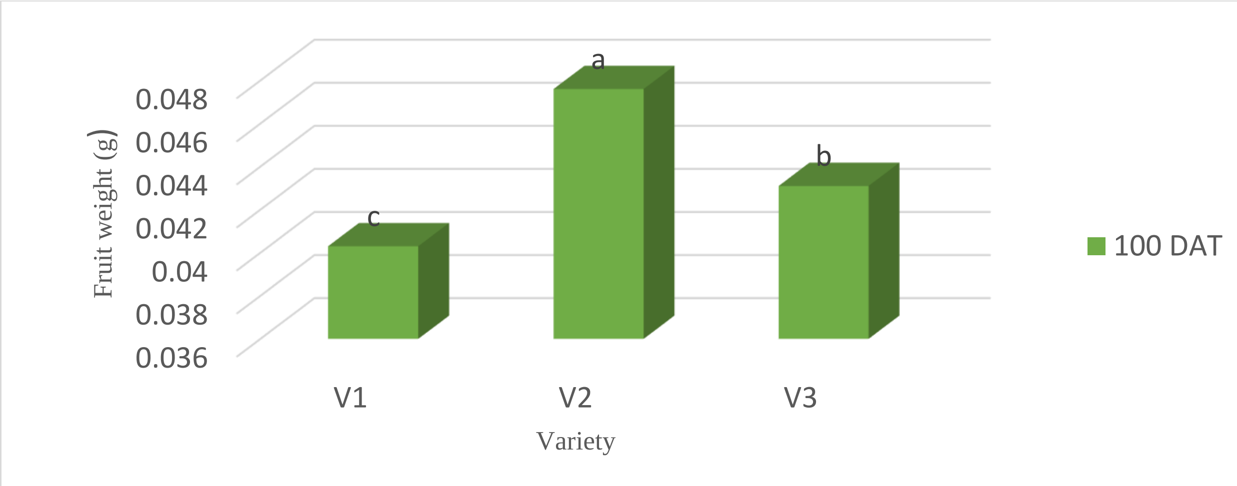


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure15. Effects of drought with potassium levels on fruit weight at days after transplanting

4.8.2 Varietal effects on fruit weight

Drought and potassium effects on different genotype was found statistically significant (P>0.05) at fruiting stage 100 DAT. At fruiting stage, extensive fruit weight (0.064g) was recorded from BARI Tomato 15 and the lightest fruit weight (0.028g) was recorded from BARI Tomato 2. Weershinghe *et al.* (2003) found that fruit number per tomato plant decreased in drought condition compared to normal condition. Potassium uptake increases rapidly during fruiting stage of tomato (Huett and Dettmann, 1988). Potassium plays an important role in the pigmentation of tomato fruit (Hartz *et al.,* 2005). Inadequate potassium often leads to uneven ripening, blotchy ripening, high levels of internal white tissue, yellow shoulder, decreased lycopene, irregular shape, and hollow fruit (Madakadze and Kwaramba, 2004).



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 16. Varietal effect on fruit weight at days after transplanting

4.8.3 Interaction effects of drought with potassium levels and tomato varieties on fruit weight

The interaction effect on fruit weight between varieties and drought condition with potassium was found significant differences at fruiting stage at 100 DAT. At fruiting stage, the extensive fruit weight was found from BARI Tomato 15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lightest fruit weight was found from BARI Tomato 16 at T_1 (control) treatment combination.

Sakya *et al.* (2018) in the drought conditions tomato fruit weight decreased. Cui *et al.* (2020) founded lower fruit weight in tomato plant at drought condition. Giuliani *et al.* (2018) also found the similar result. 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) found that fruit weight per plant was decreased in drought condition. Thippeswami and Sreenivasa, (1998); Rao *et al.* (2000); Lutfor-Rahman *et al. (*2000) and Nuruddin *et al. (*2003) were found Similar results in case of tomato. Mazed, et al. (2015) resulted that application of potassium fertilizer improve the weight of individual fruit. Akand *et al.* (2016) found potassium and gibberellic acid increase fruit weight. Hossain et al. (2009) resulted that the potassium increase tomato fruit weight. Quddus et al. (2019) found the similar result in case of mung bean. Ghourab *et al.* (2000) stated that application of adequate K increases fruit weight by increasing translocation of photosynthates to fruit and water use efficiency. But excess use of potassium reduced fruit production.

Table 8. Interaction effects between drought with potassium levels and tomato varieties fruit weight

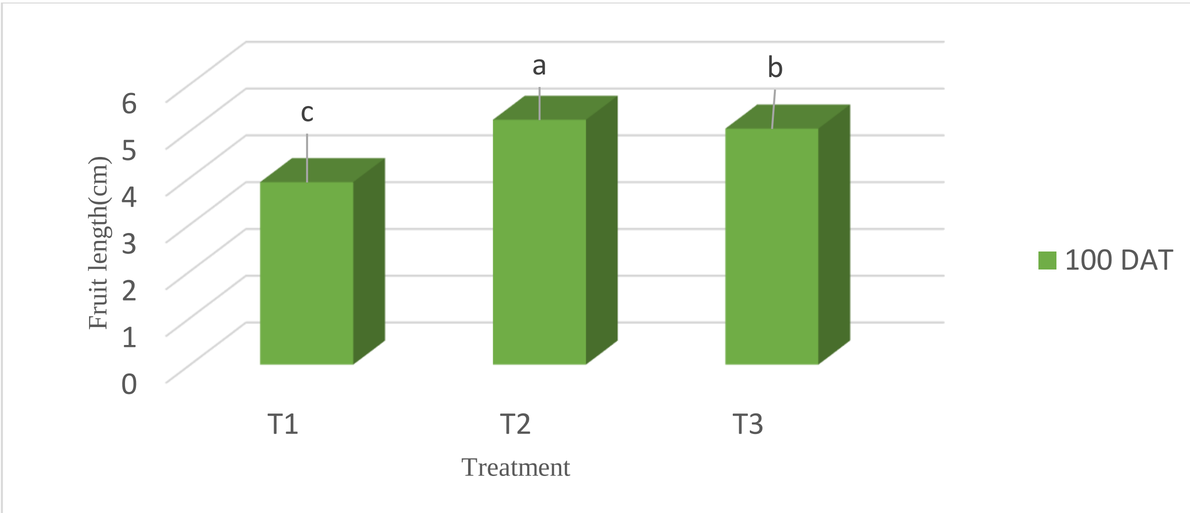
Treatment combinations	**Fruit Weight at days after transplanting**
	100
$T_1 \times V_1$	0.041 f
$T_2 \times V_1$	0.051 c
$T_3 \times V_1$	0.028 h
$T_1 \times V_2$	0.048 d
$T_2 \times V_2$	0.063 a
$T_3 \times V_2$	0.031 g
$T_1 \times V_3$	0.029 h
$T_2 \times V_3$	0.056 b
$T_3 \times V_3$	0.044 e
CV (%)	3.24

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.9 Fruit length(cm)

4.9.1 Effects of drought with potassium levels on fruit length

Fruit length was measured on Fruiting stage at 100 DAT. Effects of drought and potassium on Fruit length was significantly different from one another. At fruiting stage 100 DAT, the biggest fruit (5.5 cm) was obtained from T_2 (0.4g K/pot+ 200 ml water/kg Soil) condition. The smallest length fruit (3.5cm) was recorded from application of treatment T_1 . Rahman *et al.* (1999) found that fruit yield decreased with increased water stress during drought condition due to producing smaller size of fruits. Potassium increases tomato fruit size and weight of per plant and then ultimately increased overall fruit yield.

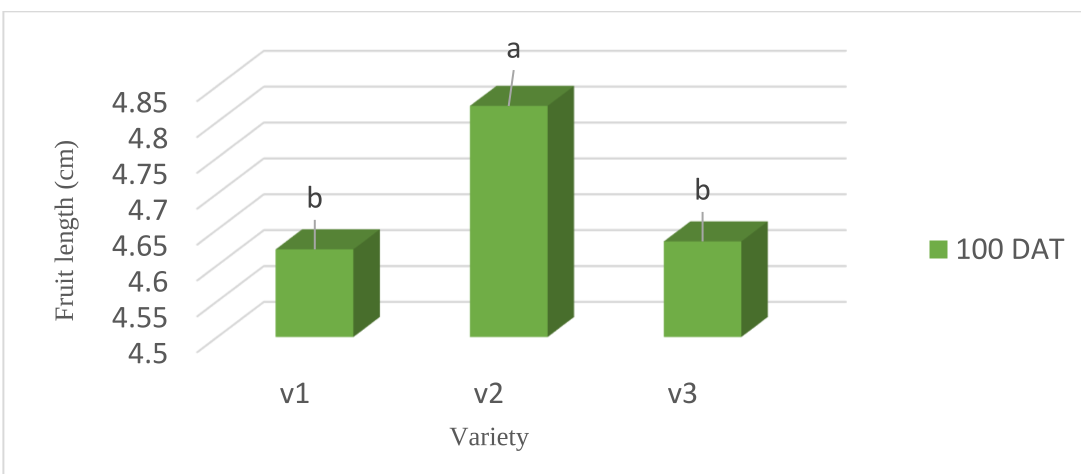


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure17. Effects of drought and potassium levels on fruit length at days after transplanting

4.9.2 Varietal effects on fruit length

Effects of drought and potassium on different genotype was significantly different at fruiting stage 100 DAT. At fruiting stage, biggest fruit length (5.5 cm) was recorded from BARI Tomato 15, The smallest fruit length (3.5 cm) was recorded from BARI Tomato 2. Potassium increases tomato fruit size there was an increase on fruit weight and overall production.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 18. Varietal effects on Fruit length at days after transplanting

4.9.3 Interaction effects of drought with potassium levels and tomato varieties on fruit length

The interaction effect on fruit length between varieties and drought condition with potassium levels was found significant differences at fruiting stage at 100 DAT. At fruiting stage 100 DAT, the biggest fruit length was found from BARI Tomato 15, with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The smallest fruit length was found from BARI Tomato 2, at T_1 (control)treatment combination.

Rahman *et al.* (1999) found smaller size of tomato fruit in drought condition. Rao *et al.* (2000) found similar result. Rao and Padma (1991) found small tomato fruit in low water deficiency. Klepper *et al.* (1971) reported that the fruit length changes occur at different level of water stress. Lapushner *et al.* (1986) observed that the fruit size of tomato was reduced by water stress. Similar result was reported from Lutfor-Rahman *et al.* (2000); Nuruddin *et al.* (2003). Hossain (2003) reported that pod size decreased with increased level of water stress in mung bean. Similar result was also found by Taub (2003) in chickpea. Sultana *et al.* (2015) found use of potassium fertilizer increased tomato fruit size. Hossain et al. (2009) found similar kind of result. Mazed, *et al.* (2015) resulted that application of potassium fertilizer improve the fruit size. Drought stress reduced fruit size use of potassium fertilizer improve it. But excess level of K fertilizer reduced the production

Table 9. Interaction effects between drought with potassium levels and tomato varieties on Fruit length

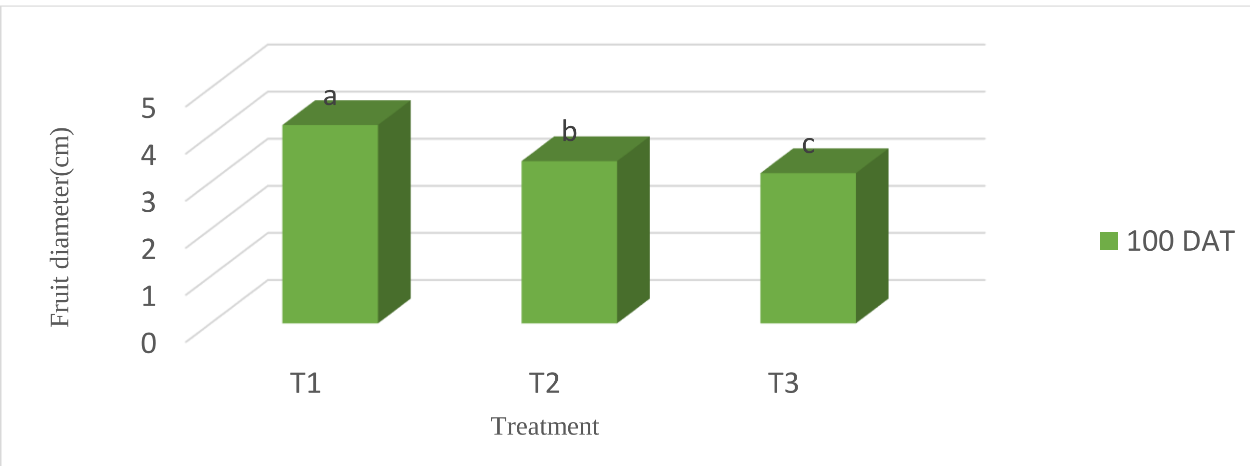
Treatment combinations	**Fruit length at different days after transplanting**
	100
$T_1 \times V_1$	3.63 e
$T_2 \times V_1$	5.16 b
$T_3 \times V_1$	5.10 b
$T_1 \times V_2$	3.93 d
$T_2 \times V_2$	5.40 a
$T_3 \times V_2$	5.13 b
$T_1 \times V_3$	3.83 d
$T_2 \times V_3$	5.13 b
$T_3 \times V_3$	4.90 c
CV (%)	1.94

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.10 Fruit diameter

4.10.1 Effects of drought with potassium levels on fruit diameter

Fruit diameter was measured on Fruiting stage at 100 DAT. Effects of drought and potassium on Fruit diameter significantly different from one another. At fruiting stage, biggest fruit diameter (4.5 cm) was recorded from application of T_1 treatment. The smallest fruit diameter (3 cm) was recorded from T_3 (0.9g K/pot+ 50 ml water/kg Soil) treatment condition. Rao and Padma (1991) resulted 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. Daniel (2018) resulted that K application on tomato, fruit diameter was gradually enhanced with increased.

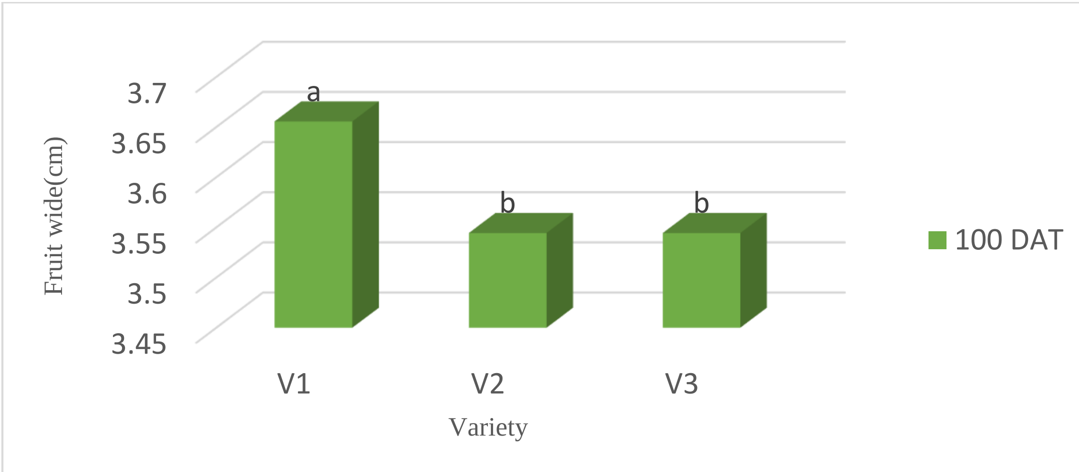


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure19. Effects of drought and potassium levels on fruit diameter at days after transplanting

4.10.2 Varietal effect on Fruit diameter

Effects of drought and potassium on different genotype significantly different at fruiting stage 100 DAT. At fruiting stage, biggest fruit diameter (4.5 cm) was recorded from BARI Tomato 2, and the smallest fruit diameter was recorded from BARI Tomato 15 and BARI Tomato 16. In the drought condition tomato diameter was reduced but application of potassium fertilizer improve the fruit size.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16
Figure 20. Varietal effects on fruit diameter at days after transplanting

4.10.3 Interaction Effect of Drought with potassium levels and varieties on fruit diameter

The interaction effect on fruit diameter between varieties and drought condition with potassium was found significant differences at fruiting stage at 100 DAT. At fruiting stage, the biggest fruit diameter was found from BARI Tomato 2 with T_1 (control) treatment combination. The smallest fruit diameter was found from BARI Tomato 16 at control T_3 (0.9g K/Pot+50ml water/kg soil) treatment combination.

Rahman *et al.* (1999) found smaller size of tomato fruit in drought condition. Rao *et al.* (2000) found similar result. Rao and Padma (1991) found small tomato fruit in low water deficiency. Sibomana and Aguyoh (2013) resulted tomato diameter reduced in drought stress. Klepper *et al.* (1971) reported that the fruit length changes occur at different level of water stress. Lapushner *et al.* (1986) observed that the fruit size of tomato was reduced by water stress. Mazed, *et al.* (2015) resulted that application of potassium fertilizer improve fruit diameter in tomato plant. Sultana *et al*. (2015) found similar result. When water stress was occurred on fruiting stage, it reduced cell elongation and prevent photosynthates (Mahhou *et al.*, 2006). As a result, the fruit diameter decreases with the increase of drought level. K application increases the size of fruits, (Perkins and Robert, 2003). This could be ascribed to activation of enzymes by K and its involvement in adenosine triphosphate (ATP) production which is important in regulating the rate of photosynthesis which enable the plants to have more food to be stored in the fruits (Havlin, *et al*., 2005). ATP is also used as the energy source for many plant activities (Van Brunt and Sultenfuss, 1998) including cell divisions. Then cell division determines to a large extent the final number of cells in a fruit and there after the final fruit size (Lemaire *et al*., 2005). But excess amount uses of k fertilizer reduce the fruit diameter.

Table 10. Interaction effects between drought with potassium levels and tomato varieties on fruit diameter

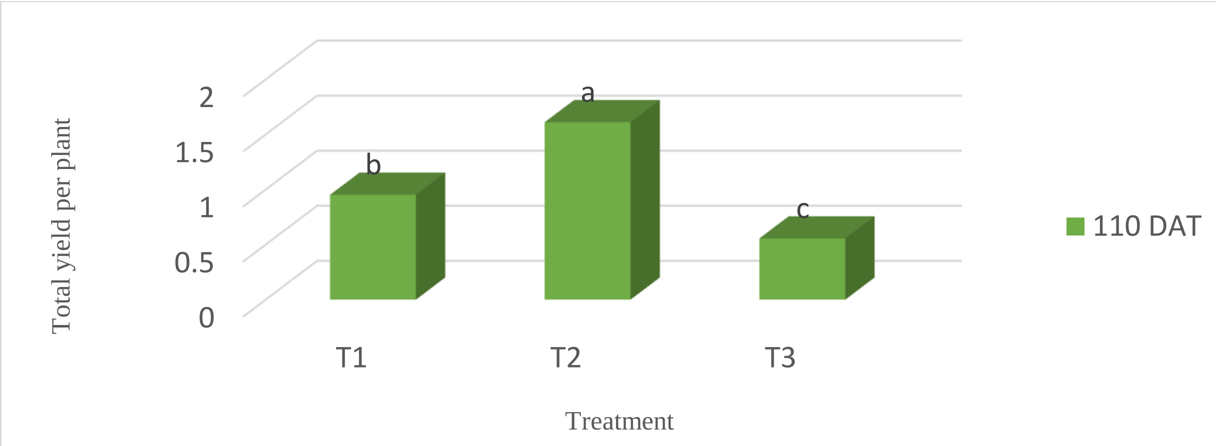
Treatment combinations	**Fruit diameter at days after transplanting (DAT)**
	100
$T_1 \times V_1$	4.40 a
$T_2 \times V_1$	3.20 d
$T_3 \times V_1$	3.20 d
$T_1 \times V_2$	4.16 b
$T_2 \times V_2$	3.46 c
$T_3 \times V_2$	3.33 cd
$T_1 \times V_3$	4.06 b
$T_2 \times V_3$	3.36 c
$T_3 \times V_3$	3.03 e
CV (%)	2.27

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.11. Yield per plant

4.11.1 Effects of drought and potassium levels on total yield

Total yield per plant was measured on at 110 DAT. Effects of drought and potassium on yield per plant was statistically significant (P>0.05). At 110 DAT, highest yield (2.176 kg) was obtained from T_2 (0.4g K/pot+ 100 ml water/kg Soil) treatment. The lowest yield (0.540 kg) was recorded from T_3 treatment (0.9g K/pot+ 50 ml water/kg Soil). Drought stress shows very complex effect on plant growth and development process (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.

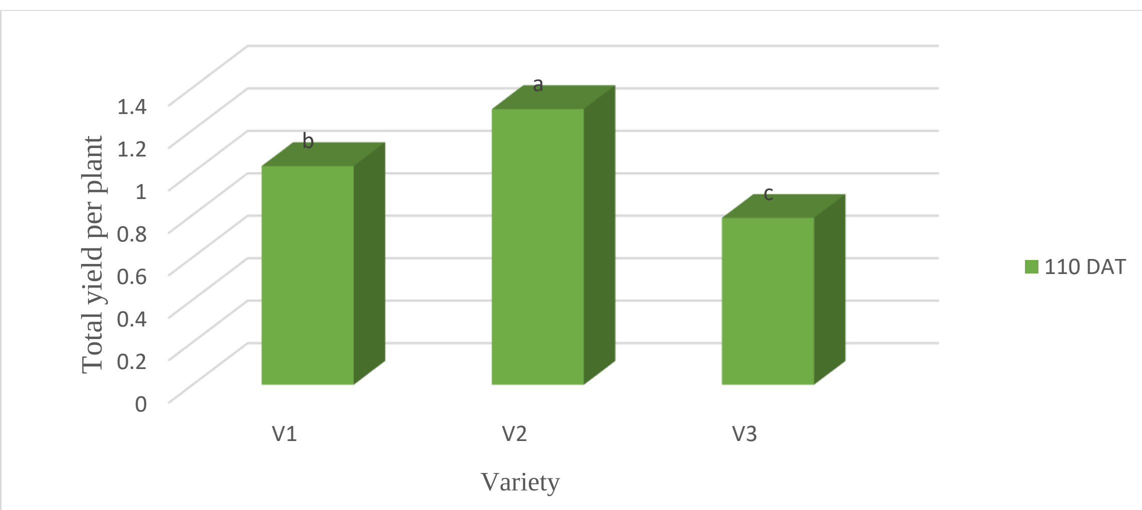


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure21. Effects of drought with potassium levels on total yield at days after transplanting

4.11.2 Varietal effect on total yield per plant

Effects of drought and potassium on different genotype was significantly different at fruiting stage 110 DAT.At 110 DAT, highest yield (2.176 kg) was recorded from BARI Tomato 15, the lowest yield (0.54 kg) was recorded from BARI Tomato 16.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 22. Varietal effect on Total yield per plant at days after transplanting

4.11.3 Interaction Effect of Drought with potassium levels and Tomato varieties on Total yield per plant

The interaction effect on Yield per plant between varieties and drought condition with different dose of potassium was found significant differences at 110 DAT. At 110 DAT, the highest yield was found from BARI Tomato-15, along with T_2(0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest yield was found from BARI Tomato-16, at T_1 (control) treatment combination.

Kozlowski *et al.* (2011) resulted drought stress reduce plant growth. Sibomana and Aguyoh (2013) found similar findings. Ragab *et al*. (2007) found same result in different vegetables. Sultana et al. (2015) found potassium increase the tomato production, but excess fertilizer reduce production. Mazed, *et al.* (2015) resulted that application of potassium fertilizer increase the yield. Akand, *et al*. (2016) found similar findings in case of application of potassium and gibberellic acid. Quddus *et al*. (2019) reported that potassium increases mungbean yield. Akhter *et al*. (2010), Khan *et al*. (2005), Gupta and Senger (2000) who found increased tomato yield by increasing levels of potassium. Javaria *et al*. (2012) found an incremental increase yield by increasing levels of K. while Iqbal *et al.* (2011) found maximum yield found potassium application. Elmer *et al*., (2012) reported similar result.

Table 11. Interaction effects between drought with potassium levels and tomato varieties on total yield per plant

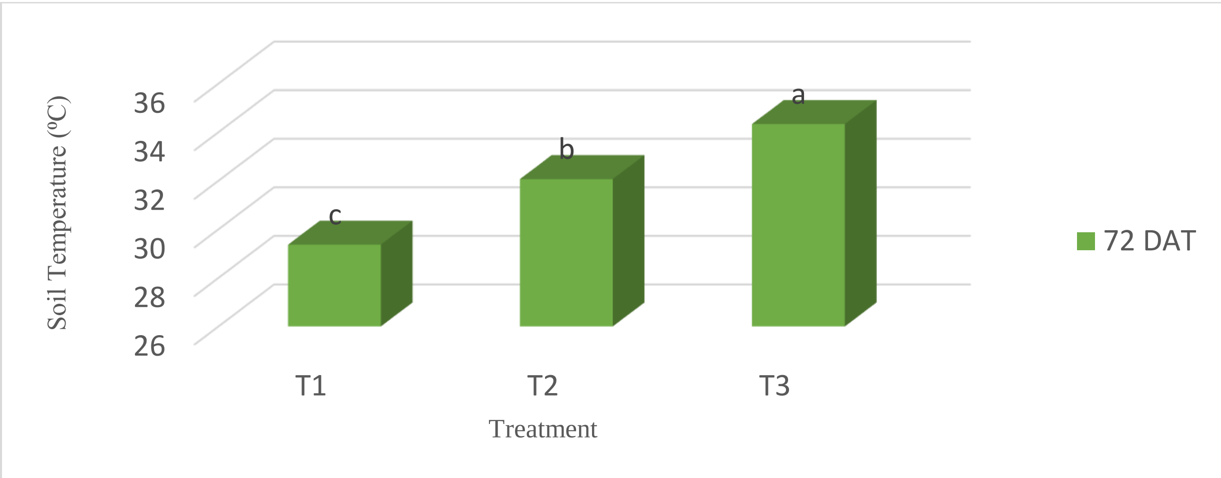
Treatment combinations	**Total yield per plant at days after transplanting**
	110
$T_1 \times V_1$	1.0967 e
$T_2 \times V_1$	1.4283 b
$T_3 \times V_1$	0.05697 f
$T_1 \times V_2$	1.2473 d
$T_2 \times V_2$	2.0787 a
$T_3 \times V_2$	0.5660 f
$T_1 \times V_3$	0.5120 f
$T_2 \times V_3$	1.3257 c
$T_3 \times V_3$	0.5310 f
CV (%)	4.29

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.12 Soil temperature (°C)

4.12.1 Effects of drought with potassium levels on soil temperature (°C)

Soil temperature is an important factor, it was measured by digital soil thermometer at morning. Soil temperature was measured on 72 DAT, and it was found statistically significant (P>0.05). Soil temperatures increased when drought condition and potassium level was increased. At 72 DAT, highest soil temperature (34.8˚ C) was obtained from T_3 (0.9g K/Pot +50 ml water/kg Soil) treatment and the lowest soil temperature (28.3˚ C) was recorded from T_1 (control) treatment.

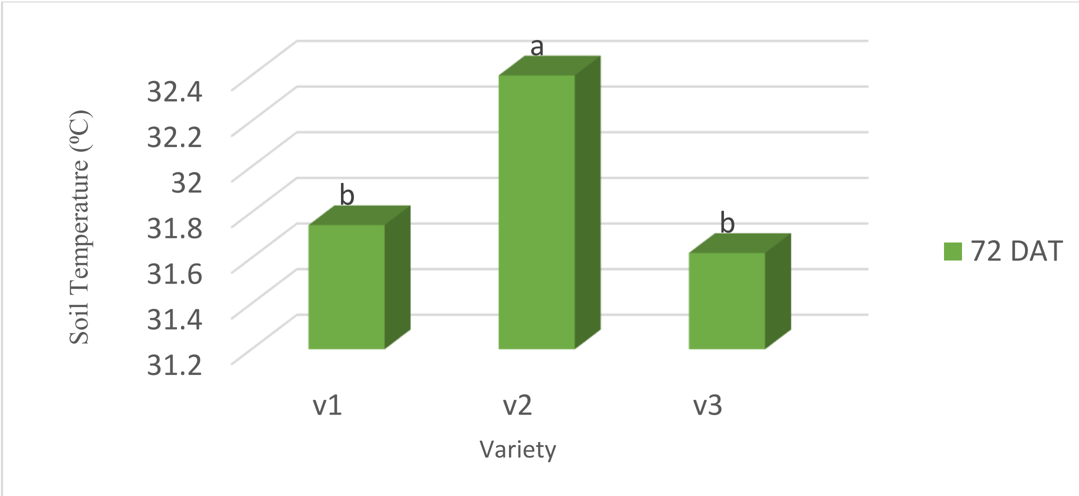


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure23. Effects of drought with potassium on soil temperature at days after transplanting

4.12.2 Varietal effects on Soil temperature

Effects of drought and potassium on different genotype was statistically significant (P>0.05) at 72 DAT. At 72 DAT, highest soil temperature (34.8˚ C) was recorded from BARI Tomato 15, The lowest soil temperature (28.3˚ C) was recorded from BARI Tomato 16.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 24. Varietal effects on Soil temperature at days after transplanting

4.12.3 Interaction effects of drought with potassium levels and tomato varieties on soil temperature (˚ C)

The interaction effect on soil temperature between varieties and drought condition with different dose of potassium was found significant at 72 DAT. At 72 DAT, the highest soil temperature (34.8˚ C) was found from BARI Tomato 2 with T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination. The lowest soil temperature (28.3˚ C) was found from BARI Tomato 2 at T_1 (control) treatment combination (Table 6).

In the drought condition soil temperature was increased. When the temperature is greater than the optimum, plants suffer from high temperature stress. Extreme temperatures disrupted various biochemical reactions and the plant metabolism, (Hasanuzzaman, *et al.*, 2013) Nutrient management is one of the best options for extreme temperature stress tolerance, and among all the nutrients, K plays a significant role in coping with temperature stress. Potassium helps to activate the various physiological and metabolic processes. Potassium may work as an osmolyte, and it helps to maintain stomatal conductance to prevent damage (Azedo-Silva, *et al.*, 2004).

Table 12. Interaction effects between drought with potassium levels and tomato varieties on soil temperature

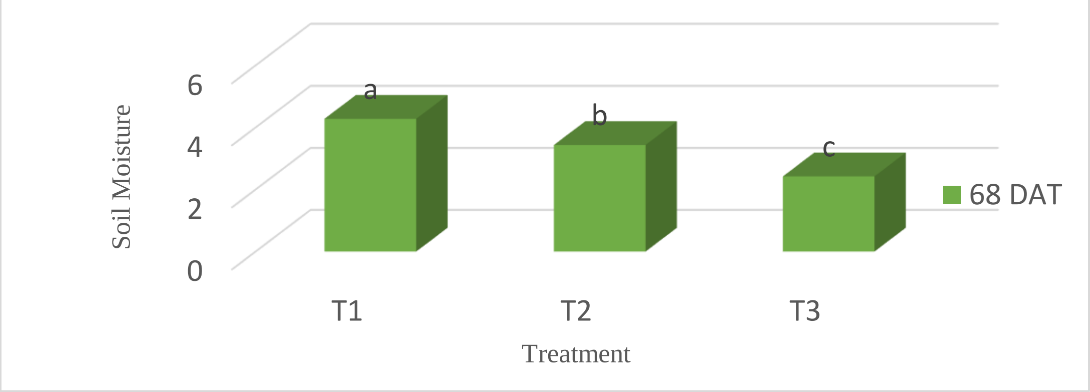
Treatment combinations	Soil temperature (° C) at days after transplanting (DAT)
	72
$T_1 \times V_1$	28.30 h
$T_2 \times V_1$	32.26 d
$T_3 \times V_1$	34.66 a
$T_1 \times V_2$	30.40 f
$T_2 \times V_2$	32.46 d
$T_3 \times V_2$	34.33 b
$T_1 \times V_3$	29.40 g
$T_2 \times V_3$	31.46 e
$T_3 \times V_3$	34.00 c
CV (%)	0.58

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.13 Soil moisture content

4.13.1 Effects of drought with potassium levels on soil moisture

Soil moisture content was measured by moisture meter on 68 DAT and it was statistically significant (P>0.05). Soil moisture content decreased with increasing of drought condition and potassium level. At 68 DAT, highest soil moisture (4.4) was obtained from T_1 (control) treatment condition. The lowest soil moisture (2.1) was recorded from T_3 treatment (0.9g K /Pot +50 ml water/kg Soil).

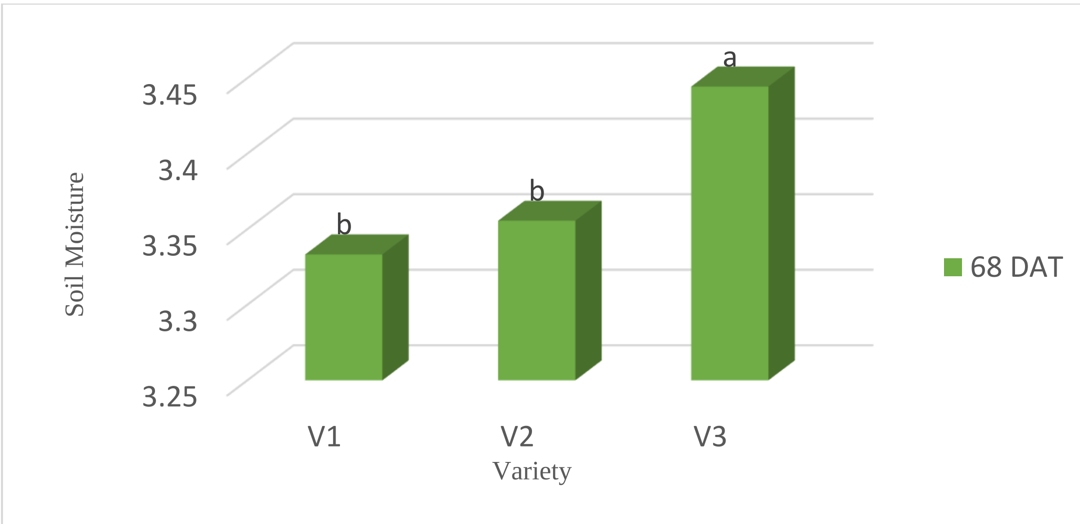


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure25. Effect of drought with potassium levels on soil moisture at days after transplanting

4.13.2 Varietal effect on Soil moisture

Effects of drought and potassium on different genotype was statistically significant (P>0.05) at 68 DAT. At 68 DAT, the highest and the lowest soil moisture (4.4, 2.1) was recorded from BARI Tomato 16 and BARI Tomato 2.



Here V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16
Figure 26. Varietal effect on Soil moisture at days after transplanting

4.13.3 Interaction effects of drought with potassium levels and varieties on soil moisture

The interaction effect on soil moisture between varieties and drought condition with potassium levels was found significant at 68 DAT. At 68 DAT, the highest soil moisture (4.4) was found from BARI Tomato 2 with T_1 (control) treatment combination, lowest soil moisture (2.1) was found from BARI Tomato 16 at T_3 (0.9g K/Pot +50 ml water/kg Soil) treatment combination (Table 7).

Soil moisture content was observed in plant causes low water availability and physical limitations in plants. Stomata are plant cells that control movement of water, carbon dioxide, and oxygen into the plant. During moisture stress, stomata are closed to conserve water. (Hatem, *et al.*, 2006). that excessive and insufficient soil moisture had negative effects on tomato yield, while increasing soil moisture during the last stages could significantly promote tomato yield (Chen, *et al.*, 2015). Additionally, soil water deficit during flowering and yield formation stages sharply reduces the marketable yield of tomato (Kuşc, *et al.*, 2014 and Gunter, 2005). Similar findings found in this experiment K treatments at low soil moisture significantly decreased tomato yield. Hernandez and Aarmenta (1985) found that reduced soil moisture restricts the vegetative and reproductive growth that leads to fewer cluster production per plant.

Table 13. Interaction effects between drought with potassium levels and tomato varieties on soil moisture

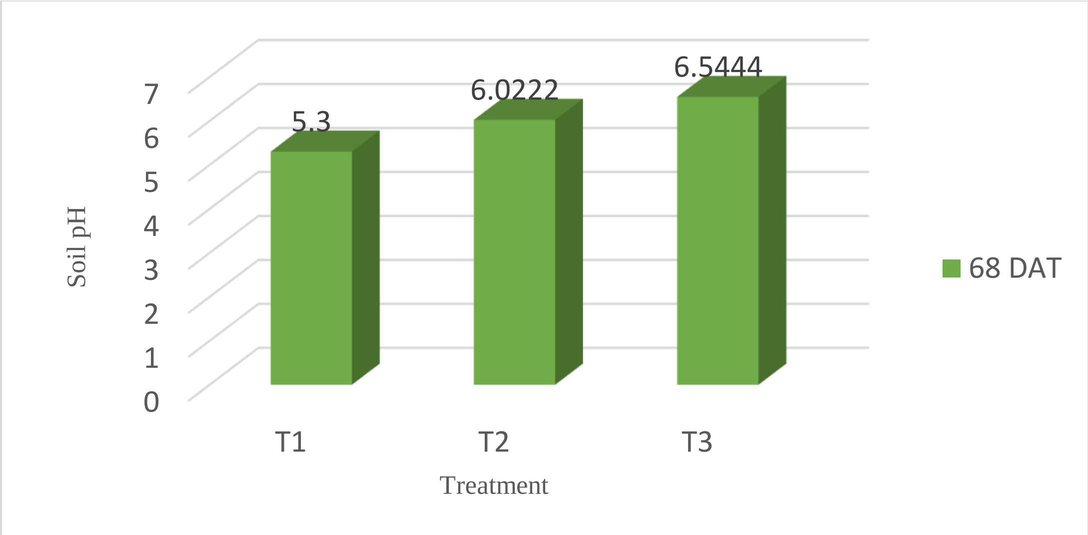
Treatment combinations	**Soil Moisture Content at days after transplanting (DAT)**
	68
$T_1 \times V_1$	4.40 a
$T_2 \times V_1$	3.46 d
$T_3 \times V_1$	2.13 h
$T_1 \times V_2$	4.06 b
$T_2 \times V_2$	3.20 e
$T_3 \times V_2$	2.80 f
$T_1 \times V_3$	4.36 ab
$T_2 \times V_3$	3.63 c
$T_3 \times V_3$	2.33 g
CV (%)	2.23

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

4.14 Soil pH

4.14.1 Effects of drought with potassium levels on soil pH

Soil pH content was measured with pH meter on 68 DAT. Effects of drought with potassium on soil pH content statistically significant (P>0.05). Soil pH content increase when drought condition and potassium level was increased. Soils can be naturally acid or alkaline, and this can be measured by testing their pH value. Having the correct pH is important for healthy plant growth. At 68 DAT, highest soil pH (6.4) was obtained from T_3 (0.9g K/Pot +50 ml water/kg Soil) treatment and the lowest soil pH (5) was recorded from T_1 (control) treatment.

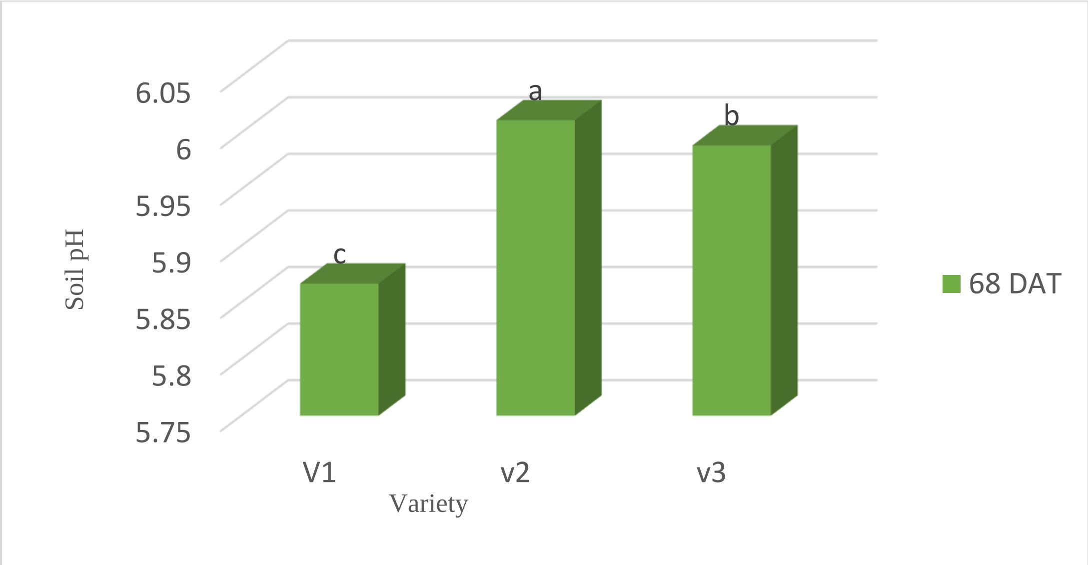


Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil)

Figure27. Effects of drought with potassium levels on soil pH at days after transplanting

4.14.2 Varietal effects on soil pH

Effects of drought with the potassium on different genotype statistically significant (P>0.05) at 68 DAT.At 68 DAT, highest soil pH (6.4) was recorded from BARI Tomato 15, The lowest soil pH (5) was recorded from BARI Tomato 2.



Here, V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

Figure 28. Varietal effects on Soil pH at days after transplanting

4.14.3 Interaction effects of drought with potassium levels and varieties on Soil pH

The interaction effect on soil pH between varieties and drought condition with potassium levels was found significant at 68 DAT. At 68 DAT, the highest soil pH (6.4) was found from BARI Tomato 16 with at T_3 (0.9g k/Pot +50 ml water/kg Soil) treatment combination. The lowest soil pH (5) was found from BARI Tomato 15 at T_1 (control) treatment.

Ghourab *et al*. (2000) stated that application of adequate K increases fruit weight by increasing of photosynthates to fruit and water use efficiency. At high Soil pH reduce the growth and yield of the plant.

Table 14. Interaction effects between drought with potassium levels and tomato varieties on Soil pH

Treatment combinations	**pH at days after transplanting (DAT)**
	68
$T_1 \times V_1$	5.46 e
$T_2 \times V_1$	6.06 c
$T_3 \times V_1$	6.43 b
$T_1 \times V_2$	5.03 f
$T_2 \times V_2$	6.13 c
$T_3 \times V_2$	6.50 b
$T_1 \times V_3$	5.40 e
$T_2 \times V_3$	5.86 d
$T_3 \times V_3$	6.70 a
CV (%)	1.31

Here, T_1=control condition, T_2= (0.4g K/pot+ 200 ml water/kg Soil), T_3 = (0.9g K/Pot+ 50ml water/kg Soil) and V_1 = BARI Tomato 2, V_2= BARI Tomato 15, V_3= BARI Tomato 16

CHAPTER 5

SUMMARY CONCLUSION AND RECOMMENDATIONS

SUMMARY

Drought is one of the major stress factors among the abiotic stresses. potassium (K) is one of the vital elements required for plant growth and physiology. The experiment was conducted at Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The two factors experiment was laid out in Randomized Complete Block Design (RCBD) with 3 replications. The factors are Factor A**:** Doses of K with drought condition control, (0. 4g k/pot + 200ml water/kg soil) and (0. 9 g k/pot + 50 ml water/kg soil).) and factor B: Tomato varieties (BARI Tomato 2, BARI Tomato 15 and BARI Tomato 16**.** The total treatment combinations were 9(3×3).

The data collected at difference days after transplanting. Data on different growth parameters, physiological parameters and yield with yield contributing characters of tomato were recorded. The analyses were done following the software STATISTIX 10. The significance of the difference among the means was evaluated by the Least Significant Difference Test (LSD) at 5% level of probability (Gomez and Gomez, 1984).

At 45, 60 and 85 DAT the tallest plant (40 cm, 52.5 cm, and 85.667 cm) was found from BARI Tomato 15 and BARI tomato 16 with T_2 (0.04g K/Pot+200ml water/kg soil) treatment combination. The shortest plant (33.000 cm, 47.000 cm, 76.333 cm) was found from BARI Tomato 16 and BARI Tomato 2 at T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination. At 35, 55 and 80 DAT, the highest plant branch (6,7,9) was found from BARI Tomato 15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest branches per plant (3,3,4) was found from BARI Tomato 2 at T_3 (0.9g/pot + 50ml water/kg soil) treatment combination. At 45 and 65 DAT, the highest number of plant leaves (7 and 12) was found from BARI Tomato 2 and BARI Tomato-15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest leaves per plant (5 and 9) was found from BARI Tomato 16, at T_3(0.9g K/pot + 50ml water/kg soil) treatment combination

At 50 and DAT, the highest SPAD value (54.9 and 55) was found from BARI Tomato 2 with T_1 (control) treatment combination. The lowest SPAD value (37.7 and 47.7) was found from BARI Tomato 15 and BARI Tomato 16 at T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination. At 72 DAT, the highest soil temperature (34.8˚ C) was found from BARI Tomato 2 with T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination. The lowest soil temperature (28.3˚ C) was found from BARI Tomato 2 at T_1 (control) treatment combination. At 68 DAT, the highest soil moisture (4.4) was found from BARI Tomato 2 with T_1 (control) treatment combination, and the lowest soil moisture (2.1) was found from BARI Tomato 16 at T_3 (0.9g K/Pot +50 ml water/kg Soil) treatment combination. At 68 DAT, the highest soil pH (6.4) was found from BARI Tomato 16 with at T_3 (0.9g K/Pot +50 ml water/kg Soil) treatment combination. The lowest soil pH (5) was found from BARI Tomato 15 at control treatment combination.

At 70 DAT, the highest number of flowers per plant was found from BARI Tomato 15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest of flowers per plant was found from BARI Tomato 16 at T_1 (control) treatment combination. At 70 DAT, the highest number of clusters per plant was found from BARI Tomato 15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest of cluster per plant was found from BARI Tomato 16 at T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination. At 85 DAT, the highest number of fruits per plant was found from BARI Tomato 15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest of fruit per plant was found from BARI Tomato 16 at T_3 (0.9g K/pot + 50ml water/kg soil) treatment combination. At 100 DAT, the highest fruit weight was found from BARI Tomato 15 with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest fruit weight was found from BARI Tomato 16 at T_1 control treatment combination. At 100 DAT, the highest fruit length was found from BARI Tomato 15, along with T_2 (0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest fruit length was found from BARI Tomato 2, at control treatment combination. At 100 DAT, the highest fruit diameter was found from BARI Tomato 2, along with control treatment combination. The lowest fruit diameter was found from BARI Tomato 16, at T_3 (0.9g K/Pot+50ml water/kg soil) treatment combination.

At 110 DAT, the highest yield was found from BARI Tomato 15, along with T_2(0.4g K/Pot+200ml water/kg soil) treatment combination. The lowest yield was found from BARI Tomato 16, at T_1 (control) treatment combination.

CONCLUSION

Tomato is one of the important vegetable crops of Bangladesh and it is very sensitive to drought stress. Potassium (K) is one of the vital elements required for plant growth and physiology. Use of potassium in drought condition improve the yield of tomato.

- The morphological growth, physiological and yield component, BARI tomato 15 showed the best performance than BARI Tomato 2 and BARI tomato 16.
- Highest yield found in application of T_2 (0.4g K/Pot+200ml water/kg soil) treatment than T_3(0.9g K/Pot+50ml water/kg soil) treatment.
- The tallest plant, highest number of branches per plant, height number of leaves per plant were found from BARI Tomato 15 with T_2 (0.04g K/Pot+200ml Water/Kg soil) treatment combination. Highest SPAD value was found from BARI Tomato 15 with T_1 (control) treatment combination. Highest number of flowers was found from BARI tomato 15 with T_2 (0.04g K/Pot+200ml Water/Kg soil) treatment combination.

RECOMMENDATIONS

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

- Drought tolerant variety and more levels of potassium should be used in future.
- Furthermore, growth and yield based research on this similar topic should be done in future to get more accurate results.
- More research on physiological, biochemical and molecular mechanisms of drought tolerance should be undertaken.

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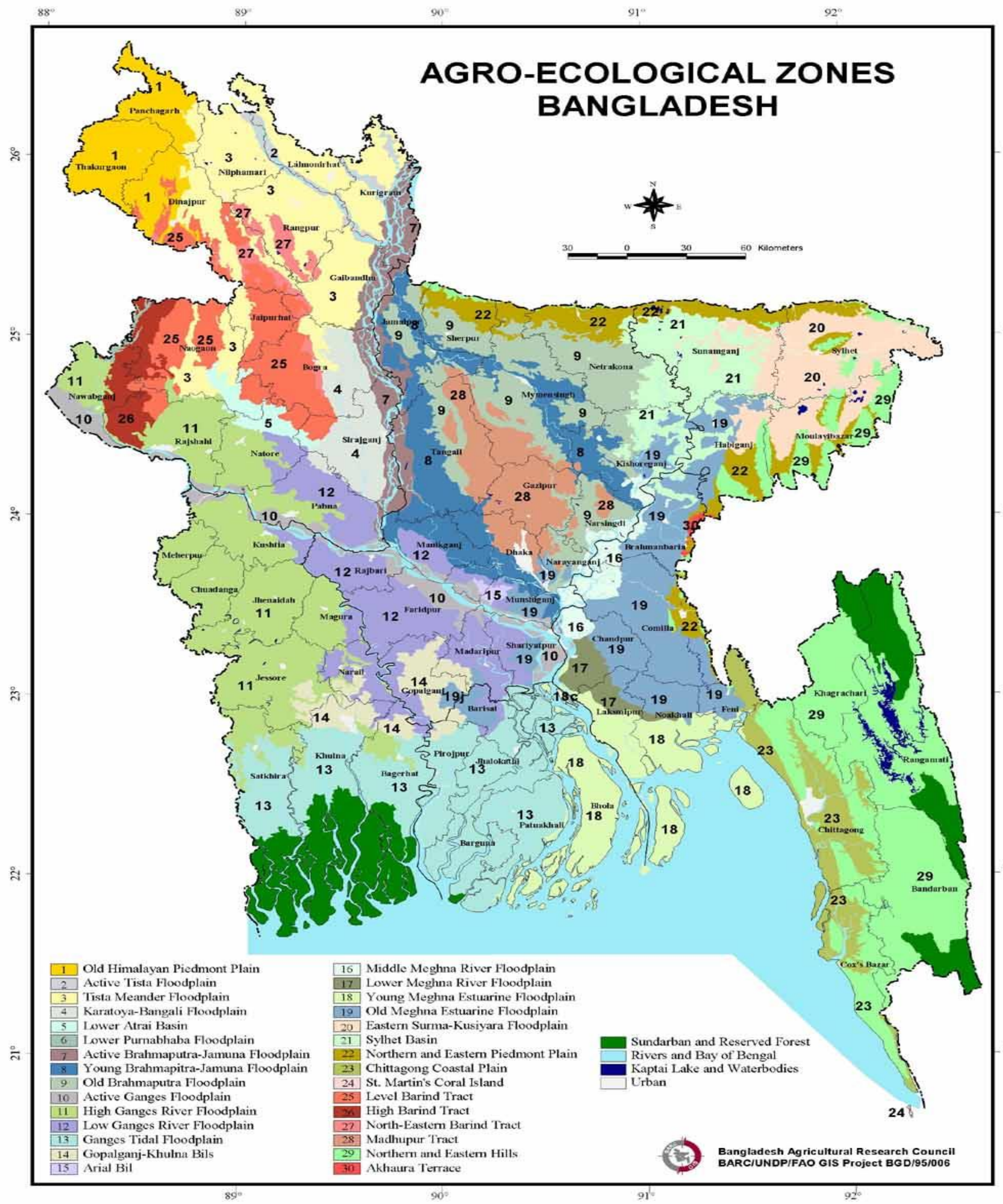
APPENDICES

Appendix I. Experimental location on the map of agro-ecological zones of Bangladesh



Map showing the experimental site under the study

Appendix 2. 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 3. Factorial ANOVA Table for all the growth and yield parameters of tomato varieties under different treatment

Factorial ANOVA Table for Plant Height in 45 days

Source	DF	SS	MS	F	P
Replication	2	0.519	0.2593		
variety	2	68.963	34.4815	372.40	0.0000
treatment	2	50.074	25.0370	270.40	0.0000
variety*treatment	4	31.926	7.9815	86.20	0.0000
Error	16	1.481	0.0926		
Total	26	152.963			

Grand Mean 36.963

CV 0.82

Factorial ANOVA Table for Plant height in 60 days

Source	DF	SS	MS	F	P
Replication	2	0.0185	0.0093		
variety	2	3.8519	1.9259	20.80	0.0000
treatment	2	79.4630	39.7315	429.10	0.0000
variety*treatment	4	7.9259	1.9815	21.40	0.0000
Error	16	1.4815	0.0926		
total	26	92.7407			

Grand Mean 50.019

CV 0.61

Factorial ANOVA Table for Plant Height in 85 days

Source	DF	SS	MS	F	P
Replication	2	1.556	0.7778		
variety	2	2.000	1.0000	9.00	0.0024
treatment	2	168.222	84.1111	757.00	0.0000
variety*treatment	4	39.111	9.7778	88.00	0.0000
Error	16	1.778	0.1111		
total	26	212.667			

Grand Mean 80.778
CV 0.41

Factorial ANOVA Table for Number of branches in 35 Days

Source	DF	SS	MS	F	P
replication	2	0.5185	0.25926		
variety	2	12.5185	6.25926	35.58	0.0000
treatment	2	8.2963	4.14815	23.58	0.0000
variety*treatment	4	3.4815	0.87037	4.95	0.0087
Error	16	2.8148	0.17593		

Grand Mean 3.7037

CV 11.32

Factorial ANOVA Table for Number of branches in 55 days

Source	DF	SS	MS	F	P
replication	2	1.1852	0.59259		
variety	2	9.8519	4.92593	11.57	0.0008
treatment	2	9.8519	4.92593	11.57	0.0008
variety*treatment	4	8.3704	2.09259	4.91	0.0089
Error	16	6.8148	0.42593		

Grand Mean 4.8148

CV 13.55

Factorial ANOVA Table for Number of branches in 80 days

Source	DF	SS	MS	F	P
replication	2	3.8519	1.92593		
variety	2	11.1852	5.59259	10.15	0.0014
treatment	2	18.9630	9.48148	17.21	0.0001
variety*treatment	4	10.3704	2.59259	4.71	0.0106
Error	16	8.8148	0.55093		

Grand Mean 5.2593

CV 14.11

Factorial ANOVA Table for Number of leaves per plant in 45 days

Source	DF	SS	MS	F	P
Replication	2	0.07407	0.03704		
variety	2	0.51852	0.25926	0.79	0.4713
treatment	2	1.18519	0.59259	1.80	0.1967
variety*treatment	4	0.14815	0.03704	0.11	0.9762
Error	16	5.25926	0.32870		
Total	26	7.18519			

Grand Mean 6.2593

CV 9.16

Factorial ANOVA Table for Number of leaves per plant in 65 days

Source	DF	SS	MS	F	P
Replication	2	1.5556	0.77778		
variety	2	2.6667	1.33333	4.80	0.0233
treatment	2	12.6667	6.33333	22.80	0.0000
variety*treatment	4	1.3333	0.33333	1.20	0.3489
Error	16	4.4444	0.27778		
Total	26	22.6667			

Grand Mean 10.111

CV 5.21

Factorial ANOVA Table SPAD Values in 50 days

Source	DF	SS	MS	F	P
Replication	2	0.316	0.158		
variety	2	13.123	6.561	18.73	0.0001
treatment	2	587.850	293.925	839.23	0.0000
variety*treatment	4	102.450	25.613	73.13	0.0000
Error	16	5.604	0.350		
Total	26	709.343			

Grand Mean 44.463

CV 1.33

Factorial ANOVA Table for SPAD Values in 70 days

Source	DF	SS	MS	F	P
Replication	2	1.001	0.500		
variety	2	4.045	2.023	5.86	0.0123
treatment	2	206.045	103.023	298.66	0.0000
variety*treatment	4	27.235	6.809	19.74	0.0000
Error	16	5.519	0.345		
Total	26	243.845			

Grand Mean 49.241

CV 1.19

Factorial ANOVA Table for Soil temperature (˚ C) in 72 days

Source	DF	SS	MS	F	P
replication	2	0.642	0.3211		
variety	2	3.149	1.5744	45.71	0.0000
treatment	2	111.287	55.6433	1615.45	0.0000
variety*treatment	4	5.818	1.4544	42.23	0.0000
Error	16	0.551	0.0344		
Total	26	121.447			

Grand Mean 31.922
CV 0.58

Factorial ANOVA Table for Soil Moisture Content in 68 days

Source	DF	SS	MS	F	P
replication	2	0.0089	0.00444		
variety	2	0.0622	0.03111	5.46	0.0155
treatment	2	15.5356	7.76778	1364.10	0.0000
variety*treatment	4	1.1289	0.28222	49.56	0.0000
Error	16	0.0911	0.00569		
Total	26	16.8267			

Grand Mean 3.3778

CV 2.23

Factorial ANOVA Table for Soil pH in 68 days

Source	DF	SS	MS	F	P
replication	2	0.00222	0.00111		
variety	2	0.10889	0.05444	8.91	0.0025
treatment	2	7.02889	3.51444	575.09	0.0000
variety*treatment	4	0.44889	0.11222	18.36	0.0000
Error	16	0.09778	0.00611		
Total	26	7.68667			

Grand Mean 5.9556

CV 1.31

Factorial ANOVA Table for Number of flowers per plant in 70 days

Source	DF	SS	MS	F	P
Replication	2	5.85	2.926		
variety	2	515.63	257.815	143.16	0.0000
treatment	2	823.41	411.704	228.61	0.0000
variety*treatment	4	43.26	10.815	6.01	0.0038
Error	16	28.81	1.801		
Total	26	1416.96			

Grand Mean 47.963

CV 2.80

89

Factorial ANOVA Table for Number cluster per plant in 70 days

Source	DF	SS	MS	F	P
replication	2	0.2222	0.11111		
variety	2	10.8889	5.44444	28.00	0.0000
treatment	2	12.6667	6.33333	32.57	0.0000
variety*treatment	4	5.1111	1.27778	6.57	0.0025
Error	16	3.1111	0.19444		
Total	26	32.0000			

Grand Mean 7.6667

CV 5.75

Factorial ANOVA Table for Number of fruits per plant

Source	DF	SS	MS	F	P
replication	2	4.222	2.111		
variety	2	340.222	170.111	218.71	0.0000
treatment	2	593.556	296.778	381.57	0.0000
variety*treatment	4	46.222	11.556	14.86	0.0000
Error	16	12.444	0.778		
Total	26	996.667			

Grand Mean 22.778

CV 3.8

Factorial ANOVA Table for Fruit Weight.

Source	DF	SS	MS	F	P
Replication	2	2.667E-06	1.333E-06		
variety	2	2.389E-04	1.194E-04	59.72	0.0000
treatment	2	2.384E-03	1.192E-03	596.06	0.0000
variety*treatment	4	9.682E-04	2.421E-04	121.03	0.0000
Error	16	3.200E-05	2.000E-06		
Total	26	3.626E-03			

Grand Mean 0.0437

CV 3.24

Factorial ANOVA Table for Fruit length.

Source	DF	SS	MS	F	P
Replication	2	0.0674	0.03370		
variety	2	0.2274	0.11370	13.72	0.0003
treatment	2	10.9163	5.45815	658.64	0.0000
variety*treatment	4	0.1348	0.03370	4.07	0.0184
Error	16	0.1326	0.00829		
Total	26	11.4785			

Grand Mean 4.6926

CV 1.94

Factorial ANOVA Table for Fruit diameter.

Source	DF	SS	MS	F	P
Replication	2	0.01407	0.00704		
variety	2	0.07407	0.03704	5.59	0.0144
treatment	2	5.46074	2.73037	412.42	0.0000
variety*treatment	4	0.34593	0.08648	13.06	0.0001
Error	16	0.10593	0.00662		
Total	26	6.00074			

Grand Mean 3.5815

CV 2.27

Factorial ANOVA Table for Total yield per plant

Source	DF	SS	MS	F	P
Replication	2	0.01726	0.00863		
variety	2	1.16699	0.58350	293.90	0.0000
treatment	2	5.11509	2.55755	1288.22	0.0000
variety*treatment	4	0.74147	0.18537	93.37	0.0000
Error	16	0.03177	0.00199		
Total	26	7.07259			

Grand Mean 1.0395

CV 4.29

PLATES

Plates1. Transplanted plant

Plates 2. Flowering stage

Plate 3. Fruiting stage

Plate 4. Tagging

Plate 5. Watering the plants

Plate 6. Measurement of SPAD value of leaf

Plate 7. Measurement of soil P^H and soil moisture

Plate 8. Data collection

Plate 9. Measurement of fruit weight

Plate 10. Measurement of fruit height and diameter