EFFECT OF PLANT GROWTH REGULATORS ON GROWTH, YIELD AND QUALITY OF TOMATO UNDER DROUGHT STRESS

A Thesis

by

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JUNE, 2021

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A Thesis
Submitted to the Department of Horticulture
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
IN
HORTICULTURE
Semester: January-June, 2021

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CERTIFICATE

This is to certify that the thesis entitled, "EFFECT OF PLANT GROWTH REGULATORS ON GROWTH, YIELD AND QUALITY OF TOMATO UNDER DROUGHT STRESS " submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in the partial fulfillment of the requirements for the degree ofMASTER OF SCIENCE (M.S.) IN HORTICULTURE, embodies the result of a piece of bona fide research work carried out byMD. MIJANUR RAHMAN, Registration No. **14-05939** *under my supervision andguidance. No part of the thesis has been submitted for any other degree or diploma.*

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

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Dedicated to

My Beloved Parents

Who has always helped me and believed that I could do it

ACKNOWLEDGEMENTS

All praises are due to the Almighty "Allah" Who kindly enabled the author to complete the research work and the thesis leading to Master of Science (M.S.) in Horticulture.

The author feels proud to express his profound respect, deepest sense of gratitude, heartful appreciation to my venerable research supervisor Associate Professor ***Dr. Shormin Choudhury****, Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh for her constant inspiration, scholastic guidance and invaluable suggestions during the conduct of the research and for her constructive criticism and whole hearted cooperation during preparation of the thesis.*

The author express his heartfelt gratitude and indebtness to reverend co-supervisor, ***Prof. Dr. Md. Nazrul Ialam****, Department of Horticulture, Sher-e-Bangla AgriculturalUniversity, Dhaka for his constructive instruction, critical reviews and heartiest cooperation during preparation of the manuscript.*

The author also expresses his special thanks to Chairman, ***Prof. Dr. Khaleda Khatun****, Department of Horticulture, Sher-e-Bangla Agricultural University and thanks to all the teachers of the Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka for their help, valuable suggestions and encouragement during the period of study.*

The Author is also wish to acknowledge to the Farm Division of SAU and other staff of the Department of Horticulture for their co-operation in the implementation of research works.

The author is deeply indebted to his friends and well-wisher especially Sujauddaula Shaikat and Atikur Rahman Shaon for their kind help, constant inspiration, continuous co-operation and moral support which can never be forgotten.

The Author

EFFECT OF PLANT GROWTH REGULATORS ON GROWTH, YIELD AND QUALITY OF TOMATO UNDER DROUGHT STRESS

ABSTRACT

The experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka during October 2019 to February 2020 to find out the effects of plant growth regulators on tomato growth, yield and quality when subjected to drought stress. Two varieties of tomato namely BARI Tomato 2 and BARI Tomato14 were used in this experiment. The treatments i.e. T_0= Control (No water stress), T_1=Drought stress, T_2 =Drought + 100 ppm Indole Acetic Acid (IAA), T_3 =Drought + 100 ppm Abscisic Acid (ABA), T_4 = Drought + 100 ppm Salicylic Acid (SA) were used in this experiment. Twenty five days old, healthy and uniform seedlings were transplanted in plastic pot. Ten days after transplanting drought was imposed for three weeks. Ten days after transplanting treatments were also applied by hand sprayer. Three weeks after drought stress the plants were rewatered again. The results indicated that drought stress significantly reduced morphological, yield and quality parameters of tomato. The plant growth regulators effectively reduced the effects of drought stress. Among the plant growth regulators, IAA is the most suitable for mitigating drought stress and maintaining tomato growth, yield and fruit quality.

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LIST OF ACRONYMS

Full word	Abbreviations	Full word	Abbreviations
Agriculture	Agric.	Milliliter	mL
Agro-Ecological Zone	AEZ	Milliequivalents	Meqs
And others	*et al.*	Triple super phosphate	TSP
Applied	App.	Milligram(s)	mg
Bangladesh Bureau of Statistics	BBS	Millimeter	mm
Biology	Biol.	Mean sea level	MSL
Biotechnology	Biotechnol.	Metric ton	MT
Botany	Bot.	North	N
Centimeter	Cm	Nutrition	Nutr.
Cultivar	Cv.	Regulation	Regul.
Degree Celsius	°C	Research and Resource	Res.
Department	Dept.	Review	Rev.
Development	Dev.	Science	Sci.
Dry Flowables	DF	Silver nitrate	$AgNO_3$
East	E	Soil plant analysis development	SPAD
Editors	Eds.	Soil Resource Development Institute	SRDI
Completely Randomized Design	CRD	Technology	Technol.
Entomology	Entomol.	Tropical	Trop.
Environments	Environ.	Thailand	Thai.
Food and Agriculture Organization	FAO	United Kingdom	U.K.
Gram	g	University	Univ.
Horticulture	Hort.	United States of America	USA
International	Intl.	Wettable powder	WP
Journal	J.	Serial	Sl.
Kilogram	kg	Percentage	%
Least Significant Difference	LSD	Microgram	µ
Liter	L	Number	No.

CHAPTER I

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is belongs to Solanaceae family and one of the most popular vegetables. It is economically attractive due to its good yielding capacity in a short duration. It has a significant role in human nutrition because of its rich source of lycopene, minerals and vitamins such as ascorbic acid and B-carotene which are anti-oxidants and promote good health. Lycopene in tomato is a vital anti-oxidant that helps to fight against cancerous cell formation as well as other kind of health complications and diseases (Kumavat and Chaudhari, 2013). Nevertheless, it plays a vital role in providing a substantial quantity of vitamin C and A in human diet (Farooq *et al*., 2005). At present, tomato ranks third, next to potato and sweet potato, in terms of world vegetable production (FAO, 2012). The leading top ten tomato producer country in the world are China, India, United States, Turkey, Egypt, Iran, Italy, Spain, Brazil and Mexico (FAQ 2012). The world dedicated 4.8 million hectares in 2012 for tomato cultivation and the total production was about 161.8 million tons. Bangladesh produces 416 thousand tons of tomato from 28526 hectares of land, the average yield being 14.54 t ha^{-1} (BBS, 2021).

The productivity of crops is not increasing in parallel with the food demand due to changing environmental factors both biotic and abiotic. Various abiotic environmental stresses such as drought, high or low temperature, salinity, flooding, metal toxicity, etc. which pose serious threat to world agriculture. Drought stress is a major environmental cue impairing many physiological and metabolic processes in plants, which may lead to suppressing plant growth and development, reducing crop productivity or plant death. Drought reduces crop production on 25 % of arable land throughout the world (Farooq *et al*., 2009). Drought slows growth, induces stomatal closure, and therefore reduces photosynthesis (Nemeth *et al*., 2002). So, the main consequence of drought stress is decreased growth and development caused by reduced photosynthesis, a process in which plants combine water, carbon dioxide and light to make carbohydrates for energy. Across plant species drought imposes various physiological and biochemical limitations and adverse effects (Chaves and Oliveira, 2004; Wang *et al*., 2005). Drought stress elevates generation of reactive oxygen species (ROS), an effect common in plants exposed to most abiotic stresses (Foyer and Noctor, 2005).

Increased the accumulation of such ROS may lead to many deleterious effects like protein degradation, lipid peroxidation and pigment bleaching in tomato plants.

The alleviation of oxidative damage and increase resistance to environmental stresses, at critical growth stages of plant, are often correlated with an efficient antioxidative system, phytohormones such as auxins (IAA), abscisic acid (ABA), cytokinin (CTK), salicylic acid (SA), gibberellin (GA) and jasmonic acid (JA) could modulate the plant tolerance to drought stress. SA plays an essential role in preventing oxidative damage in plants by detoxifying super oxide radicals, produced as a result of stress (Khadary S.F.A, 2004).

In response to environmental stresses, endogenous ABA levels increase rapidly. activating specific signaling pathways and modifying gene expression levels (Brien *et al*., 2013). ABA also acts as an internal signal enabling plants to survive under adverse environmental conditions (Keskin *et al*., 2010). ABA treatment is beneficial before exposing the plants or tissues to adverse environmental conditions and making plants more tolerant to future stress exposure (Travagalia *et al.*, 2013).

Phytohormones such as IAA could modulate the plant's tolerance to drought stress. Studies confirmed the alleviation of drought stress in plants after the application of hormones (Akter *et al*., 2014). However, the changes of endogenous hormones were not illustrated. IAA regulates many processes during plant growth and development (Du *et al*., 2012). Recently, evidence indicates the possible link between IAA and other hormones (Li and Yan 2014), indicating the cross - talk among phytohormones might play a key role during plant stress response.

SA plays an important role in regulating a number of plant physiological processes such as photosynthesis, stomatal closure, ion uptake, inhibition of ethylene biosynthesis, transpiration and stress tolerance (Arfan *et al*., 2007). Exogenous application of SA also has been reported to modulate activities of intracellular antioxidant enzymes superoxide dismutase (SOD), peroxidase (POD) and increase plant tolerance to environmental stresses (Sakhabutdinova *et al*., 2004; Senaratna *et al*., 2000). SA shows protective effects against drought stress (Senaratna *et al*., 2000; Shakirova *et al*., 2003) on plants. When Tomato plants treated with SA increased their drought tolerance (Senaratna *et al.*, 2000). In cucumber and tomato, the fruit yield enhanced significantly when the plants were sprayed with lower concentrations of salicylic acid (Larque-Saavedra and Martin-Mex, 2007).

In recent years, some studies have indicated that salicylic acid can enhance the plant growth, yield and quality (Khodary, 2004). Salicylic acid, indole acetic acid and abscisic acid are nonhazardous and provide stress resistance via metabolic defense mechanisms, resulting in improved plant growth and yields. As a result, the current study was investigated under following objectives:

1. To determine the possible role of plant growth regulators on growth, yield and quality of tomato under drought stress

2. To find out the most suitable growth regulators that can mitigate drought stress and enhance growth and yield of tomato.

CHAPTER II

REVIEW OF LITERATURE

Drought is a great problem in the northern region of Bangladesh, where a vast area remains fallow due to lack of proper supply of irrigation water. The situation is becoming worst because of drastically lowering the water table. Tomato is one of the important vegetable crops in Bangladesh and other countries of the world and it has drawn attention by the researchers for it various way of consumptions and nutritional value. It can be cultivated to a wide range of climates ranging from tropics to within a few degree of the arctic circle. However, in spite of its broad cultivation area, production is hindered, facing in a varied biotic factor and abiotic stress conditions. Very limited research works have been conducted to adapt tomato crop in the drought prone area of Bangladesh. An attempt was made to effect of plant growth-regulators on growth, yield and quality of two tomato varieties under drought stressed condition. To facilitate the research works different literature have been reviewed in this chapter under the following sub-headings:

2.1 Effect of Varieties of Tomato

Maiti *et al*., (2014) observed 100 genotypes of tomato grown in poly house during summer for general morphological and anatomical characters of leaves of one hundred tomato genotypes and its possible relation with drought and heat stress tolerance and resistance to insects probably tospo virus resistance. There existed a lot of variability of leaf morphology and its anatomy. It is concluded that lines having thick leaves and medium to high density of trichomes, minimum wilting, high number of flowers, may be considered for heat stress and drought tolerance. Lines with high density of trichomes are probably tospo virus resistance which could be confirmed in rainy season in the field. Genotypes with open canopy, thick petiole and thick leaves expected to be drought resistance. Anatomically compact long palisade tissue and more number of collenchyma layers in petioles offer drought resistance. Five genotypes were selected for good pollen viability. More than thirty genotypes possessed high trichome density which may be expected for TLC and Tospo virus resistance. These lines may be evaluated for TLC and tospo virus resistance at hotspots. These lines are also expected to be tolerant to drought.

Parvej *et al*., (2010); Hazarika and Phookan, (2005) conducted an experiment in a covered poly house along with an open field (control) to compare the phenological development and production potentials of two tomato varieties viz. BARI Tomato 3 and Ratan under poly house and open field conditions. Photosynthetically active radiation inside the poly house was reduced by about 40% compared to the outside (i.e. open field) while air and soil temperatures were always remained higher. From December to February the mid-day air temperature under poly house and open field varied from 31.8 to 39.1ºC and 23.3 to 31.1ºC, respectively indicating about 8ºC higher air temperature inside poly house and during that time the average air temperature inside poly house was about 28ºC which was optimum for the growth and development of tomato plants. Relative humidity had opposite trends with that of air temperature i.e. it was lower inside the poly house as compared to open field. The above micro climatic variabilities inside poly house favored the growth and development of tomato plant through increased plant height, number of branches plant^{-1}, rate of leaf area expansion and leaf area index over the plants grown in open field. Flowering, fruit setting and fruit maturity in poly house plants were advanced by about 3, 4 and 5 days, respectively compared to the crop raised in open field condition. Poly housed plants had higher number of flower clusters per plant, flower clusters and flowers per plant, fruit clusters and fruits per plant and fruit length, fruit diameter, individual fruit weight, fruit weight per plant and fruit yield over open field condition. The fruit yield obtained from the poly house was 81 t/ha against 57 t/ha from the open field.

Mehraj *et al*., (2014) conducted an experiment at Horticultural farm of Sher-e-Bangla Agricultural University, Bangladesh for performance evaluation of twenty tomato cultivar coded from V_1-V_{20} cultivated in summer. Maximum plant height (116 cm) and number of leaves (147) were found from cultivar Mini Anindyo Red (V_8) and Hybrid Tomato US440 (V_{18}) respectively. Maximum chlorophyll content, days to flower bud appearance and days to flowering were observed from cultivar BARI Tomato 6 (V_{19}); 53.0% chlorophyll, 40.3 days to bud appearance and 46.7 days for flowering. Maximum number of flower bud/bunch (6.0) and fruit bunch^{-1} (1.2) were observed from cultivar BARI Tomato 11 (V_{20}) and Aran Chan Mini (V_{12}) respectively. Maximum number of branch plant^{-1} (5.7), number of bunch plant^{-1} (15.3), number of flower bud (129.7), number of flower plant^{-1} (108.3), number of flower bunch^{-1} (6.7), number of fruit plant^{-1} (6.7), fruit length (22.8 cm), fruit diameter (61.3 mm), fruit weight (100 gm), yield/plant (667.1 gm), yield plot^{-1} (6.7 kg) and calculated yield ha^{-1} (22.3) were found from cultivar Mini Chika (V_{10}). Thus, cultivar Mini Chika (V_{10}) was found to be suitable for cultivation in summer.

Naz *et al*., (2011) conducted an experiment in Battal Valley of District Mansehra, Pakistan, to study growth, yield and nutritional composition of six exotic cultivars of tomatoes. Data on days to flowering and maturity, yield, TSS, ascorbic acid and titratable acidity was subjected to statistical analysis. Cultivar 'Roma' took minimum days to flowering (37.7 days) followed by 'Rio Fuegd' (39.0 days). Cultivar 'Lyreka' matured in 65.0 days followed by 'Roma' which took 67.7 days whereas cultivar 'Yaqui' took 85.0 days. Cultivar 'Yaqui' out-yielded other cultivars with 11.22 followed by 'Avinash' (9.52 tons ha^{-1}). 'Roma' and 'Rio Grand' yielded lowest with 6.46 and 7.96 tons ha^{-1}, respectively. Maximum TSS was observed in cultivar 'Avinash' (5.5) followed by Yaqui (5.4%) whereas it was found minimum in Roma (4.9 %) cultivar. 'Lyreka' have the most abundant ascorbic acid of 16.03 mg/100gm followed by 'Rio Grand' (15.86 mg/100 gm). The highest titratable acidity was found in 'Yaqui' (0.389%) while 'Rio Grand' was the lowest (0.313 %) in this respect.

Hazarika and Phookan (2005) evaluated 27 tomato cultivars in relation to growth, yield and quality under plastic rain shelter during summer season. Out of all the 27 cultivars, Yash recorded the maximum yield of 1.76 kg per plant followed by Arka Ahuti and Arka Ashish. Yash also recorded the maximum plant height, branch number, fruit set percentage and yield per plant. The flowers per inflorescence were found highest in cultivar BT_1. On the other hand, Arka Ahuti recorded the highest retention of matured fruits. Regarding the quality parameters, no single cultivar was found to be excellent in all the qualitative parameters. A wide range of variation was observed in both physical and chemical constituents of the fruits. However, Pusa Ruby and Arka Shreshta recorded the maximum TSS content, whereas the maximum amount of ascorbic acid was recorded in DRD-8014.

Shamim *et al*., (2014) reported that drought is one of the most important abiotic stresses reducing crop growth and yield of tomato. Development of water stress tolerant cultivars through screening and selection is one the important strategy to overcome this problem. In the present study, seeds of 120 local and exotic lines of tomato were allowed to germinate at varying levels of polyethylene glycol (PEG8000) induced water stress (PEG8000 0, 2.5%, 5.0% and 7.5%) for two weeks. Increasing PEG concentrations in the growth medium (water stress) caused a consistent decrease in seed germination percentage and seedling growth of all tomato cultivars. Moreover, a significant amount of genetic variability was found in all attributes of 120 genotypes of tomato. All lines/cultivars of tomato were ranked on the basis of relative water stress tolerance using 13 morphometric traits and categorized in four groups (tolerant, moderately tolerant, moderately sensitive, and sensitive) through multivariate analysis. Of 120 lines; 18, 25, 29 and 48 lines were ranked as tolerant, moderately tolerant, moderately sensitive and sensitive respectively. The germination percentage or speeds of germination were not found as effective indicator of genotypic differences for water stress at the seedling stage. Moreover, degree of water stress tolerance at the germination and seedling growth stage did not maintain in all tomato lines. Thus, it is not certain whether such variation is detectable at the later vegetative or reproductive growth stages. This needs to be further investigated. Overall, lines 19905, 19906, LA0716, and LA0722 were found to be water stress tolerant at least at early growth stages.

2.2 Effect of drought stress

Drought stress during vegetative or early reproductive growth usually reduces yield by reducing the number of seeds, seed size and seed quality. To assess the effect of drought stress on seed yield, seed quality and growth of tomato, the experiment was conducted by Pervej *et al*., (2010) in green house in plastic pots at Pen-y-Fridd field station, University of Wales, Bangor, U.K. during 2003-2004. Tomato cv. “Moneymaker” was used as a test crop. There were four treatments i.e. early stress (when first truss has set the fruits), middle stress (when fruits in first truss were fully matured and started changing their color), late stress (when fruits on first truss were ripened fully), whereas in control no stress was imposed. Analysis of data regarding various attributes (fruit weight and shoot dry weight per plant, number of seeds per fruit, total number of seeds and seed weight per plant and vigour of seed) showed that drought stress had non-significant effect on vigour, quality and yield of tomato seed.

Plant height, number of leaves and number of fruits per plant showed significant results toward drought stress signifying drought effects on growth of tomato.

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

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

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

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

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

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

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

Afsana *et al*., (2017) The current piece study was conducted to find out the role of exogenous foliar application of salicylic acid (SA) and calcium (Ca^{2+}) on growth, reproductive behavior and yield of tomato. The single factor experiment was laid out in Factorial Design with three replications. At the experimental farm of Sher-e-Bangla Agricultural University, Dhaka, during the winter season of November 2013 to April 2014. BARI Tomato-15 was used as planting material. Six different treatments viz., A_0= 0 mM of SA and 0 mM Ca^{2+}, A_1= 0.25 mM SA and 0 mM Ca^{2+}, A_2= 0 mM SA and 5 mM Ca^{2+}, A_3 = 0.25 SA and 5 Ca^{2+}, A_4= 0 of SA and 10 Ca^{2+} and A_5 = 0.25 SA and 10 mM Ca^{2+} were applied in the morning at 15, 30 and 45 days after transplanting (DAT). Data of plant height, branch plant^{-1}, cluster plant^{-1}, flowers plant^{-1}, fruits plant^{-1}, fruit length (cm), fruit diameter (cm) and yield were recorded and analyzed forlogical interpretation. The morphological and yield contributing characters as well as yield of tomato were positively influenced with single and combined application salicylic acid (SA) and calcium (Ca^{2+}). Significant increase of plant height and number of leaves plant^{-1} at 20, 40 and 60 DAT were observed with the application of A_3 treatment. Application of A_3 treatment also showed significant influence on production of cluster plant-1 (20.44), flowers plant^{-1} (168.1), and fruits plant^{-1} (99.42) as well as fruit yield (72.57 t ha^{-1}). However, application of A_4 treatment failed to improve the morphological and yield contributing characters as well as yield of tomato over the A_0 treatment (control). Results suggests that combined application of SA and Ca^{2+} successfully increase the tomato fruit yield by altering the morphological and reproductive characters.

Javanmardi and Akbari (2016) reported that the most of the researches on Salicylic acid (SA) have focused on postharvest application or acquiring stress resistance, while studies on its effect on plant growth, secondary metabolites and fruit quality are limited. SA as foliar application (0, 150, 300 and 450 mg/L) at different plant growth stages on fruit yield, secondary metabolites and quality features of tomato (*Solanum lycopersicum* L. cv. Kardelen) under greenhouse conditions were evaluated. Thehighest fruit yield per plant (about 1.3-fold greater than control) was obtained from 300 mg/L SA when applied three weeks after fruit set. Comparing to control plants, the highest fruit firmness, 10 days prolonged storability, highest total phenolics (22.6 mg gallic acid equivalent per 100 g); and highest antioxidant activity (65.11) were observed when 450 mg/L SA applied at fruiting stage and 3 weeks later. An increasing pattern in ascorbic acid content was observed with increasing SA concentration irrespective to application time. The same concentration effect was observed in flavonoid content when plants treated at 3 weeks after fruiting. The highest effect of flavonoids on antioxidant activity was calculated using Pearson correlation (r=0.82). SA concentrations greater than 450 mg/L showed significantly adverse effects on all measured traits. The effect of exogenous SA on tomato plant depends on the developmental stage and SA concentrations tested. Improved fruit quality factors may happen in a certain concentration range, while over that may have negative or adverse effect.

Kazemi (2014) conducted experiment to study the effect of salicylic acid and methyl jasmonate as pre-harvest treatments on the tomato vegetative growth, yield and fruit quality. The experiment was completely randomized experimental design with four replications. These factors included salicylic acid in 2 levels (0.5 and 0.75 mmolL^{-1}) and methyl jasmonate in 3 levels (0.25, 0.5 and 0.75 mmolL^{-1}) applied on tomato. Results indicated that salicylic acid (0. 5 mmolL^{-1}) and methyl jasmonate (0.25 mmolL^{-1}) either alone or in combination (0.5 mmolL^{-1} SA+ 0.25 mmolL^{-1} MJ) increased vegetative and reproductive growth, yield and chlorophyll content. The application of salicylic acid (0. 5 mmolL^{-1}) alone significantly increased the leaves-NK content and dry weight and decreased the incidence of blossom-end rot, but methyl jasmonate application alone or in combination had not significant effect on blossom-end rot and leaves-NK content. The TSS, TA and vitamin C content of tomato fruit had significantly affected by the application of salicylic acid and methyl jasmonate either alone or in combination (0.5 $mmolL^{-1}$ SA+ 0.25 $mmolL^{-1}$ MJ). Application of salicylic acid with methyl jasmonate improved the yield contributing factors that resulted in significant increase in tomato fruit yield.

Javaheri *et al.*, (2014) studied the effects of salicylic acid on some quality characters of tomato different concentration of salicylic acid (10^{-2}, 10^{-4}, 10^{-6}, 10^{-8} molar and control) in seedling stage as foliar replication. Measured characters was including (number of panicle in a bush, yield, fruit number in panicle, fruit number in bush, fruit weight and fruit diameter). Obtained results of this study show that salicylic acid significantly affected number of panicle in a bush, yield, fruit number in panicle, fruit number in bush, fruit weight and fruit diameter. Among foliar application, the highest rate of tomato yield with mean of 3059.5 g obtained in SA_3 (SA at 10^{-6} M), highest numbers of panicle in tomato bushes with mean of 31.25 measured in SA_1 (SA at 10^{-2} M). Highest fruit number in panicle and highest fruit number in bush obtained by mean of 3.5 and 66.75 in SA_1 (SA at 10^{-2} M), respectively and minimum amount of all this characters was recorded in control treatment and the highest amount of fruit weight and also fruit diameter was measured in control treatment with mean of 61.50 g and 51.75 mm, respectively.

Falcioni *et al*., (2014) reported that the salicylic acid (SA) is an inducer of systemic acquired resistance (SAR) and could be a potential candidate in the control of plant virus diseases. In this study we assayed under controlled conditions the potential effect of three doses of exogenous SA treatment on tomato plants infected with Potato virus X (PVX) and measured their effects on different physiological parameters (gas exchange, stable isotopes, chlorophyll content), the activation of secondary metabolism, viral accumulation and induction of the expression of pathogenesis-related proteins (PRs) such as ß-1, 3-glucanase (PR_2) and chitinase (PR_3). SA treatment increased the expression of PR_2, the activity of phenylalanine ammonia lyase (PAL) and the concentration of antioxidant compounds at 7 days post-treatment. Earlier expression of PR_3 compared to PR_2 was observed. SA treatment delayed the detection of PVX by ELISA in uninoculated leaves of mechanically infected tomato plants. Although the effect of PVX infection on physiological parameters was weak, moderate SA treatments showed enhanced photosynthesis, particularly for infected plants. The results obtained confirm that SA promotes major changes in the inductionof resistance in tomato plants and suggest that treatment with exogenous SA could be considered to reduce the infections caused by PVX.

Bunger and Bangerth (1983) observed the effects of SA on tolerance of tomato seedlings to cold stress were studied, with the tomato seedlings at three-leaf stage treated with a series of concentration of salicylic acid (SA) (0.5, 2.0, and 4.0 mmol/L). The results showed that SA could enhance the tolerance of tomato seedlings to cold stress, with the most effective for the concentration of SA at 2.0 mmol/L. Compared to non-treated tomato seedlings with cold stress, the rate of electrolyte leakage of tomato seedlings could be detected in the leaves of tomato seedlings treated with the concentration of SA at 2.0 mmol/L for 4 days after cold stress, which was significantly lower than other ones. While malondialdehyde (MDA) had a least increase of 73.01%. The content of soluble sugar had a highest increase of 87.35%. Chlorophyll content had a decrease of 16.47%. Therefore, the results suggested that tolerance of tomato seedlings to cold stress could be increased after a pre-treatment with SA at concentration of 2.0 mmol/L.

Salem *et al.*, (2013) held three experiments (laboratory, field and pots) those were conducted at Giza Agric. Res. Station, ARC, Egypt, during the two successive summer seasons 2012 and 2013. Seed of teosinte variety (local) were primed in five concentrations of salicylic acid (0.4, 0.6, 0.8, 1.0 and 1.2 g/L) for 24 hours, as well as control with non-priming. The aims of this study was to determine the best level of salicylic acid of pre-sowing treatment for teosinte seeds to improve germination performance, germination speed, seedling characters, anti-oxidant enzyme activity and forage yield. A completely randomized design (CRD) at laboratory experiment, a randomized complete block design (RCBD) at field experiment and a split plot design at pot experiment with three replications were used. The results showed that seed priming with 0.6 g/L salicylic acid gave the highest germination speed, germination percentage, shoot and radical length and increased plant leaf area at pot experiment. And it increased fresh and dry forage yield fed, plant height, number of tillers plant, number of leaves plant and stem diameter of teosinte plants at the field experiment.

Kowalska and Smolen (2013) was conducted a study to evaluate the effect of an increased salt concentration in a nutrient solution and foliar application of salicylic acid and $KMnO_4$ (the latter causing oxidative stress) on the yield, fruit quality and nutritional status of tomato plants. Salinity stress was stimulated by elevating the electrical conductivity (EC) of a nutrient solution by a proportional increase in the content of all macro- and micronutrients. In 2009 - 2010, tomato plants were grown on rockwool, in a heated foil tunnel. The experiment included two sub-blocks with two EC levels (2.5 and 4.5 mS cm^{-1}). Within each sub-block, the following foliar application variants were distinguished: 1. control, without foliar application; 2. salicylic acid (SA); 3. SA/$KMnO_4$. In the SA/$KMnO_4$ combination, solutions of these compounds were applied alternately every 7 days. SA was applied in the concentration of 0.01%, while the concentration of $KMnO_4$ was 0.1%. Foliar treatments were conducted at 7-day intervals from the 3rd cluster flowering stage until ten days before the first harvesting of fruits. Irrespective of the EC of the nutrient solution, foliar application of SA as well as SA/$KMnO_4$ had no significant effect on the tomato yield, total acidity and dry matter or soluble sugar content in fruits. Neither did it affect significantly the mineral status of plants except for an increase in the Mn level induced by SA/$KMnO_4$. A significantly higher content of ascorbic acid together with a decreased content of phenolic compounds and free amino acids resulted from the foliar application of SA and SA/$KMnO_4$. Salicylic acid counteracted the oxidative stress caused by $KMnO_4$.

Kazemi (2014) conducted an experiment in order to study effect of salicylic acid and calcium foliar application on growth, yield and yield components of strawberry plants as a factorial in completely randomized experimental design with four replications. These factors included of salicylic acid in 3 levels (0.25, 0.5 and 0.75 mM) and calcium in 2 levels (2.5 and 5 mM) spray on strawberry. Results showed that salicylic acid (0.25 mM) and calcium chloride (2.5 mM) spray either alone or in combination (0.25 mM SA+ 2.5 mM Ca^{2+}) affected on vegetative and reproductive growth, significantly. Mean comparisons indicated yield, and quality of strawberry plants was improved in low salicylic acid and calcium chloride concentration. In Finally, salicylic acid and calcium chloride application can be helpful for yield improvement and prevent of decreasing yield.

Kowalska and Smolen (2013) completed an experiment aimed to investigate the effect of foliar application with salicylic acid (2 mM/L) alone or combined with chitosan

(0.1%) with or without TMV inoculation on improving resistance, growth, productivity and quality of tomato Hybrid Super Jackal F. as tomato (*Solanum lycopersicum* L.) plants are considered sensitive to tomato mosaic virus especiallyduring the reproductive growth phase. The 1 study was conducted in the Experimental Farm, Faculty of Agriculture, Ain Shams University, Shoubra Elkheima, Egypt, during the two growing summer seasons of 2012 and 2013. All inoculated plants with TMV after 14 and 30 days from foliar application with combination of salicylic acid and chitosan, exhibited symptoms later and less severe than the plants inoculated with TMV in the other treatments. The SA plus CH foliar application without TMV inoculation gave the highest significant values of vegetative growth in both seasons. Combination treatment of SA plus CH increased significantly N, P, K, Fe and Zn concentration. This treatment was also effective in increasing tomato yield compared with treatment of infection alone. Our results showed that SA or CH alone or combined significantly increased ascorbic acid concentration compared with control treatment.

Shahba *et al.*, (2010) stated that soil salinity is a serious environmental problem that has negative effect on plant growth, production and photosynthesis. Fresh and dry plant weights decrease with salinity treatments. The very important role of salicylic acid (SA) in response to different stress and modification and decline damages due to stresses has established in different studies. In this research tomato seeds planted in pots containing perlite in a growth chamber under controlled conditions of 27±2°c and 23±2°c temperature, 16h lightness and 8h darkness respectively, 15 Klux light intensity and 75% humidity; NaCl concentration of 0, 25, 50, 75 and 100 mM and salicylic acid concentration of 0, 0.5, 1 and 1.5 mM were used in the form of factorial experiment in a complete randomized design (CRD). Results show that germination was decreased with salinity increasing. At low levels of salinity, SA leads to decrease in germination and had no effect in high levels of salinity. The length of shoot was not affected by salinity but decrease with increase in SA concentration. Low salinity concentrations led to significant increase in root length and high concentrations don't have significant difference with control. SA also had no effect on it. The highest amount of a, b, c and total chlorophyll and carotenoid was show in 50 mM salinity levels.

Yildirim and Dursun (2008) was conducted the study to determine the effect of foliar salicylic acid (SA) applications on fruit quality, growth and yield of tomato under greenhouse conditions in 2006 and 2007. In the study, fruit diameter, fruit length, fruit weight, fruit number per plant, Vitamin C, pH, Total Soluble Solids (TSS), titratable acidity (TA), stem diameter, leaf dry matter ratio, chlorophyll content, early yield and total yield were determined. Tomato plants were treated with foliar SA applications at different concentrations (0.00, 0.25, 0.50 and 1.00 mM). SA was applied with spraying four times during the vegetation at 10-day intervals two weeks after planting. In the study, it was determined that foliar applications of SA showed positive effect on some fruit characteristics, plant growth, chlorophyll content in leaves, early yield and total yield. SA treatments had no effect on pH, AA and TA of tomato. Total soluble solid (TSS) increased with foliar SA applications. The greatest stem diameter, leaf dry matter and chlorophyll content were obtained from 0.50 mM SA treatment. SA treatments increased the early yield of tomato compared to the control. The yield of tomato was significantly influenced by foliar SA applications. The highest yield occurred in 0.50 mM SA treatment. According to our results, applications of 0.50 mM SA should be recommended in order to improve yield. Shakirova (2003) recorded enhanced germination and seedling growth in wheat, when the grains were subjected to pre-sowing seed-soaking treatment in salicylic acid.

Shahba *et al*., (2010) investigated the effect of various concentrations of salicylic acid (SA) on the growth, pigment content and the activity of antioxidants in the laboratory grown wheat plants. The root and shoot growth was affected at higher concentration of SA in early days of growth. The activities of catalase (CAT), ascorbate peroxidase (APX) and guaicol-specific peroxidase (POX) declined with the application of SA (50, 500 and 1000 μM), the decrease being more pronounced with the increase in SA concentrations both in the root and leaf tissues. On the other hand superoxide dismutase (SOD) activity increased with the application of SA. At low concentrations, SA has no effect on the activities of these enzymes in vitro. Salicylic acid at higher concentrations (5 and 10 mM) though inhibited CAT activity; the activities of APX and POX remain unchanged. High concentration of SA increased the level of H_2O_2 and malondialdehyde both in root and leaf tissues. Thus, SA though has been reported to be a signal molecule for inducing various physiological and morphological attributes in plants, this study indicated the negative effect of the compound on growth and the activity of major enzymatic antioxidants.

Hussein *et al*., (2007) conducted a pot experiment where they sprayed salicylic acid to the foliage of wheat plants, irrigated with Mediterranean sea water and reported an enhanced productivity due to an improvement in all growth characteristics including plant height, number and area of green leaves, stem diameter and dry weight of stem, leaves and of the plant as a whole. Moreover, the plants that received treatment with SA had more proline content.

Afsana *et al*., (2017) carried out an experiment to elucidate the effect of exogenously applied salicylic acid on growth, physiology and antioxidant activity of carrot plant. The results of their experiment revealed that salicylic acid significantly enhanced the overall growth, root dry mass, sulphur concentration, carotenoids and anthocyanin contents with a concomitant enhancement of total antioxidant activity of shoot and that of storage root. The SA application also regulated the proline accumulation both in shoot and storage root increased with the application of SA. At low concentrations, SA has no effect on the activities of these enzymes in vitro. Salicylic acid at higher concentrations (5 and 10 mM) though inhibited CAT activity; the activities of APX and POX remain unchanged. High concentration of SA increased the level of H_2O_2 and malondialdehyde both in root and leaf tissues. Thus, SA though has been reported to be a signal molecule for inducing various physiological and morphological attributes in plants, this study indicated the negative effect of the compound on growth and the activity of major enzymatic antioxidants.

When a plant is subjected to drought, there is an increase in ABA biosynthesis, leading to elevated ABA levels in the tissues (Plant *et al*., 1991). The increase in the ABA concentration in leaves results in stomatal closure and minimal water loss from the plant. However, the stomatal closure reduces photosynthesis (Zegzouti *et al*., 1997). High ABA concentration in root tips was observed in plants subjected to drought stress (-1.6 MPa) (Sharp and LeNoble, 2002). Singh *et al.,* (2005) studied the role of ABA in drought, using an ABA deficient tomato. In optimal growth conditions, ABA concentration in this mutant was 50% of the wild type plant. When both the wild type and mutant were exposed to drought stress, there was a significant increase in the synthesis of ABA in the wild type but reduced in the mutant. It was recorded that the ABA concentration of the mutant under drought stress was 6% of its ABA concentration grown under optimal conditions.

The use of abscisic acid (ABA) in agriculture has increased in the last few years due to the increase in ABA commercial availability at lower costs by Balate *et al*., 2020. The objective of this study was to determine the effect of exogenous ABA on tomato fruit quality parameters such as soluble solids (SS), total and soluble pectins, titratable acidity (TA) and flesh firmness. Tomatoes from the cultivar 'Santa Clara' were the study followed a complete randomized block desig, with four treatments in five repetitions. The treatments were plants not treated with ABA (control), foliar sprayed with ABA at 500 mg L-1, 150 mL drench with ABA at 500 mg L-1, or foliar plus drench treated with ABA. After harvesting, the physicochemical characteristics of the fruits were evaluated in the laboratory. All treatments were weekly applied to the plants from anthesis to harvest at fully maturity. Root treatment increased SS by up to 26.12%, increased ratio SS/TA, firmness and decreased soluble pectin. According to the results, it can be concluded that the application of ABA to leaves and roots can improve fruit quality by increasing the SS, ratio SS/TA. The method of application affects the SS content.

Singh *et al*., (2005) carried out an investigation to see the effects of different doses of PGRs (control, 25 or 75 ppm IAA, and 25 or 75 ppm NAA) and micronutrient (control, 2500 ppm Multiplex or 2000 ppm Humaur) mixtures and their interactions on plant growth, number of branches and yield of tomato at 35 and 70 days after transplanting (DAT). Plant growth was not affected significantly by any treatment and interaction, although the effect of P_1 (25 ppm IAA) x M_2 (Humaur) interaction was better in increasing the plant growth at 75 DAT. The number of branches was significantly and highly increased by the application of 75 ppm IAA and 25 ppm NAA. The initiation time of first flowering and first fruiting was significantly and highly increased by the interaction {4(75 ppm NAA) x M_2 (Humaur). Application of 35 ppm IAA and 2000 ppm Humaru was significantly increased the tomato yield. P_4 (75 ppm NAA) x M_2 (2000 ppm Humaur) was also significantly increased the yield. It can be concluded that addition of PGR and micronutrient in tomato is useful for better produciton.

Djanaguiraman *et al*., (2004) conducted an experiment where the plants were with four different concentrations of Nitrophenols (ATONIK) at flowering and fruit setting stage. Observatios were recorded in the flowers and developing fruits. Application of nitrophenols significantly increased the activity of antioxidant enzymes namely superoxide dismutase (SOD), catalase CAT), peroxidase (POX) and auxin content coupled with decreased activity of polyphenol oxidase [catechol oxidase] (PPO) and IAA oxidase (IAAO) enzymes over the control significantly. Among the concentrations, experimented, application of nitrophenols at 0.4% during fruit set stage was found to be the most effective in recording high antioxidant enzymes activity and auxin level which was reflected in an increased number of fruit clusters per plant, fertility coefficient and yield of tomato.

CHAPTER III

MATERIALS AND METHOD

The experiment was conducted during the period from October 2019 to February 2020 to study the effect of plant growth-regulators on growth, yield and quality of two tomato varieties under drought stressed condition. The materials and methods that were used for conducting the experiment have been presented in this chapter. It includes a short description of the location of experimental site, soil and climate condition of the experimental area, materials used for the experiment, design of the experiment, data collection and data analysis procedure.

3.1 Experimental site

The experiment was conducted at the Horticulture farm of Sher-e-Bangla Agricultural University, Dhaka, during the period from October 2019 to February 2020. The location of the site in 23°74" N latitude and 90°35" E longitude with an elevation of 8.2 meter from sea level.

3.2 Climate

The experimental site is located in subtropical region where climate is characterized by heavy rain fall during the months from April to September (Kharif season) and scanty rain fall during rest of the month (Rabi season). The maximum and minimum temperature, humidity rainfall and temperature during the study period are collected from the Sher-e-Bangla Mini weather station.

3.2 Characteristics of soil that used in pot

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

3.4 Plant Materials

The tomato varieties used in the experiment were BARI Tomato 2 and BARI Tomato 14. The seeds were collected from Horticultural Research Centre (HRC), Bangladesh Agricultural Research Institute (BARI), Gazipur.

3.5 Seed bed preparation

Tomato seedlings were raised in the seedbed situated on a relatively high land at Horticulture Farm of Sher-e-Bangla Agricultural University, Dhaka. The size of the seedbed was 3 m x l m.

The soil was well prepared with the help of spade and made into loose friable and dried mass to obtain fine tilth. All weeds and stubbles were removed and 5 kg well rotten cowdung was applied during seedbed preparation. The seeds were sown in a depth of about 0.6 cm. Heptachlor 40 WP was applied @ 4 kg/ha around each seedbed as precautionary measure against ants and worm. The emergence of the seedlings took place within 5 to 6 days after sowing. Weeding, mulching and irrigation were done from time to time as and when required and no chemical fertilizer was used in the seedbed.

3.6 Growing conditions and transplanting of seedlings

The experiment was carried out using two tomato varieties in a shed house at Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh, under natural lighting conditions. Healthy and uniform seedlings (25 days old) were transplanted in the experimental pots (1 seedling/pot), filled with soil, and recommended doses of fertilizer.

3.7 Experimental design, treatments and sample collection

The experiment was laid out in completely randomized design (CRD) with four replications of each treatment. Several treatments were made to evaluate the effects of growth regulators under drought stress. T_0= Control (no stress), T_1=Drought stress, T_2 =Drought + 100 ppm Indol Acetic Acid (IAA), T_3 =Drought + 100 ppm Abscisic Acid (ABA), T_4 = Drought + 100 ppm Salicylic Acid (SA).

Two varieties of tomato namely BARI Tomato 2 and BARI Tomato14 were grown under poly house under natural lighting conditions. 25 days old seedlings (3-4 leaf stage) were transplanted in 10 L pots, filled with soil and required amount of fertilizer. Drought was imposed for three weeks on 35-day-old seedlings (vegetative stage) and plant growth regulators were also applied to 35-day-old seedlings.Drought stress was applied for 3 weeks during vegetative stage stage until the soil moisture content dropped to 25-30%. During the day of drought induction, the growth regulators SA, IAA and ABA were applied as a foliar spray at a concentration of 100 ppm.

Soil moisture (%) was determined before and after induction of drought.

$$\%Soil\ moisture = \frac{\textbf{Freash weight of soil – dry weight of soil}}{\textbf{Dry weight of soil}} \times 100$$

All morphological and physiological parameters were measured three weeks after the water was stopped. Fruit yield and quality parameters were recorded during harvesting.

3.8 Intercultural Operations

After transplanting the seedlings, various kinds of intercultural operations were accomplished for better growth and development of the plants, which are as follow:

3.8.1 Weeding

Weeding was done whenever necessary to keep the crop free from weeds.

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3.8.2 Stem management

For proper growth and development of the plants the main stems were managed upward by hand and with the help of bamboo stick. So, the rainy and stormy weather could not damage the growing stems and fruits of the plants.

3.8.4 Plant protection

Tomato is a very sensitive plant to various insect pests and diseases. So, various protection measures were taken. Melathion 57 EC and Ripcord was applied @ 2 ml against the insect pests like beetle, fruit fly, fruit borer and other. The insecticide application was made fortnightly from 10 days after seed sowing to a week before first harvesting. During cloudy and hot weather precautionary measures against viral disease was taken by spraying. Furadan 5 G was also applied @ 6 g/pit during pit preparation as soil insecticide.

3.9 Morphological and physiological parameters

3.9.1 Plant height

Plant height was taken at three times and measured in centimeter from ground level to tip of the main stem from each plant of each treatment and mean value was calculated.

3.9.2 Number of leaves per plant

Total number of leaves was counted at three times from each plant of the treatment and mean value was calculated. The pruned leaves number was also included in counting.

3.9.3 Number of branches per plant

Total number of branches was counted at two times from each plant of the treatment and mean value was calculated. The pruned branches number was also included in counting.

3.9.4 Leaf area

Leaf area (LA) was determined from middle portion of plant by measuring length and breadth of leaf using scale at flowering stage.

3.9.5 Measuring of SPAD value

Leaf chlorophyll content was measured by using SPAD-502 plus Portable Chlorophyll meter. The chlorophyll content was measured from leaves stressed at different drought treatments from four different portion of the leaf and then averaged for analysis. Measuring of chlorophyll content by SPAD meter.

3.10 Yield and yield contribution parameters

3.10.1 Number of flower clusters per plant

Number of flower cluster per plant was counted from plant. Number of flower cluster per plant was recorded for each treatment.

3.10.2 Number of fruits per plant

Number of fruits was counted from first harvest stage to last harvest. The total number of fruits per plant was counted and average number of fruits was recorded.

3.10.3 Individual fruit weight (g)

Among the total number of fruits harvests during the period from first to final harvest, the fruits, except the first and last harvests, were considered for determining the individual fruit weight in gram (g).

3.10.4 Yield per plant (kg)

A per scale balance was used to take yield per plant. It was measured by total fruit of plant separately during the period from fruit to final harvest and was recorded in kilogram (kg).

3.15.2 Biochemical parameters

3.15.2.1 pH

pH was estimated using a phs-25 pH meter. An electrolytic cell consists of two electrodes (calomel electrode and glass electrode) was standardized with buffer solution of pH 4. Any known pH value may be used as buffer solution. Then the electrodes were suspended into the test sample. A voltage corresponding resembling to the pH of the solution was determined by the instrument. For preparing sample solution of fruits, tomatoes were chopped into small pieces and ground into a fine paste by mortar and pestle. The tomato juice was transferred into a test tube and the pH of the paste was determined by inserting the electrodes into the juice and stagnated readings were recorded.

3.15.2.2 Total soluble solid (TSS)

Total soluble solids content of tomato was evaluated by using hand refractometer. Two drop of tomato juice squeezed from the fruit pulp on the prism of the refractometer. Percent TSS was gained from direct reading of the instrument.

3.15.2.3 Ascorbic acid

Ascorbic acid content (ascorbic acid) was evaluated by using 2, 6-Dichlorophenol indophenols (DCPIP) visual titration method (Rangana, 2004). 5gm tomato fruit sample was blended, juice was filtered by sieve. Volume was made up to 100ml by adding oxalic acid.10ml from solution was taken in conical flask and titrated against DCPIP (Standard dye) to a pink end point which should retain for least 15 seconds. Ascorbic acid content in terms of mg/100g pulp weight was estimated using the following formula: Ascorbic acid (mg/100g) =

$$\frac{Titra \times dye\ factor \times volume\ made\ up}{Aliquot\ of\ extract\ taken\ for\ estimation \times wt.or\ vol.of\ sample\ taken\ for\ estimation} \times 100$$

5%oxalic acid solution preparation

It was made by liquefying 50g oxalic acid powder in 1000 ml distilled water.

Dye solution preparation:

It was prepared by dispersing 260 mg of the sodium salt of 2, 6-dichlorophenol indophenol in approximately 1000 ml of hot distilled water containing 210 mg of sodium bicarbonate.

Standardization of dye solution

Ten milliliters (10ml) of standard ascorbic acid solution was taken in a conical flask and 5ml of oxalic acid was added to it. A micro burette was placed with the dye solution. The quantity of the conical flask was titrated with dye solution. The content of conical flask was titrated with dye till the pink colored end point arrived. The milliliters of dye solution requisite to complete the titration were recorded. Dye factor was estimated using the following formula:

Dye factor = 0.5/ titrate value.

3.15.2.4 Lycopene determination

Absorption determination for lycopene content was estimated following the method of Alda et al. (2009) by using T60 UV-Visible Spectrophotometer. 1g tomato from each treatment was weighed into a conical flask.

Lycopene in the tomato was extracted using hexane: ethanol: acetone (2:1:1) (v/v). One ml juice of each sample were homogenized with 25ml hexane: 12.5ml ethanol: 12.5ml acetone which were then placed on electric shaker for 30 minutes. Then 10ml distilled water was added and agitated continuously for 2 min. The solution was then left to separate into two distinct polar and non-polar layers. The absorbance was measured at 472nm, using hexane as a blank in spectrophotometer. The lycopene concentration was a calculated using its extinction coefficient (E 1%1cm) of 3450 in hexane at 472nm. The lycopene concentration was expressed as mg/100g product.

At λ = 472nm: lycopene content (mg/100g) = $\frac{E}{3.45} . \frac{20}{m}$.

3.16 Statistical analysis

The recorded data on various parameters were statistically analyzed by using STATISTIX 10 statistical package programmed. The mean for all the treatments was calculated and analysis of variance for all the significant difference of the characters by least significant difference (LSD) test at the 5% level of probability according to Gomez and Gomes, (1984).

CHAPTER IV

RESULTS AND DISCUSSION

This chapter comprises the presentation and discussion of the results from the experiment. The experiment was conducted to determine theeffect of plant growth-regulators on growth, yield and quality of two tomato varieties under drought stressed condition. Some of the data have been presented and expressed in table and others in figure for ease of discussion, comparison and understanding. A summary of all the parameters have been shown in possible interpretation wherever necessary have given under the following headings:

4.1 Plant height (cm)

Plant height is one of the important parameters, which is positively correlated with the yield of tomato. The plant height was varied due to application of plant growth regulators (Fig. 1). During the present study, plant height was markedly decreased by drought stress in both tomato varieties such as BARI Tomato 2 and BARI Tomato 14. Under drought stress, significantly higher reduction of plant height in tomato varieties when subjected to low moisture levels (15-20%) which was supported (Nahar *et al*., 2011).

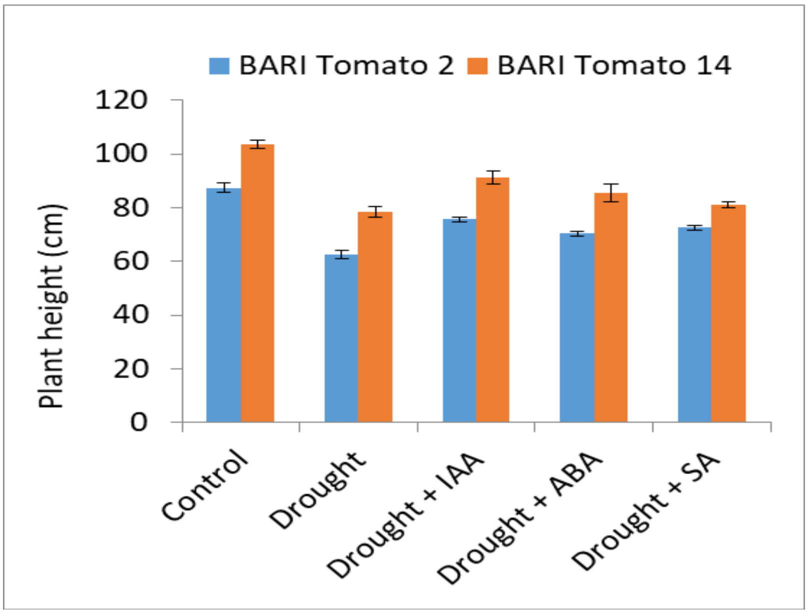

Figure 1: Effect of plant growth regulators on plant height (cm) in tomato varieties under drought stress condition

However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. Under drought stress, plant height (91.33 cm)was found in BARI Tomato 14 with application of IAA which was significantly different from other treatments; significantly ameliorated the adverse effect of drought stress on the plant height. These results are clearly in agreement with the substantial studies of Singh *et al*., (2005) and Zhao (2008).

4.2 Number of leavesplant^{-1}

A good number of leaves plant^{-1} indicated better growth and development of plants. The number of leaves plant^{-1} was varied due to application of plant growth regulators (Fig. 2). During the present study, plant height was markedly decreased by drought stress in both tomato varieties as BARI Tomato 2 and BARI Tomato 14. Under drought stress, significantly higher reduction of number of leaves in tomato varieties when subjected to low moisture levels (15-20%) which was followed (Giannakoula and Ilias, 2013).

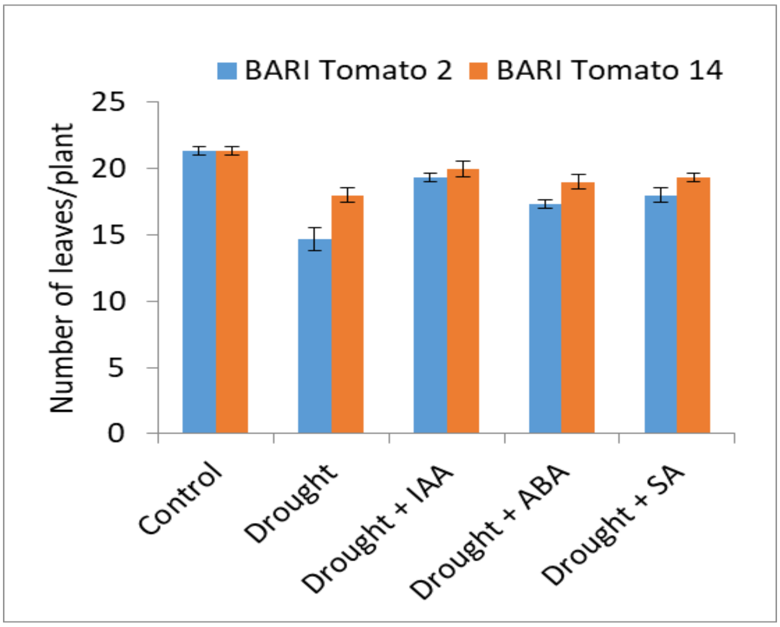

Figure 2: Effect of plant growth regulators on number ofleavesplant^{-1}in tomato varieties under drought stress condition

However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. Under drought stress, number of leaves plant^{-1} (20.00) was found in BARI Tomato 14 with application of IAA with number of leaves plant^{-1} (19.33) has no significant difference between BARI Tomato 2 with application of IAA and BARI Tomato 14 with application of SA; significantly ameliorated the adverse effect of drought stress on number of leaves plant^{-1}. These findings are consistent with Shahba *et al*., (2010).

4.3 Leaf area (cm^2)

Leaf area of tomato showed significant differences due to application of plant growth regulators (Fig.3). Drought stress caused a significant decrease of plant height in both tomato varieties asBARI Tomato 2 and BARI Tomato 14. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels which was supported (Chaves and Oliveira, 2004).

However, exogenous applied of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively ameliorated the drought stress condition. Under drought stress, leaf area (54.10 cm^2) was found in BARI Tomato 14 with application of IAA which was significantly different from other treatment; significantly mitigated the adverse effect of drought stress on leaf area. These results are consistent with Wang *et al*., (2005).

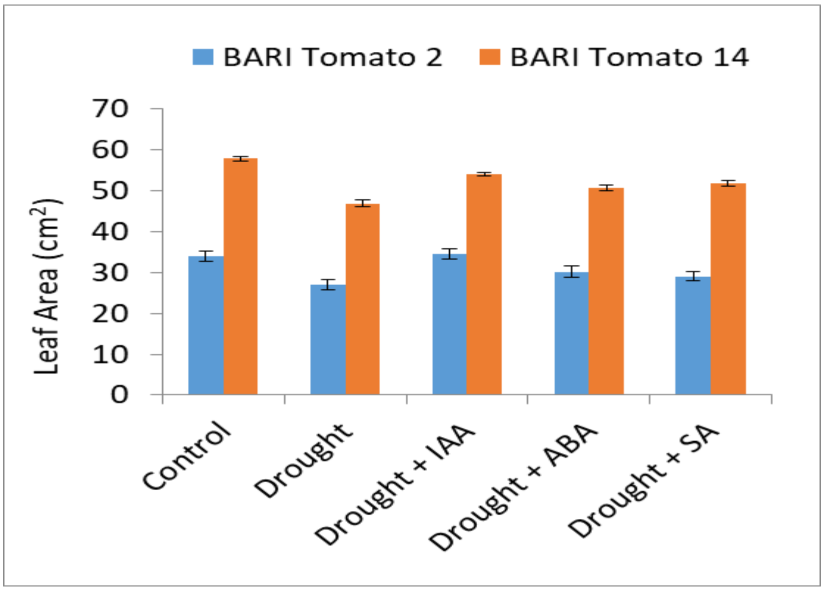

Figure 3: Effect of plant growth regulators on leaf area (cm^2) in tomato varieties under drought stress condition

4.4 Number of branches plant^{-1}

The number of branches plant^{-1} of tomato showed significant differences due to application of plant growth regulators (Fig.4). Drought stress caused a significant decrease of number of branches plant^{-1} in both tomato varieties asBARI Tomato 2 and BARI Tomato 14. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels (15-20%)which was followed (English *et al*., 1990).

However, exogenous applied of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively ameliorated the drought stress condition. Under drought stress, number of branchesplant^{-1}(6.33) was found in BARI Tomato 2 with application of IAA with number of branches plant$^{`1}$ (5.66) has no significant difference between BARI Tomato 14 with application of IAA and BARI Tomato 2 with application of SA; significantly mitigated the adverse effect of drought stress on number of branchesplant^{-1}. Auxin regulates plant growth by mitigating drought stress (Woodward and Bartel, 2005).

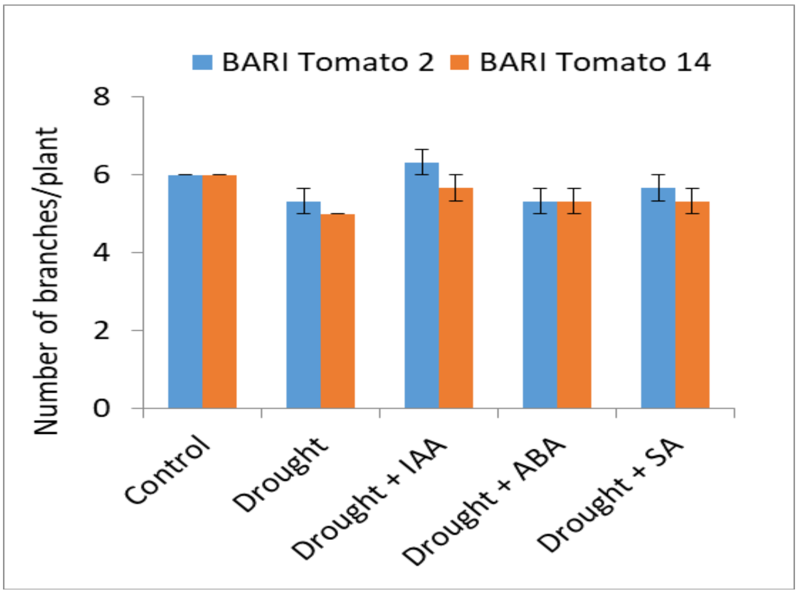

Figure 4: Effect of plant growth regulators onnumber of branches plant^{-1} in tomato varieties under drought stress condition

4.5 SPAD value in flag leaf (mg/g)

Chlorophyll content (measured by SPAD meter)showed significant difference due to apply plant growth regulators (Fig. 5). During the present study, plant height was markedly decreased by drought stress in both tomato varieties as BARI Tomato 2 and BARI Tomato 14. Under drought stress, significantly higher reduction of plant height in tomato varieties when subjected to low moisture levels (15-20%) which was supported (Giannakoula and Ilias, 2013).

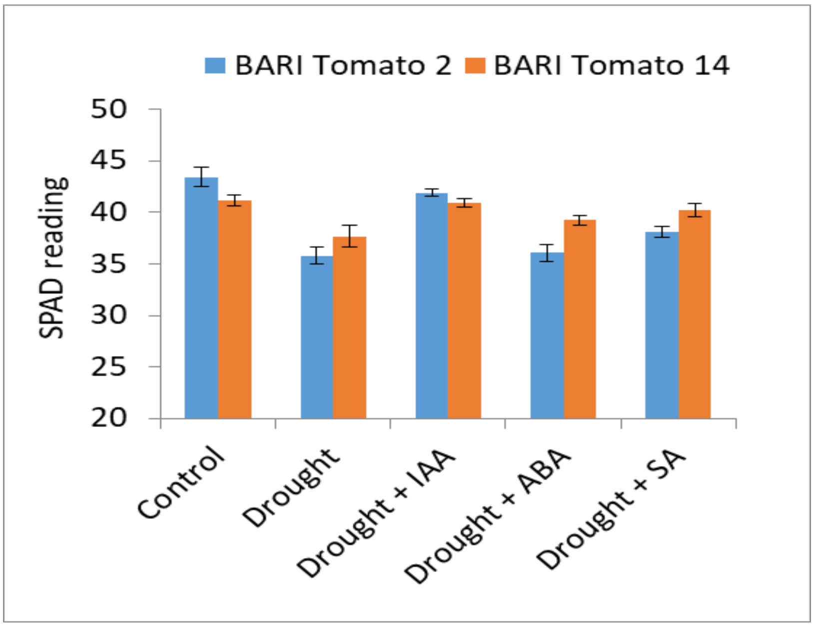

Figure 5: Effect of plant growth regulators on leaf chlorophyll content (SPAD reading) in tomato varieties under drought stress condition.

However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. Under drought stress, chlorophyll content in flag leaf (41.90 mg/g)was found in BARI Tomato 2 with application of IAAand (40.90 mg/g)was found in BARI Tomato 2 with application of IAAwith chlorophyll content in flag leaf (40.20 mg/g) has no significant difference between BARI Tomato 14 with application of IAA and also application of SA; significantly ameliorated the adverse effect of drought stress on chlorophyll content.

Exogenous application of SA results in many different changes in plant physiological processes and increases in plant height, number of branches, number of leaves and antioxidant activity reactions (Javanmardi and Akbari, 2016).

4.6 Number of flower clusters plant^{-1}

The plant growth regulators had significant effect on the number of flower clustersplant^{-1} (Fig. 6) which was significantly different from other. Drought stress caused a significant decrease of number of flower clusters/plantin both tomato varieties as BARI Tomato 2 and BARI Tomato 14. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels which was followed (Parvez *et al*., 2009).

However, exogenous applied of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively ameliorated the drought stress condition. Under drought stress, number of flower clusters plant^{-1} (6.01) was found in BARI Tomato 14 with application of IAA with number of flower clusters plant^{-1} (5.91) has no significant difference in BARI Tomato 14 with application of SA; significantly mitigated the adverse effect of drought stress on number of flower clusters. These findings are consistent with Kazemi (2014).

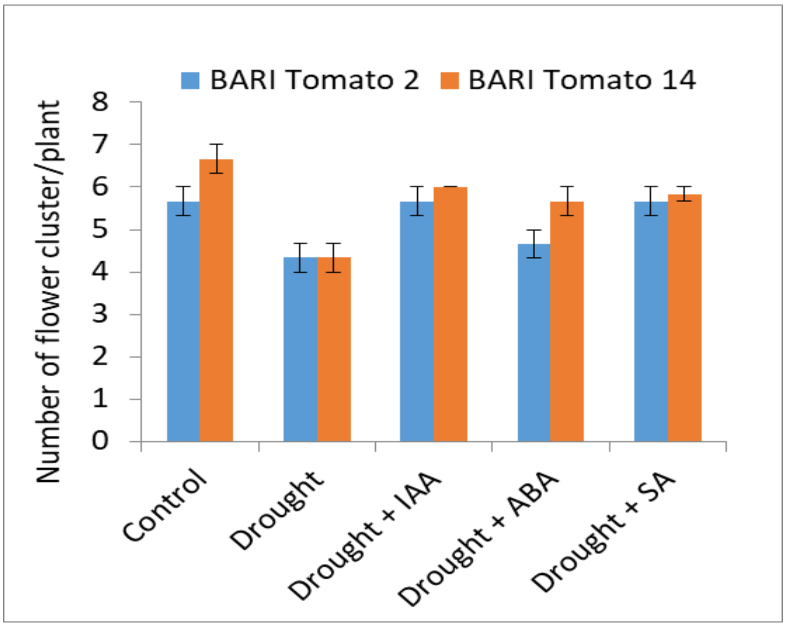

Figure 6: Effect of plant growth regulators on number of flower clusterplant^{-1} in tomato varieties under drought stress condition

4.7 Number of fruits plant^{-1}

The plant growth regulators showed significant variation in the number of fruits plant^{-1}. A significant variation was observed among the treatment combinations of plant growth regulators in number of fruits plant^{-1}(Fig. 7). During the present study, plant height was markedly decreased by drought stress in both tomato varieties as BARI Tomato 2 and BARI Tomato 14. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels (15-20%) which was supported (Giannakoula and Ilias, 2013).

However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. Under drought stress, number of fruitsplant^{-1}(31.66) was found in BARI Tomato 14 with application of IAA which was significantly different from other treatments; significantly ameliorated the adverse effect of drought stress on number of fruits plant^{-1}. Varga and Bruinsma (1976) reported that, application of auxin in drought stressed plants increased fruits number compared to non-sprayed plants.

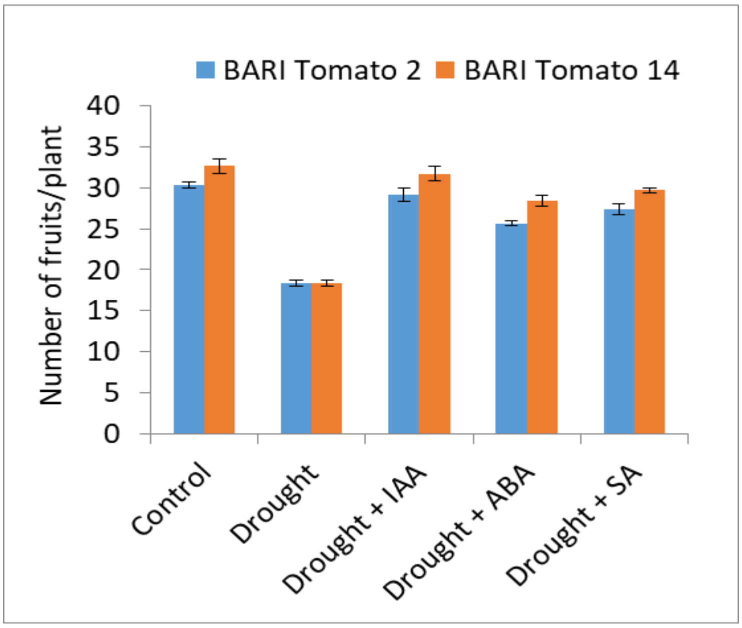

Figure 7: Effect of plant growth regulators onnumber of fruitplant^{-1} in tomato varieties under drought stress condition

4.8 Individual fruit weight (g)

The fruit weight was influenced by plant growth regulators (Fig. 8)which wassignificantly different from other. Drought stress caused a significant decrease of fruit weightin both tomato varieties asBARI Tomato 2 and BARI Tomato 14. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels which was followed (Birhanu and Tilahun, 2010).

However, exogenous applied of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively ameliorated the drought stress condition. Under drought stress, fruit weight (59.93 g)was found in BARI Tomato 2 with application of IAAwith fruit weight (59.75 g) has no significant difference between BARI Tomato 2 with application of SA; significantly mitigated the adverse effect of drought stress on fruit weight. Application of SA improved yield of tomato under green/poly house condition (Yildirim and Dursun, 2008).

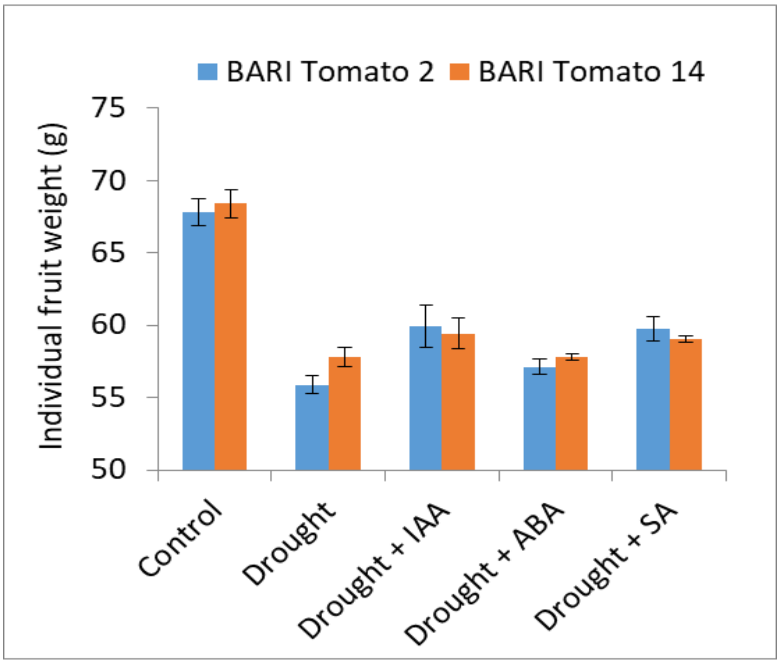

Figure 8: Effect of plant growth regulators on individual fruit weight (g) in tomato varieties under drought stress condition

4.9 Yield plant^{-1} (kg)

The plant growth regulators showed significant variation in yield plant^{-1}(Fig. 9) which was significantly different from other. During the present study, plant height was markedly decreased by drought stress in both tomato varieties as BARI Tomato 2 and BARI Tomato 14. Under drought stress, significantly higher reduction of plant height in tomato varieties when subjected to low moisture levels (15-20%) which was supported (Pervez *et al.*, 2009).

However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. Under drought stress, yield plant^{-1} (1.88 kg) was found in BARI Tomato 14 with application of IAAwhich was significantly different from other treatments; significantly ameliorated the adverse effect of drought stress on yieldplant^{-1}. IAA plays important in the development and yield of fruits (Wang *et al*., 2005).

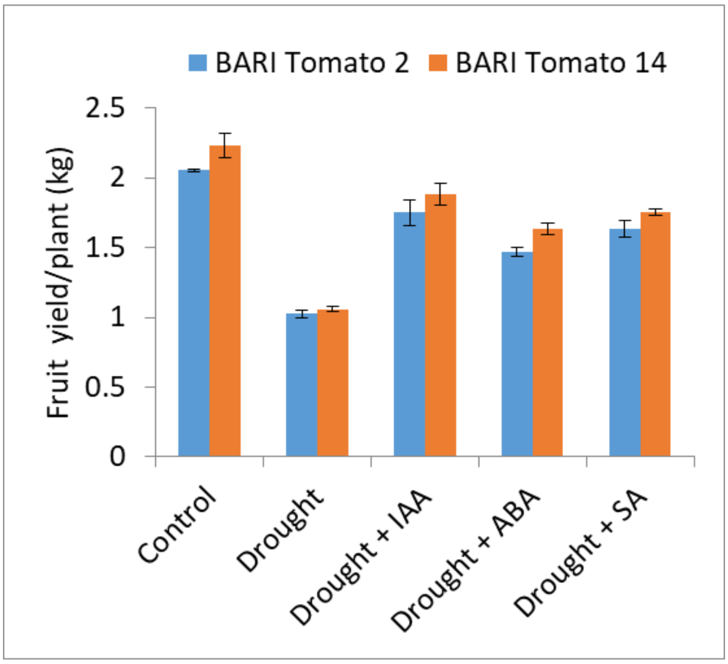

Figure 9: Effect of plant growth regulators on fruit yield plant^{-1} (kg) in tomato varieties under drought stress condition.

4.10 pH

The plant growth regulators had significant effect on pH (Fig. 10). Drought stress caused a significant decrease of pHin both tomato varieties asBARI Tomato 2 and BARI Tomato 14. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels (15-20%) which was followed (Nahar Gretzmacher, 2002). However, exogenous applied of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively ameliorated the drought stress condition. Under drought stress, pH (3.68) was found was found equally in BARI Tomato 2 with application of SA with pH (3.65) has no significant difference in BARI Tomato 2 with application of IAA; significantly mitigated the adverse effect of drought stress on pH level. These findings are consistent with Javaheri *et al*., (2014).

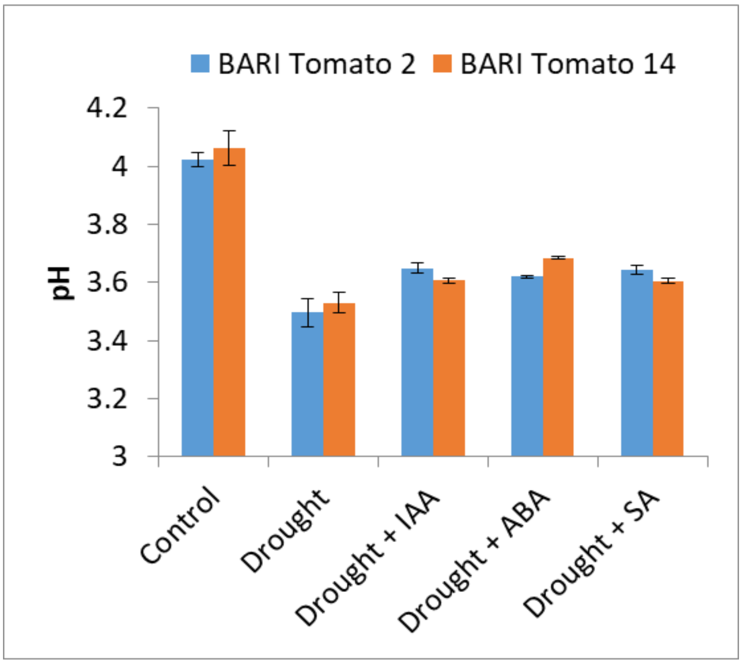

Figure 10: Effect of plant growth regulators on pH in tomato varieties under drought stress condition

4.11 Total soluble solid (TSS)

Due to apply of plant growth regulators performed significant effect on total soluble solid content(%) (Fig.11)which wassignificantly different from other. During the present study, total soluble solid was markedly decreased by drought stress in both tomato varieties as BARI Tomato 2 and BARI Tomato 14. Under drought stress, significantly higher reduction of total soluble solid in tomato levels. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels which was supported (Farooq *et al*., 2009).

However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. Under drought stress, total soluble solid (5.66 %) was found equally in BARI Tomato 2 with application of IAA, ABA, SA and BARI Tomato 14 with application of ABA and SA; significantly ameliorated the adverse effect of drought stress on total soluble solid. Drought stress might have a main role to decrease total soluble solids in fruit thus it decreased internal fruit quality.

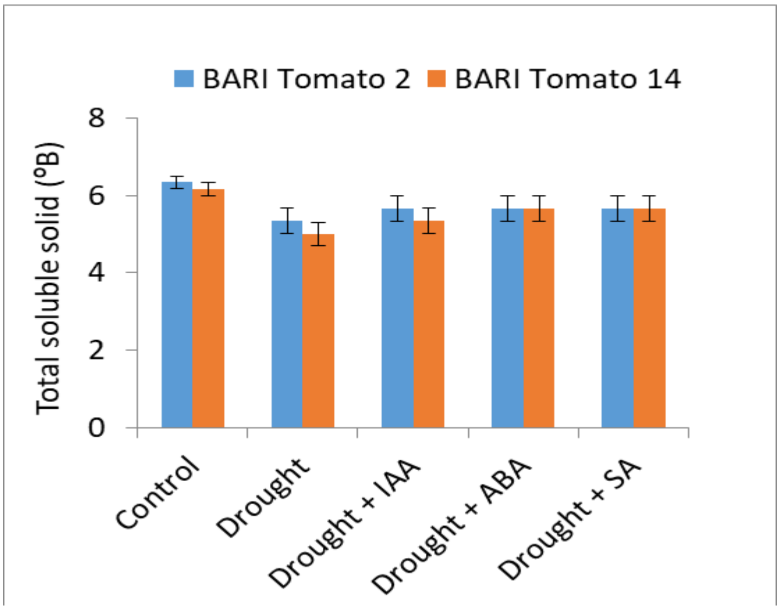

Figure 11: Effect of plant growth regulators ontotal soluble solids (%) in tomato varieties under drought stress condition

4.12 Lycopene and ascorbic acid content

The plant growth regulators had significant effect on lycopene content and ascorbic acid content (Fig. 12) which was significantly different from other. Drought stress caused a significant decrease of lycopene content and ascorbic acidin both tomato varieties asBARI Tomato 2 and BARI Tomato 14. The level of decrease was significantly higher in drought stress in both varieties when subjected to low moisture levels which was followed (Kirda and Kanber, 1998).

However, exogenous applied of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively ameliorated the drought stress condition. Under drought stress, lycopene content (8.00 mg/100g) was found in BARI Tomato 14 with application of SA with no significant difference among lycopene content (7.87 mg/100g) in BARI Tomato 2 with application of SA, (7.80 mg/100g) in BARI Tomato 14 with application of IAA and (7.79 mg/100g) in BARI Tomato 14 with application of ABA; significantly mitigated the adverse effect of drought stress on lycopene content. SA induces stress tolerance in tomato plants (Senaratna *et al*., 2000).

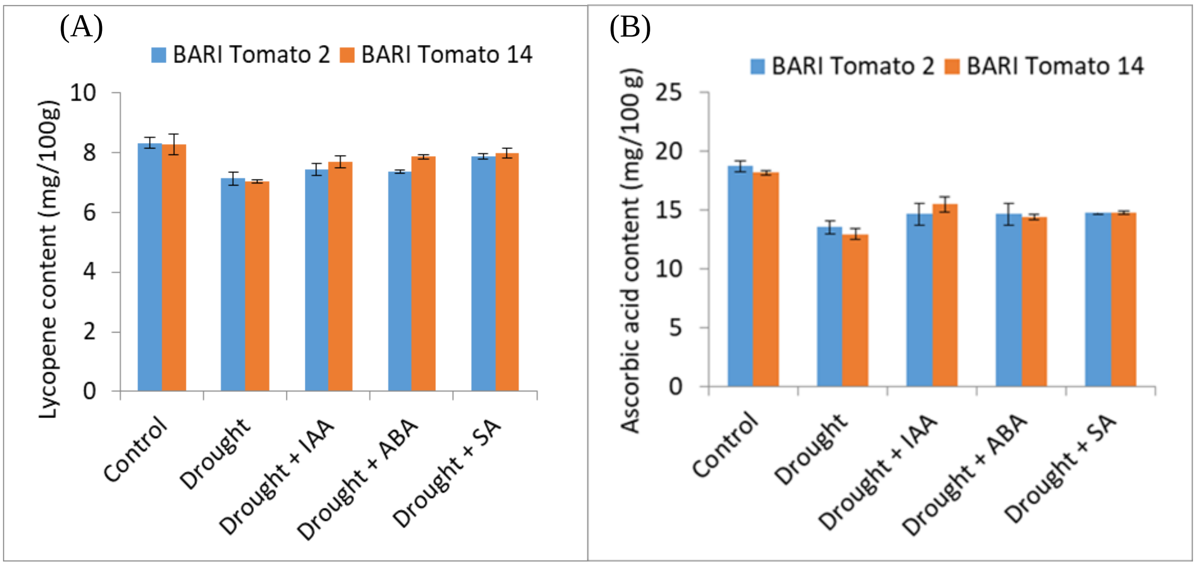

Figure 12: Effect of plant growth regulators on lycopene (mg/100g) (A) and ascorbic acid content (mg/100g) (B) in tomato varieties under drought stress condition

During the present study, lycopene content and ascorbic acid was markedly decreased by drought stress in both tomato varieties as BARI Tomato 2 and BARI Tomato 14 (Fig. 13). Under drought stress, significantly higher reduction of ascorbic acidin tomato varieties when subjected to low moisture levels (15-20%) which was supported (Giannakoula and Ilias, 2013).

However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. Under drought stress, ascorbic acid content (15.50 mg/100 g)was found in BARI Tomato 14 with application of IAA with no significant difference in ascorbic acid content (15.17 mg/100g) was found in BARI Tomato 2 with application of SA; significantly ameliorated the adverse effect of drought stress on ascorbic acid. Application of plant growth regulators increased ascorbic acid in tomato fruits (Bunger- Kibler and Bangerth, 1983). Auxin plays important role to retain quality of fruits under stressed condition (Ulmasov *et al*., 1999).

CHAPTER IV

SUMMARY AND CONCLUSION

The experiment was conducted during the period from October 2019 to February 2020 to study the effect of plant growth regulators on growth, yield and quality of tomato varieties under drought stress condition. The experiment was laid out in a Completely Randomized Design (CRD) with four replications. The plant growth regulators have previously been shown to boost plant growth, yield and quality. This study examines the effects of salicylic acid (SA), indole acetic acid (IAA), and abscisic acid (ABA) on tomato growth, yield, and fruit quality when subjected to drought stress. Two varieties of tomato namely BARI Tomato 2 and BARI Tomato 14 were grown under poly house under natural lighting conditions.

Drought stress is a major abiotic environmental cue impairing many physiological and metabolic processes in plants, which may lead to suppressing plant growth and development, reducing crop productivity or plant death. The main consequence of drought stress is decreased growth and development caused by reduced photosynthesis, a process in which plants combine water, carbon dioxide and light to make carbohydrates for energy. The performance of different parameters of tomato under drought stress showed better performance in the application of plant growth regulators. Plant growth regulators in reducing the adverse effects of drought stress on both tomato varieties. The use of plant growth regulators is highly efficient in plant growth, yield and quality from the adverse effects of drought stress.

During the present study, plant height was markedly decreased by drought stress in both tomato varieties as BARI Tomato 2 and BARI Tomato 14. Under drought stress, significantly higher reduction of plant height in tomato varieties when subjected to low moisture levels (15-20%). However, exogenous application of plant growth regulators as indole acetic acid (IAA), Abscisic acid (ABA) and salicylic acid (SA) effectively mitigated the drought stress condition. In our results, the use of IAA, which was different from other treatments, dramatically reduced the negative effects of drought stress.

Under drought stress, the application of IAA effectively mitigated drought stress with higher value in different parameters as plant height (91.33 cm), number of leaves plant^{-1} (20.00), leaf area (54.10 cm^2), number of branches plant$^{`1}$ (6.33), chlorophyll content in flag leaf (41.90 mg/g), number of flower clusters plant^{-1} (6.01), number of fruits plant^{-1} (31.66), fruit weight (59.93 g), yield/plant (1.88 kg) but pH (3.68) was found was found application of SA with pH (3.65) has no significant difference in application of IAA.

Total soluble solid (5.66 %) was found equally in application of IAA, ABA, SA; lycopene content (8.00 mg/100g) was found in application of SA and ascorbic acid content (15.50 mg/100 g)was found in application of IAA. Among the plant growth regulators, IAA was highly significant in different from other treatments to ameliorate the negative effects of drought stress on tomato plants.

Plant growth regulators were highly efficient in reducing the adverse effects of drought stress on both tomato varieties. The use of plant growth regulators is maintained plant growth, yield and quality from the adverse effects of drought stress. Among the growth regulators, IAA was the most effective at mitigating the adverse effects of drought stress on tomato plants.

CHAPTER VI

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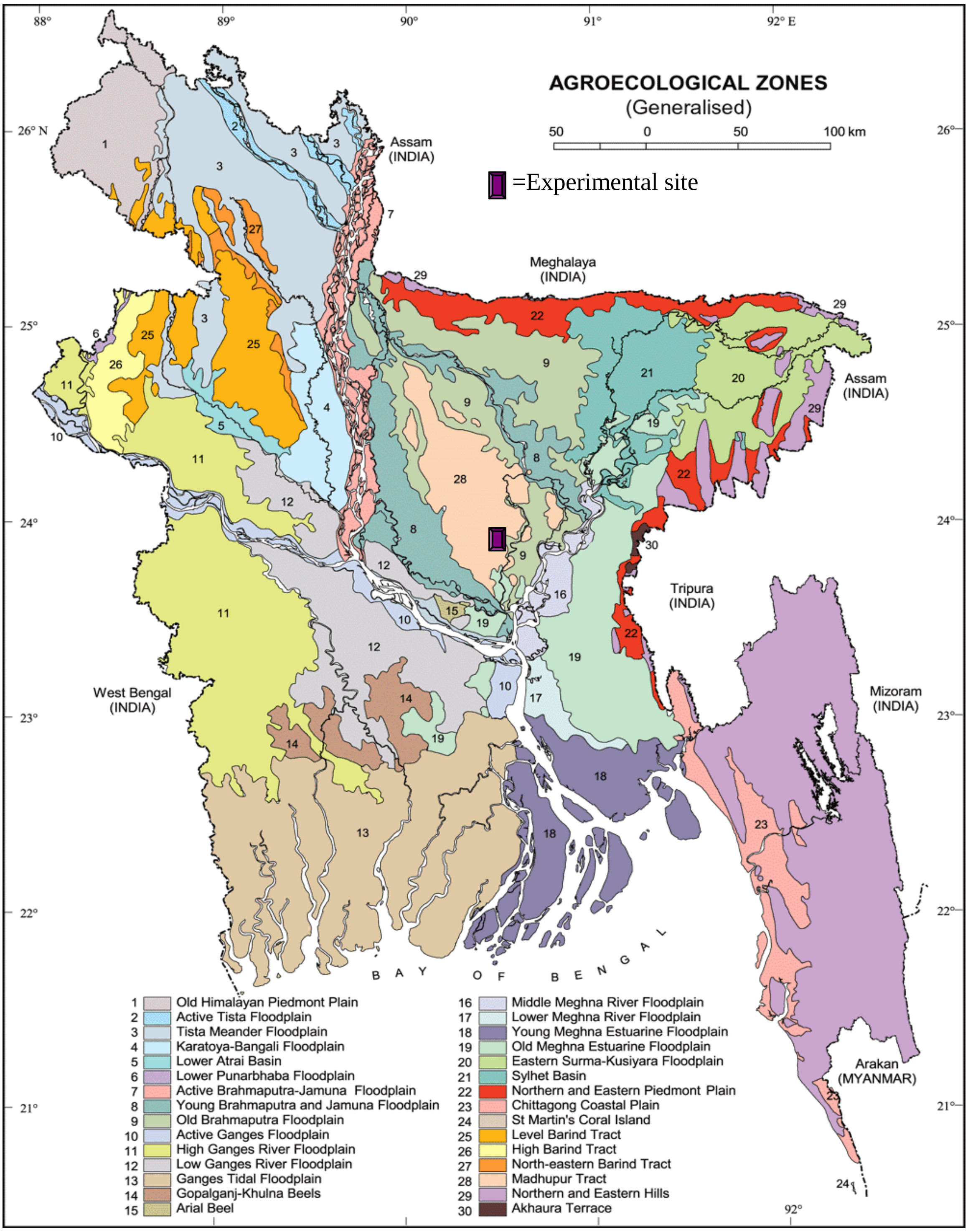
CHAPTER VII

APPENDICES

Appendix I: Experimental location on the map of Agro-Ecological Zones of Bangladesh



Appendix II. Monthly meteorological information during the main experimental period

Year	Month	Air temperature (^0C)		Relative humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2019	November	19.9	29.0	78	122
	December	15.0	25.8	70	00
2020	January	25.5	13.1	41	00
2020	February	25.9	14	34	7.7

(**Source:** Metrological Centre, Agargaon, Dhaka (Climate Division)

Appendix III. Characteristics of soil of experimental pots

A. Morphological characteristics of the experimental field

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

B. The physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

Physical characteristics

Constituents	**Percent**
Sand	26
Silt	45
Clay	29
Textural class	Silty clay

Chemical characteristics

Soil characteristics	**Value**
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10

Appendix IV: Analysis of variance of the data on plant height (cm), number of leaf plant^{-1}, number of branch plant^{-1} of tomatovarieties as influenced byplant growth regulators

Sources of variation	**Degrees of freedom**	**Mean square**		
		Plant height (cm)	**Number of leaf plant^{-1}**	**Number of branch plant^{-1}**
Variety	1	1540.8*	14.7*	0.533*
treatment	4	484.13*	20.5*	0.883*
Variety × treatment	4	57.33*	2.3667*	0.117*
Error	20	17.6	0.8	0.23333

*significant at 5% level of probability

Appendix V: Analysis of variance of the data on leaf area (cm^2), SPAD value in flag leaf(mg/g), number of flower cluster plant^{-1} of tomato varieties as influenced by plant growth regulators

Sources of variation	Degrees of freedom	Mean square		
		Leaf area (cm^2)	**SPAD value in flag leaf (mg/g)**	**Number of flower cluster plant^{-1}**
Variety	1	3425.08*	4.408*	0*
treatment	4	68.78*	33.92*	2.53*
Variety × treatment	4	7.44*	7.868*	4.33*
Error	20	3.35	2.936	0.33333

*significant at 5% level of probability

Appendix VI: Analysis of variance of the data on number of fruit plant^{-1}, individual fruit weight (g), yield plant^{-1} (kg) of tomato varieties as influenced by plant growth regulators

Sources of variation	Degrees of freedom	Mean square		
		Number of fruit per plant^{-1}	**Individual fruit weight (kg)**	**Yield plant^{-1} (kg)**
Variety	1	28.033*	1.133*	0.12*
treatment	4	164.583*	123.211*	0.98*
Variety × treatment	4	1.783*	1.664*	0.004*
Error	20	1.033	2.093	0.00882

*significant at 5% level of probability

Appendix VII: Analysis of variance of the data on pH, total soluble solid (TSS), lycopene content (mg/100g) and ascorbic acid (mg/100g) of tomato as influenced of varieties and plant growth regulators

Sources of variation	Degrees of freedom	Mean square			
		pH	TSS (%)	Lycopene (mg/100g)	Ascorbic acid (mg/100g)
Variety	1	0.00048	0.20833	0.10561	0.2412
treatment	4	0.24975	0.925	0.10089	22.2805
Variety × treatment	4	0.00197	0.04167	0.11679	0.4866
Error	20	0.00244	0.25	0.06757	0. 6841

*significant at 5% level of probability